Design of Fixed Wing Unmanned Aerial Vehicles
Dr. Subrahmanyan Sadrela
Department of Aerospace and Aeronautical Engineering
Indian Institute of Technology - Kanpur

Lecture – 14
Weight Estimation, Common Propulsion Systems

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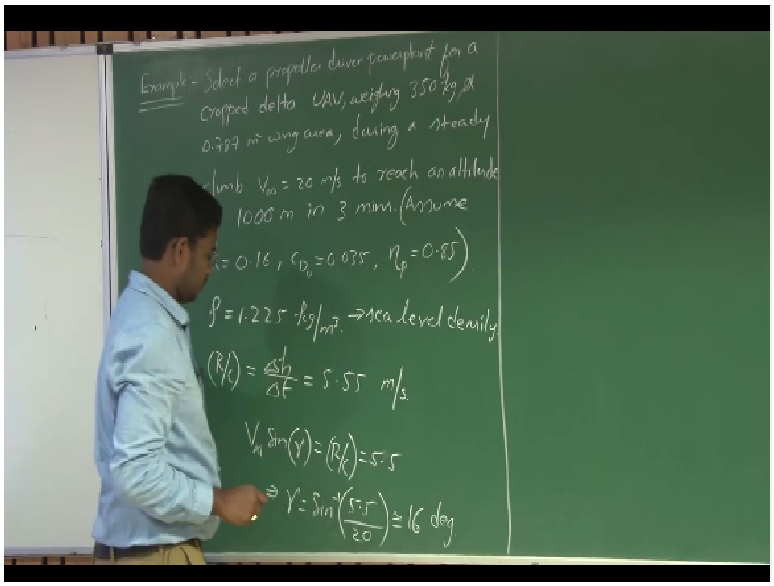

Welcome back. In our previous example, we tried to select a power plant by estimating the power required by the system during this climb. So in this, while estimating this, what we assumed is? The density during this climb remains constant which we considered as sea level density which is 1.225… m cube. So let us repeat the same exercise by considering density at 1 km altitude, right and see what is the difference in the power requirement.

Now when you select a power plant, you need to select based upon the maximum requirement. Let us see which of this is going to have the maximum requirement, either at sea level or at 1 km altitude. Now what we have, from yesterday we figured out the rate of climb as for this particular case is 5.55 m/s which is the vertical velocity of climb and since we need to fly at 20 m/s, what we have, V infinity sin gamma is rate of climb which is equals to 5.5. Gamma is sine inverse 5.5/20 m/s which is approximately 16 degrees, right. Gamma is 16 degrees here.

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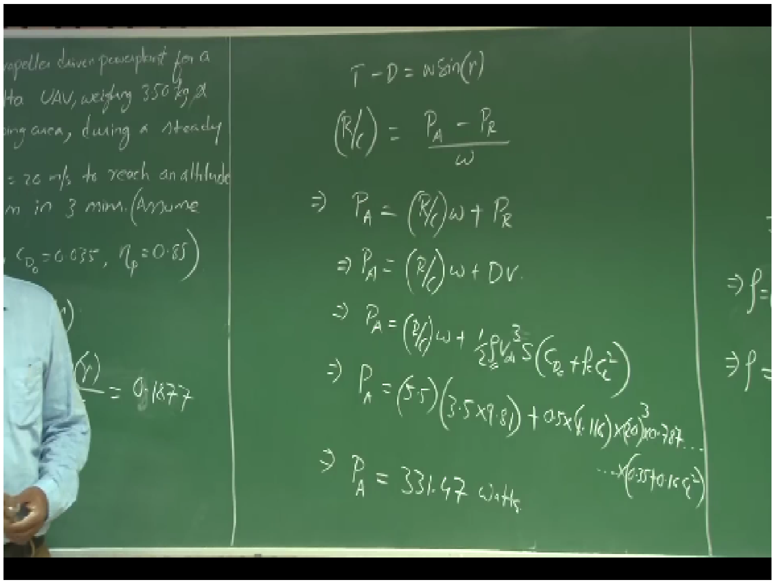

So from equations of climb, climb 1 and climb 2, CL1 and CL2, what we have T-D=W sin gamma, right. So rate of climb=power available-power required/weight. This implies power available, the power that the power, I mean the engine has to deliver, =rate of climb*rate of the system+power required. This is which is density*corresponding velocity of climb. So the rate of climb here is 5.5, we need to figure out what is the D and, yes, what should be the drag here.

If we know that, then we will be able to estimate the corresponding power that has to be delivered from the power plant. So rate of climb*W+1/2 rho V infinity square S, so it will be V infinity cube S*CD0+K*CL square. We have CD0 and K from here, right. So now we need to figure out what is the density at 1 km altitude. So to do that, let us recall our standard atmosphere.

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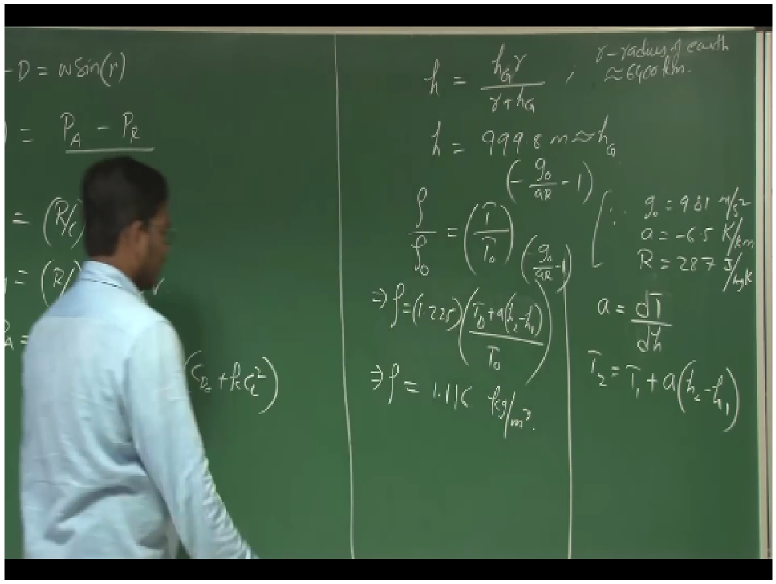

First we will try to convert the geometric altitude to geopotential altitude, r*hG/r+hG, where r is radius of earth approximately 6400 km, right. So from here for 1 km altitude, it will be approximately 999.8 m which is almost equivalent to hG, right. So it is not going to make much of a difference.

Now I have rho 2/rho 1 or rho at an altitude/rho at sea level=T at an altitude/sea level temperature raise to the power of -g0/aR-1, right, where g0=9.81 m/s square and a=-6.5 K/km and R=287 J/kgK, it is a universal gas constant, right. This equals to rho 0*, what is rho 0? Rho 0 is 1.225 kg/m cube, right. So how to find T? We know from the definition of lapse rate which is a=dT/dh. So T2=T1+a*h2-h1 for a gradient layer. So a is -6.5 for the first gradient layer, right.

Now what is rho? Is 1.225*T1+a*h2-h1/T0, in this case, -g0/aR-1. So you solve this the density at this, at 1 km it turns out to be 1.116 kg/m cube. Now substituting this density in this equation, 5.5 m/s*3.5 kg*9.81, to convert this into Newton's, and 1/2*, what is the density here? 1.116*20 cube*0.787…*0.35+0.16 CL square. So for the same flight condition, we need to find out the corresponding CL values here, right.

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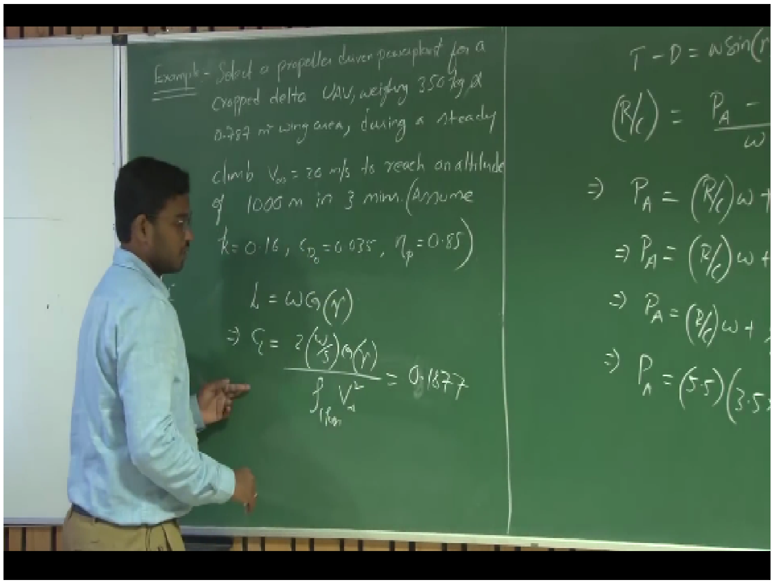

So the CL for this condition is, we have L=W cos gamma from CL2, equation CL2, right. So what is CL, twice the wing loading, *cos gamma/density at 1 km, we have to use at 1 km altitude, *V infinity square, right. So this turns out to be 0.187, right. Just check. So CL is 0.1877, is the CL for this case. Now substitute this CL here in this equation to figure out what is the corresponding power requirement from the power plant, right? Just substitute that. It will be 331.47 watts, right.

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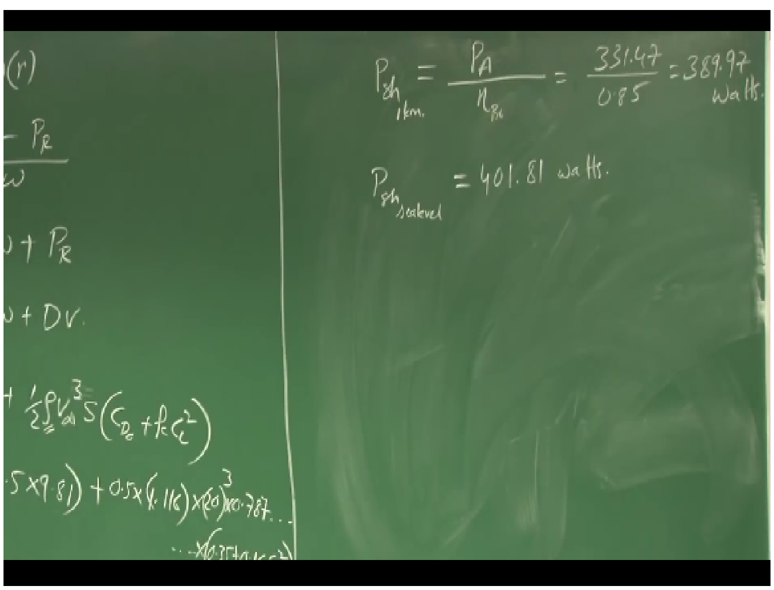

Now what is the shaft power required to achieve this flight, flight conditions? This is power actually required by the system, entire system/propeller efficiency. This is 331.47/0.85, is approximately 389.97 watts, right. This is the shaft power that is required at 1 km altitude, right.

This is the power requirement from the system. So when we calculated the same shaft power at sea level, what we, this is 401.81 watts.

So you have to consider the highest shaft power that is required, right. Then you have to use this shaft power to select the corresponding power plant by a factor of safety, right. So till now, we assume that the weight of the aircraft is given, of the UAV is given. But for a designer, it is never an input. Weight is never an input. You have to estimate the weight of the system. So in order to estimate the weight, we need to understand the total weight.

How this total weight of the system is summed up, right. What are the components that are contributing towards this total weight? What are the major components?

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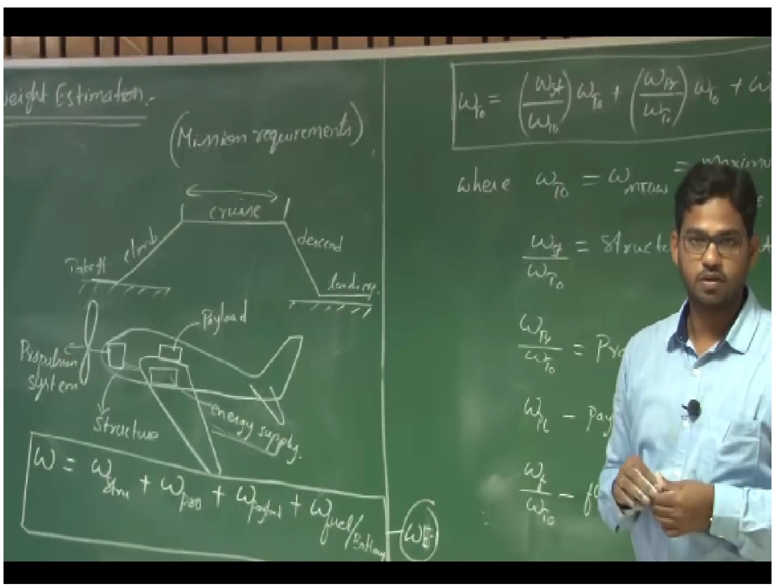

Now let us look at weight estimation, right. So what does this weight estimation depend upon? Why it varies from one aircraft to the other aircraft or one UAV to the other UAV? So there is something called mission requirements, right. So this weight of a system varies from one aircraft to the other aircraft or one UAV to the other UAV based on the mission requirements. Mission requirement or the set of the task that this aircraft has to perform or the set of performance parameters that this aircraft had to, has to posses, right.

So what will be a typical mission requirement of a UAV? Say again going back to the profile, right, mission profile. So it has to climb to a certain altitude. Either it has to cruise to a different location and land, right. So again climb and in some cases, you also have takeoff, right. There is something also called takeoff, climb, cruise, descent or glide, you can say landing, approaching landing, right.

So this is one such profile, what this UAV has to perform, mission profile what this UAV has to perform. And here in this cruise, so although you have 2 different, I mean, 2 UAVs which are performing the similar type of mission profile, the weight can vary, right. So this entirely depends upon the cruise as well as the weight it has to carry. So what do you have in a UAV in the first place?

We are talking about fixed wing UAV, right, okay. So what you have is wing, tail, fuselage, right. All this in sums up to structure and we have an engine or a power plant, right. So this is the propulsion system. What is the purpose of this, purpose of any UAV? Of course it is definitely not going to carry passengers. But it is designed to perform a task which involves either sensing or taking payload from one location, taking certain cargo from one location to the other location, right.

So either sensors and all these things are considered as payload, right. So there will be payload, right. At the same time, you have a power plant here and this power plant has to be, so where do this energy, I mean how this power plant is running? There should be onboard energy storage, right. So energy supply. So this can be broadly considered this way. Of course, there will be avionics, right which will be a smaller percentage compared to all these things and you can sum it up to either of these, either structure or propulsion part, right.

So the total weight of this UAV is contributed from structure, power plant or propulsion system and payload, same time you have energy supply. In some cases, it is fuel or battery, right. Either fuel or battery. Now why this weight changes from UAV to UAV? It may have to carry different payloads, right. A smaller UAV has, suppose to carry a smaller camera which may weigh up to 250 g, right.

And it may, it can be used for a surveillance purpose with a 1-hour endurance, right. So as the requirement changes, the weight changes, weight of the system changes, right. So there can be a (()) (16:58) class UAV. It is of 2000 kg class where the structural weight is, the structure has to be designed accordingly, right, whatever the payload that it has to carry. And that cannot be compared with the weight of a 5 kg UAV, right.

The structural weight of a 2000 kg UAV cannot be compared with a 5 kg UAV, right. It is altogether a different story. Now how to start with the weight estimation, right. So we broadly understood that these are the major components that contributes towards the total weight of the system, right. How to start with this? How to start estimating these weights? If I know the individual components, then I will get to know what is the total weight, that is the whole idea, right.

Now payload is one thing which is given as an input, that comes from the mission requirements. So this is a known quantity. So unknown for this new design, before starting anything, the unknown for this new design will be what is the structural weight, what is the propulsion weight and what is the fuel weight ratio, right?

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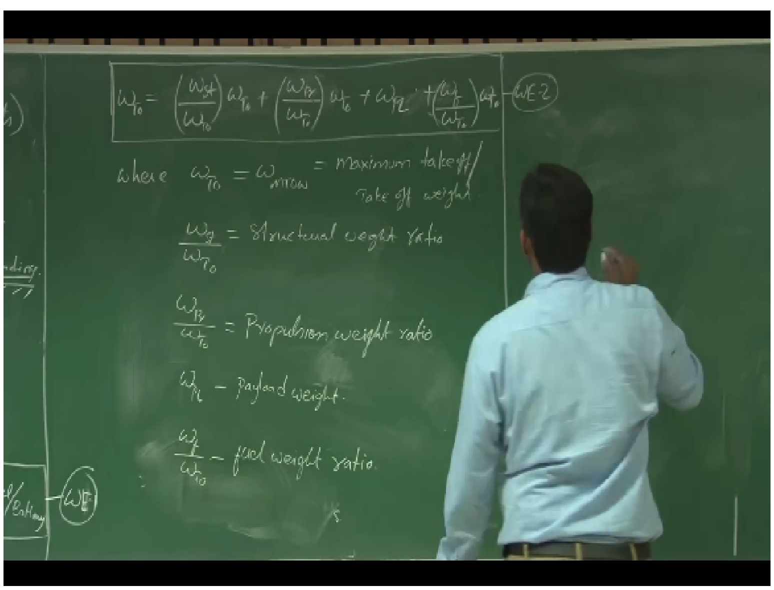

Now how to start? Let us say W is the total weight. Can I write this as W or W takeoff or maximum takeoff weight or takeoff weight, whatever it is, right, *W takeoff+W propulsion system, W payload +, so let me represent payload as PL, propulsion, ST structures, Pr stands for propulsion, PL stands for payload, and weight of the fuel. So let us initially talk about the fuel powered UAV, right.

So the energy is supplied to this power plant is by means of fuel, right. This is W (()) (19:25). So where WTo is equivalent to WMToW, maximum takeoff weight, MToW, is the maximum takeoff or takeoff weight, simply takeoff. ST stands for structural weight ratio. ST/WTo. WPr/WTo stands for propulsion weight ratio. WPL stands for payload, weight of payload; fuel weight ratio, right. So let us consider this equation as W1. Let this be weight estimation 1, WE-1. This as WE-2, okay. Now let us rewrite this WE-2, right.

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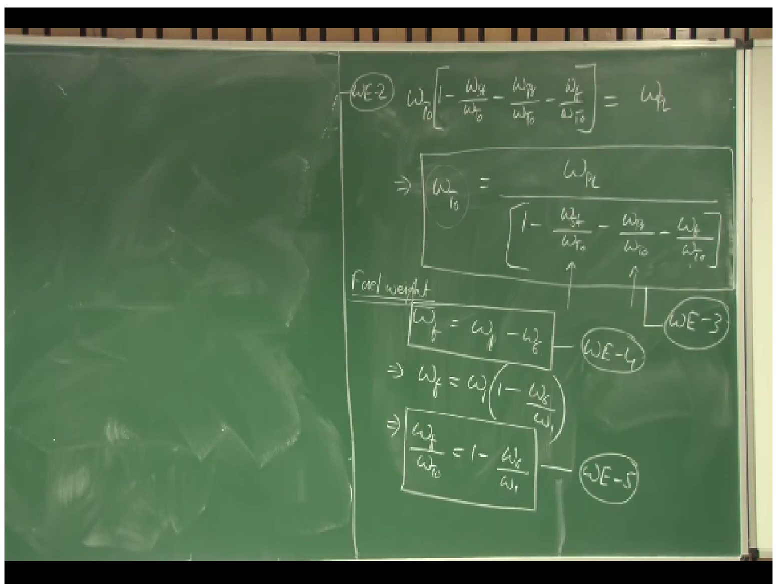

So W takeoff*1-W structural weight/W overall takeoff Weight-W propulsion weight to W takeoff and fuel weight ratio, yes, -fuel weight ratio=or is the, what we left with the right hand side is the payload, weight of the payload. This implies W takeoff=W payload/1-structural weight fraction subtracted propulsion weight fraction and then -fuel weight fraction. So if you know these values, the structural weight ratio, propulsion weight ratio and fuel weight ratio, you will be able to, since payload will be given as an input there, you will be able to figure out what is the overall takeoff weight.

So why we call this as estimate here? Why it is an estimation? There should be some meaning, right. Because we are not actually calculating, we are trying to estimate based upon the historical data here, right. So the structural to takeoff weight ratio, we consider this from the historical data of the aircraft which are of, which are designed to perform this similar mission, right. At the same time, propulsion weight ratio, we will also figure out it from the historical database of the UAVs which were designed to perform the similar mission requirements, right.

And then when you are doing this, like when you are trying to estimate, when considering, by considering the values of previous UAVs, what is the new with this WT? What is the new with this particular UAV that you are going to design? So this fuel weight ratio will vary, okay. If you are designing a UAV based upon this IC engine which has, where fuel is the energy that is supplied to the system, right.

So if you are designing that UAV, so this fuel consumption or the ratio changes based upon your particular mission requirement, this particular mission requirements, right. So say if you want to, your previous UAVs may be doing a 1-hour cruise or 2-hour cruise. So your UAV may, the one that you are going to design may have to perform a 5 hours' endurance, right or should be capable of travelling 500 km instead of 200 km.

Let us say if 200 is the range of previous UAVs, right. So this factor initially is going to affect this W takeoff, right. Now once you know what is the takeoff weight, so initial iteration, right, then you will be able to figure out, once you know the takeoff weight, you will be able to find out what is the corresponding power requirement, right. If you know the power requirement, for various phases based upon the mission requirement, right, you need to, say if this is the particular mission, you need to know what is the power requirement during climb, during cruise, during takeoff, right.

So takeoff, it will be very minimal here, anyways, right. So if you know the power requirement, you will be able to select the corresponding power plant. Once you have the power plant, you have an accurate value of this WPr here, of the propulsion system, right. You have an accurate value here. Now you need to figure out what is the structural weight based upon this. Once you have the accurate value of this propulsion power plant, then you will be able to, then you have to again iterate this step, iterate the process and you have to update the fuel weight again.

Once you have these 2, then you will be able to find out what is the structural weight because you will be designing the structure, right. So once you have all these values, you are actually bringing this equation to the particular UAV that you are going to design, right. So you have started with the data of the previous UAVs, but right now you are trying to adapt this equation to your particular design, right. Let us do this step by step, right. First we need to understand what is this weight ratio? What are these weight ratios? So let us segment this mission profile.

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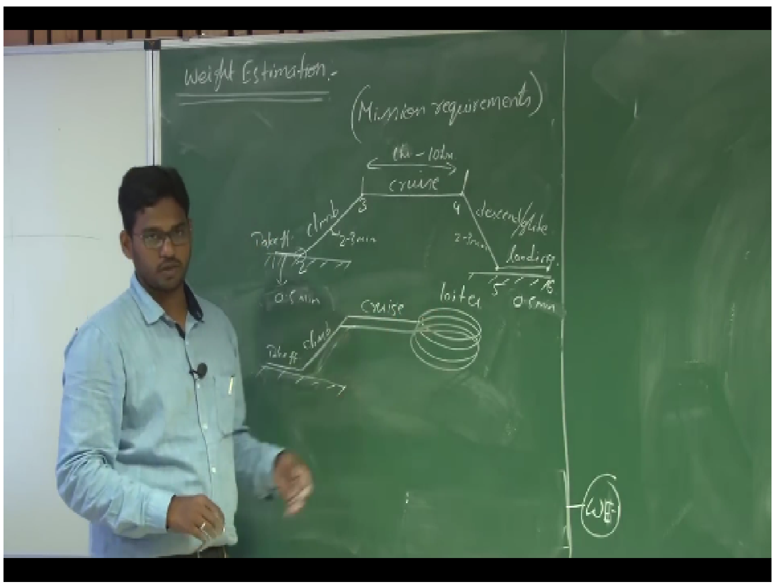

So the starting of takeoff is, consider this as 1 and the starting of climb, consider this as 2, and the starting point of this cruise consider is 3, and the end of cruise is 4, and say 5 is the starting of landing and finally 6, this point 6 is the what do you call, once you landed and, yes, end of the mission. Okay. So how much do you, time do you think takeoff require? So in our first introductory lecture, we saw a flying wing, right, flight of a flying wing where there is typically there is no takeoff.

We just launched hand launch system, right. So we can at max consider a takeoff of 30 seconds or half a minute, right. So climb may be 3 minutes or 2 minutes, 2 to 3 minutes, whereas cruise can range from anything between 60 minutes to or 1 hour to say 10 hours, 24 hours, right, it depends and descent again it may take 2 to 3 minutes. Generally, it will be a gliding flight, glide.

So where the fuel consumption is very very minimal, right. And once you landed then it might take around say half a minute again, 30 seconds or 0.5 minute.

It is a 0.5 minute; this is also both 0.5 minute. So now it is clear that the fuel consumption is maximum during cruise, right. That means if you look at the fraction W4/W3 will be higher compared to W3/W2 and W2/W1, right. Same type W5/W4 and W6/W5. So we need to figure out this fuel load that need to be carried in order to perform this particular task which is either cruise or loiter and a combination of them, right.

Some applications may need only loiter around the launch point, right, surveillance about the launch point. In some applications, you have to reach to a particular destination and then perform a surveillance there, right. So it may involve both cruise and loiter. So the major time that is spent, the major time that is spent here is for cruise as well as the loiter, right. Loiter is, say you have to reach a particular destination and perform a loitering and may come back to the home, right.

So cruise, loiter, climb, takeoff. So major time of this mission is spent in performing cruise and loiter missions, right. So we need to figure out what is the fuel loads for this cruise and loiter. At the same time, let us also look from the historical database what is the fuel ratios for various mission segments, right.

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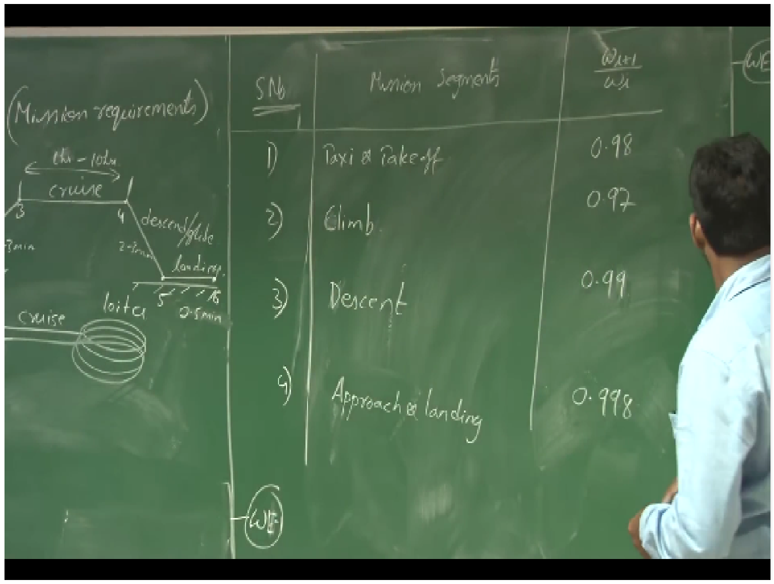

So serial number, let us say mission segments, weight fractions. So let us say first say Taxi and takeoff. So you cannot lift 800 kg definitely from your hanger, you have to take it to the runway. So you need to do the taxi. At the same time, you need to takeoff from the launch point, right. So typical value of this is 0.98, right. So this is from the historical database of 150 aircrafts, right, 150 UAVs.

So the second one, you have 150 or 130-150 UAVs, right. And the second one is climb. So the third one is say descent. So we cannot comment much about this cruise because for each and every UAV, the mission is different. You cannot compare it, right. The fourth one is landing, approach and landing, right. Typical values of these are, this is 0.97, this is 0.98, this is 0.998. This is 0.99, I am sorry.

So these values are from historical database. See if you look at these, it is almost equal to 1, that is W3/, say in this case, W2/W1 is almost equal to 1, compared to overall takeoff weight, the fuel weight consumed is very very less, right. Similarly, you can see for the climb, it is also 0.97 and for descent, it is 0.99 and approach and landing it is 0.999, right. So here it is almost more closer to 1, right.

So the major difference for each and every design will come due to the cruise and loiter that is the major segment of your mission, right. Now let us estimate this, loads for this fuel loads for this particular segment, cruise and loiter, right. See what will be the fuel weight? What do you think is the fuel weight for any aircraft, let us say, a fuel-powered aircraft? So what do you think is the fuel weight here?

So you have W1 and W6. So the difference between W1 and W6 is the fuel weight, do not you think so? W1-W6. What is the fuel weight? Fuel weight is Wf=W1-W6 where W1 is the maximum takeoff weight and W6 is after landing, right. So during this entire process, whatever the fuel that has been consumed will be Wf. This is straightforward. So Wf=W1*1-W6/W1, right, where W1 is the takeoff weight.

Am I correct? So to estimate this Wf/W takeoff, we need to find out what is the weight ratio of W6/W1. Since we have segmented this mission profile, we can express this W6/W1 as… I will erase this part? This is, this equation limiter WE-3 and this equation is WE-4, weight estimation equation 4 and this as weight estimation equation 5.

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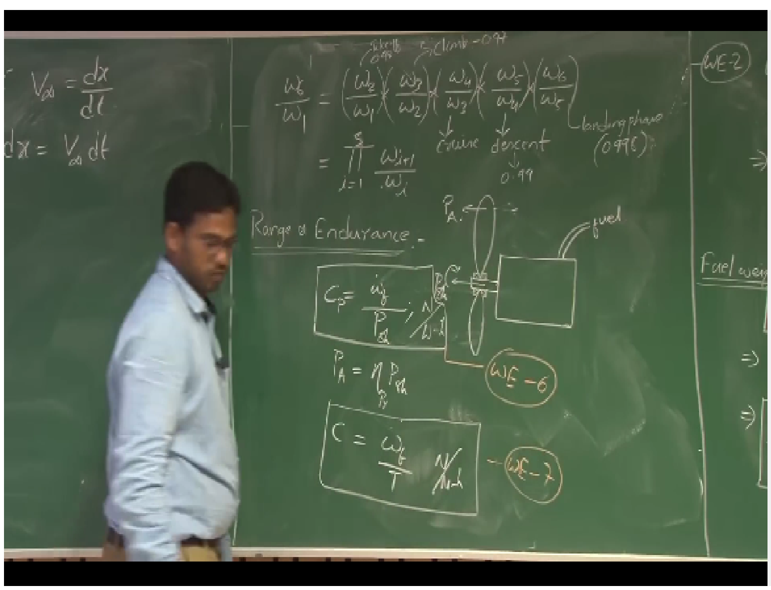

So what is this W6/W1? So we have various segments here, right. So the climb dynamics is completely different to takeoff dynamics, that means the fuel consumption or the power requirements are different and the fuel consumption is different here. Whereas in cruise again the dynamics compared to climb and descent is completely different and so the fuel consumption, right.

So since each segment has different dynamics and different fuel consumption, right, so we can express this as W2/W1*W3/W2*W4/W3*W5/W4*W6/W5. Am I correct? Am I correct, this one? 1 to 5, right. So in this case it is, we just witnessed like from the table with the historical database, we looked at like what is W2/W1, W3/W2 and W5/W4 and W6/W5. So this particular weight ratio belongs to descent which is almost 0.99, right.

This corresponds to landing phase which is 0.998. So this is for cruise. So to start with the initial estimate, the unknown is this cruise part, right. Why? Because, so these things can be compared with the, I mean, can be considered from the historical database. This corresponds to the climb phase and it is approximately 0.97 and this is again 0.98. Takeoff phase which is 0.98. So your new design will vary because the weight, fuel weight ratio of your new design will majorly differ with the previous design because of this cruise and loiter phase, is W4/W3 phase, right.

Now how to figure out this W4/W3 phase? Now let us look at something called range and endurance or loiter. So let us confine ourself to this propeller driven aircrafts, right. Because we are not go into, I mean, we do not see generally a jet driven unmanned system, right. So let us look at the propeller driven system here. And why range and endurance? It talks about the distance that you can travel with a given load of fuel, right.

That means you can, you will be able to figure out the fuel load to travel a particular distance. Because cruise we say 1 hour or 10 hours, right or so many kilometers. So when you mention that from these mission requirements that means you are specifying either range or endurance of the system, right. So once you know the range, what should be the corresponding fuel load that you need to carry to perform this particular task, right?

So let us define, since we are talking about IC engines, right or a propeller driven engine. So let us consider this fuel powered IC engine. So the output that you get is, actual output will be this shaft power. Whatever the output that you have from, this is a shaft power and you use the propeller to convert this to useful power, right, power available from the system which is the useful power that accelerates your aircraft or provides the required velocity for this UAV, right.

Now let us have a look at, it is worth showing this IC engine.

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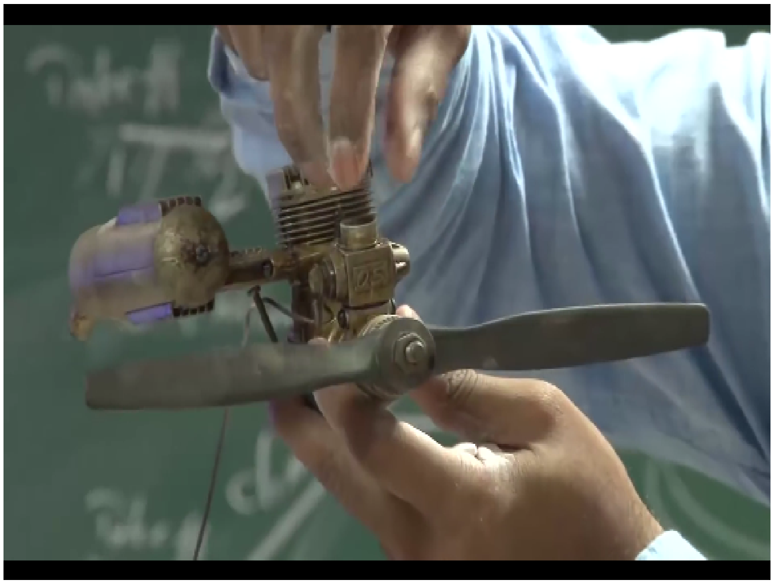

It is a small IC engine, right. So these are carburettors that controls the fuel-air mixture and there is a valve inside with which you can control this fuel-air mixture and the corresponding RPM, right and the shaft power. So what is shaft power here? The power that is available along this shaft, right. So it is in, this is a mechanical power that will be available by, so this is a fuel inlet, the valve that you can see here is a fuel inlet, right.

So whatever the fuel that is going to use to generate this power, right. So in other words, what is the amount of fuel that is consumed to produce a unit of power, right. So that is defined as specific fuel consumption, right. Specific fuel consumption for this IC engine is Cp which is defined as weight of the fuel consumed in producing unit power. So what are the units of this? Newton/watt hour, right.

This is for IC engine. So see this shaft power is converted to useful power by means of this propeller, by means of, I mean, we are using a combination of propeller with this IC engine to convert this mechanical power to the useful power, right. So the power that is available, the specific fuel consumption is defined with respect to this shaft power. We know the useful power to us is the propeller efficiency times this shaft power, right. This is the propeller efficiency. How efficient this propeller is going to convert this available mechanical power to the useful power for us.

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So we can also look at this electric powered systems, right. This is a brushless motor. It is an outrunner brushless motor and there is a propeller combination here. So for this IC engine, fuel is given as an input, right. For propeller based, for electric based system, we give, we use battery power as an input to this brushless motor, right. And again here, the output will be a shaft power. In either the case, the output is a mechanical power by means of this propeller, we convert it into the useful power, right.

Useful power for UAV, right. So this is typically an 1100 kv motor, right which means it rotates at 1100, it has an RPM of 1100 per volt, right. So when you are operating this with 4-cell battery, which is approximately 12 volts, right, so you have to multiply the corresponding RPM, right and that is a maximum kv, right. And it will deliver a thrust of 2 kgs, right when operated using a 12 volts battery.

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There is also a ducted fan, right which is also powered by electricity like we use onboard battery to power this particular power plant. You can see here there is a fan, right. So the output again here is a shaft power. See this is the back side of this particular EDF. We call it as electric ducted fan. So the output is a shaft power here. It has a similar concept of this outrunner motor, brushless outrunner motor.

So the only thing is here to minimize the propeller diameter, we use fan, right, series of fans here. Series of, here it is a single fan, with multiple blades, right. So this is going to deliver you the, this fan is going to convert the available mechanical power to the useful power, right. So in all the cases, we need to multiply the available shaft power with the efficiency. So wherever this particular EDF delivers a 4.5 kg thrust with a 6S battery which is approximately 24 volts, is an input voltage to this.

And you can control the speed by means of speed controller like, we will discuss about these things in the later lectures and one more announcement that I would like to make is like most of the students were mistaken this course as aeromodelling course, right, some of those, some of the students. So I kindly request you not to mix this course with the aeromodelling course, right and we are talking about design.

Design when you say, it is a 3-dimensional, I mean, either 3D CAD model that has to come out as an output. So the 3D, when you say 3D CAD model, it has certain geometry with size, right, wing size, fuselage size, what is the engine size or the engine capacity and what is the tail size? So all these numbers we arrive by means of this dynamics, aircraft dynamics, right with the help of flight stability, I mean, both performance and stability control.

We use those concepts and moreover aircraft design or a UAV design is the synthesis of this performance and stability and control, right. Although you may not be learning new things here, but you will try to apply what you have learnt in performance and stability and control course to design the flight vehicle, right. Of course, in one lecture, one of these lectures, we will try to show you how to build a UAV but that is not the main motive of this particular course, right.

So coming back to this, like whatever the shaft power available either from the fuel based or the electric based engine, it has to be multiplied by the efficiency factor of the propeller or the ducted or the fan, right to get the available power, right. So now the power available is the power, propeller efficiency times shaft power and we have defined something called specific fuel consumption of this propeller based engine, right.

So specific fuel consumption here=the amount of fuel consumed to produce unit power, right. What happens to a jet engine? Of course, we will not be talking much about jet engines but we need to define specific fuel consumption, is the thrust specific fuel consumption is defined as weight of the fuel consumed in producing unit thrust.

So units are (()) (49:40), right. So this is the thrust specific fuel consumption. This is specific fuel consumed. Now since we are talking about cruise, ranges like what is the distance that you travel during cruise, right. Even endurance for that case is the same. We will talk about cruise. Both these parameters talk about cruise.

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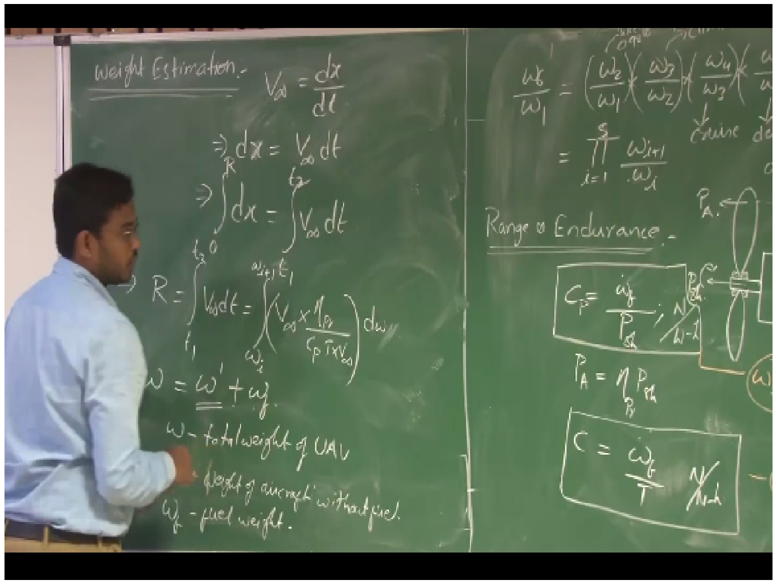

Which means, you have constant velocity which is the distance travelled over particular time, right. So this dx=V infinity*dt, right. Okay. So dx=V infinity*dt and, yes, and if I integrate this from 0 to R range which happens over a time t1 to t2, right. So this is V infinity*dt, right. So this integration is range R t1 to t2 V infinity dt. Again we need to discuss what is, okay, let us go back to this weight again.

Let us look at this weight. So what is weight of the fuel? A total weight of this aircraft=weight of the fuel+total weight other than fuel, right. Do you accept this? Total weight of the aircraft=weight of the fuel+weight of the aircraft-fuel, right. So this may include payload. We cannot say it as empty weight, right. So it may also include payload. Wf is the fuel.

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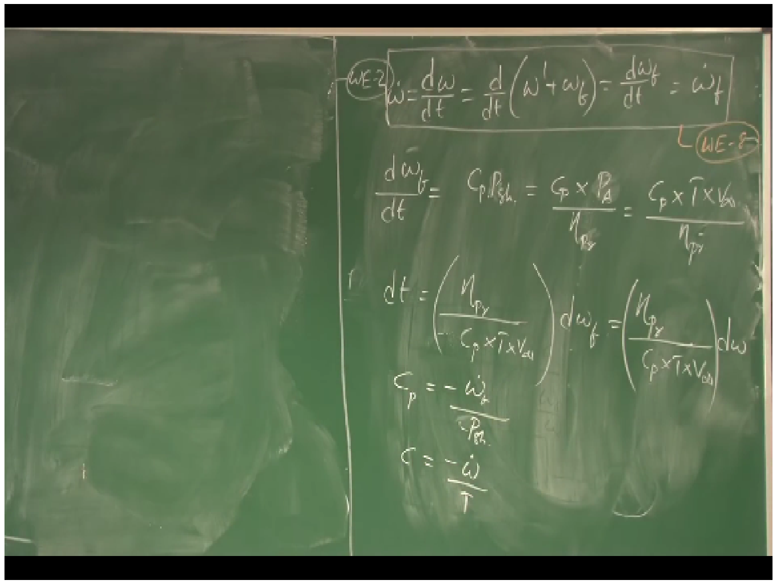

So now say change in the total aircraft weight is the change due to fuel consumption because this is going to remain constant. This is d/dt of Wf which is W dot f, right. So this d/dt is W dot of the aircraft is the W dot of the fuel, right. You accept this? Okay. Now what is W dot f here. For a propeller engine, W dot f=, or dW/dt=Cp*Psh, shaft power. What is shaft power? Shaft power is efficiency or available power/efficiency, efficiency of the propeller.

So what is available power? Is thrust*velocity, right. Is the propeller efficiency, okay? Now what is dt? dt=eta of the propeller/Cp*T*V infinity, right, *dWf. We just manipulated this equation. So you may consider this as this equation as W8, WE8, weight estimation 8, okay. So now substitute this dt in this equation. Let us substitute the dt in this equation, range equation. So from t1 to t2, what you have is W, at t1 say Wi, say Wi+1 at t2, okay.

So this is at the starting of this mission which is t1 and the end of this particular segment of this mission, right. So this is V infinity*eta of the propeller efficiency/Cp*T*V infinity*dW of the fuel. So do not you think this dW of the fuel is equals to dW of the aircraft, Cp*T*V infinity*dW. Since dW=dWf, right. Yes, you can change this to dW, right. Now let us integrate this. And what is the relation between Cp and C? We will look into that. Once we finish this, we look at that.

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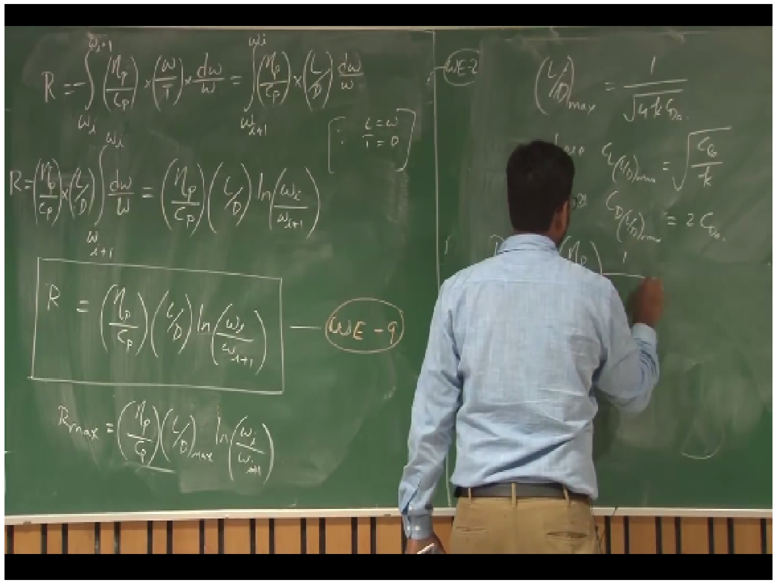

Range=integral Wi to Wi+1. So again small correction. So here the Cp=-W dot of f/Psh, right. You have to include - here. Because the reduction in weight, so Wf is the reduction in weight. So it is negative. So Cp is a figure of merit. So it is like negative*negative, ultimately Cp becomes positive here. So Cp is defined as -Wf. Similarly, C is defined as -W dot/T, right. Please make the correction here.

So the same will be reflected here, like substituting - here, - of eta of the propeller/Cp*W/T*dW/W, right. This equals to -Wi+1 to Wi, right=eta of propeller*Cp*, what is W/T? Since this is cruise, right. What we have from C1 and C2? C1 and C2, L=W with C2, T=D. So W/T is L/D. So I can substitute L/D in this equation. This equals, so this is L/D and to dW/W, right, okay.

So this is W of i+1 to Wi, R=, eta p and Cp remains constant, right throughout the flight and then L/D, since it is a cruise, it will be flying at a constant L/D here, right. And what you have is dW/W. This equals eta of the propeller/Cp*L/D*ln of Wi/Wi+1, right. So for a given fuel load and the weight of this aircraft, you will be able to, and if you know the L/D of your flight, you will be able to have a range R, right, here.

So if you want to, if you want the maximum range, so finally range=eta p/Cp*L/D*ln of Wi/Wi+1. So this is your range which can be used for weight estimation WE, 8, this can be 9.

This is our 9th equation for weight estimation. Now if you want to maximize the range, you have to maximize the L/D, right. L/D max will directly reflect in your range maximum. So what is the condition for L/D maximum? So CL has to be, L/D max is, so R max, you can have when your L/D is maximum, right. So when is L/D max, what is the condition for L/D max?

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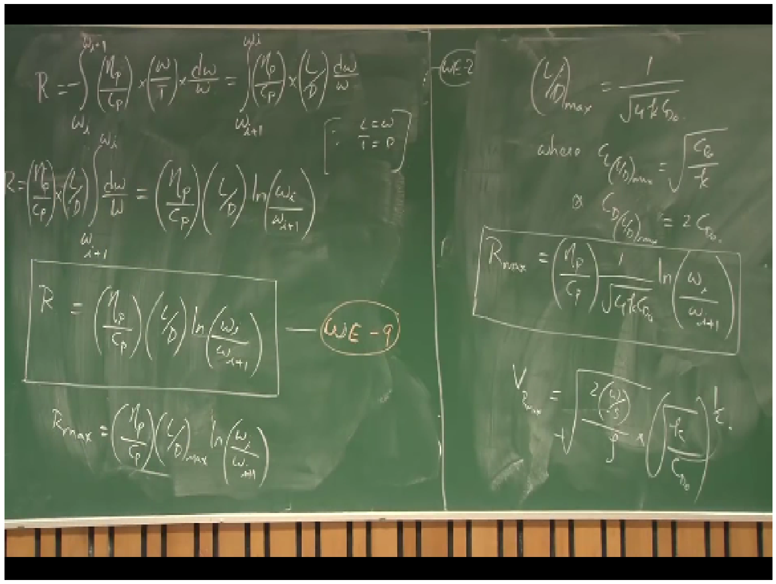

So L/D max=1/root over 4K CD0, right where CL for L/D max is root over CD0/K and CD for L/D max=2 CD0, twice the profile drag, the induce drag=profile drag in this case. So if you substitute this, the range maximum will be eta p/Cp*1/root over 4KCD0*ln of Wi/Wi+1, right. This is the maximum range that you can obtain for a given fuel load. And the corresponding velocity for R max will be root over twice the wing loading/rho*root over K/CD0 to the power of 1/2 or 4th root over CD0, right.

Now coming back to this WE-9, what we are interested is, interested in is finding out the weight ratio, Wi/Wi+1, right.

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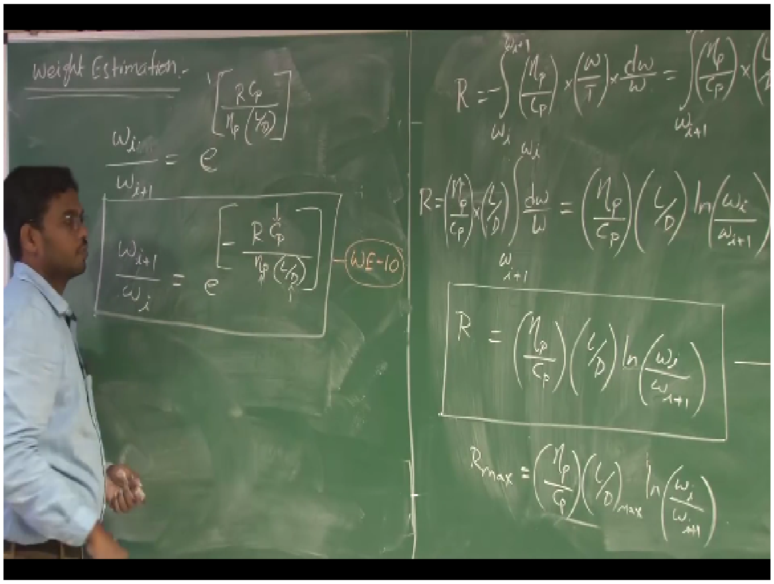

So or say Wi+1/Wi, otherwise Wi/Wi+1 to start with, =e raise to the power of R*Cp/eta p*L/D, right. So this is the weight fraction, then Wi+1/Wi=e raise to the power of -range*Cp/eta p*L/D. So this is your fuel-weight ratio that you need to carry. This is your WE-10. So if you want to have a range, right, as per your mission requirement, you need to carry this much fuel load.

So the assumption that you have to make here is what is your L/D of your flight, right and what can be the propeller efficiency as well as from the historical data, you will get to know what is the Cp of this particular, I mean, Cp of the engine that is used for this particular weight class of vehicles, right.