Aircraft Design
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Lecture - 31
Numericals: Wing Loading

Good morning friends we have been talking about wing loading thrust loading many understanding formulation, historical train etcetera I have been discussed. Today I thought we will take a simple example to see that how all those thing can be made use of and how mechanically you should be able to do it to some extent, and you will soon see that once we do it mechanically there is a time when you have to take a very serious call which will required lot of understanding of overall performance of the aero plane today I will be just.

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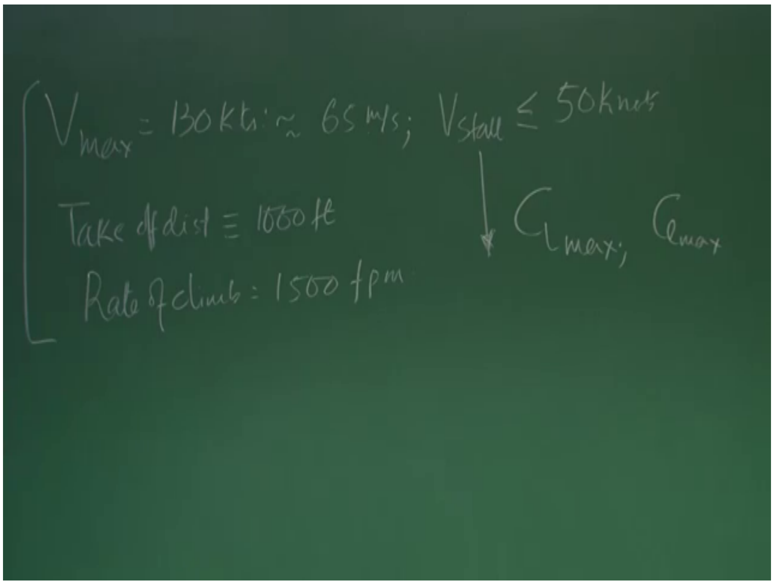

Solving one example to estimate wing loading this example is taken from Reimer’s book it purposely following is solved example. So, that you can go through it and you learn by reading more book, rather than only listening to my lectures I still do that and I will keep on doing because you never know there are many salient point which I may miss I may not give that much of weight has to a particular interpretation which you may find it more important when I discuss.

That is part of learning a designer has to have that open mind. So, coming back to wing loading as we say we need to have some mission requirement let us say V max is one thirty knots I am using FPS because the old book of Reimer uses the FPS, but you know that 31 30 knots is roughly 65 meter per second. I let us say take off distance 6000 feet which is around 300 meters roughly then rate of climb one fifth or 1500 feet per minute. Let us say this 3 parameters we are using to calculate w by s. I will also it is given which is another very important thing in a regulatory body gives you have to V stall limitation it is not more than 50 knots.

When you see V stall we start thinking in terms of CL max when you start thinking about CL max I think about aerofoil and then I start checking from the aerofoil data the CL max 2 D and in the process of visualizing.

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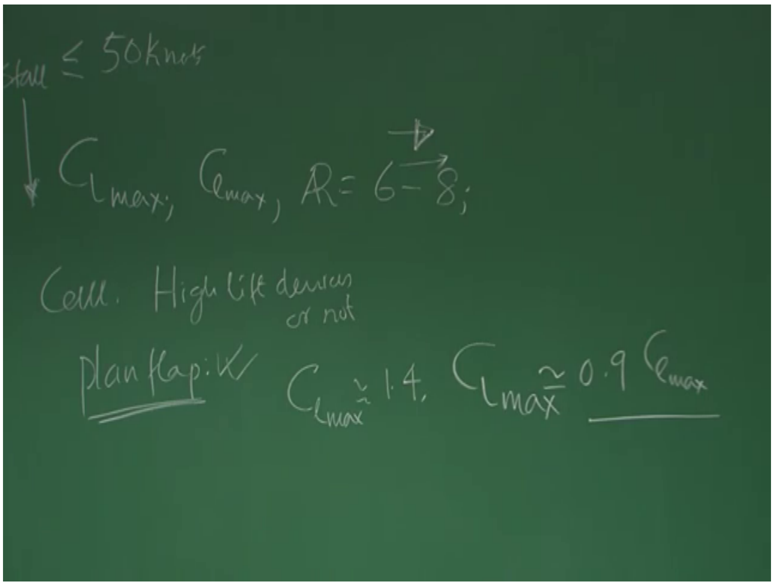

I have already taken in action on aspect ratio will be between 6 to 8 something like that for a particular type of aircraft. So, we have already done some calculation for getting w naught from the mission requirement, there also you have assume some aspect ratio right based on the ratio of weighted area and the reference area right.

Typically at this point we need to take a call whether you are going to use any sophisticated highly devices or not, we are talking about V stall and when you are having this sort of a mission requirement you have already identified a base line aero plane, from that base line aero plane let us say for this case we only want to use a plane flap.

So, within conceptual case you know I will use a plane flap this is more governed by the weight class right because more weight means takeoff distance all we will increase. So, if we see historical data for this sort of a mission requirement where range is around 280 nautical miles.

Seeing the historical data we will decided I will use plane flap to start with. When I use a plane flap I know the CL max could be around 1.4 to d CL max and that also you understand that when you are talking about CL max 2 D and once I putting the plane flap down, it has both flapped and un flapped area without going much into how much is the flap size because you have not done any flap sizing now as on today, we know if aspect ratio its around this then the CL max I can approximate roughly equal to 0.9 90 percent of CL max 2 D. This is one first number you are you are taking based on the overall experience.

If that is true then I know at CL max which I going to use for V stall will be 0.9 into let us say 1.4 and roughly let us say it is 1.2. I am giving some numbers not exact numbers the idea is how to use all those expression which I have I have discussed.

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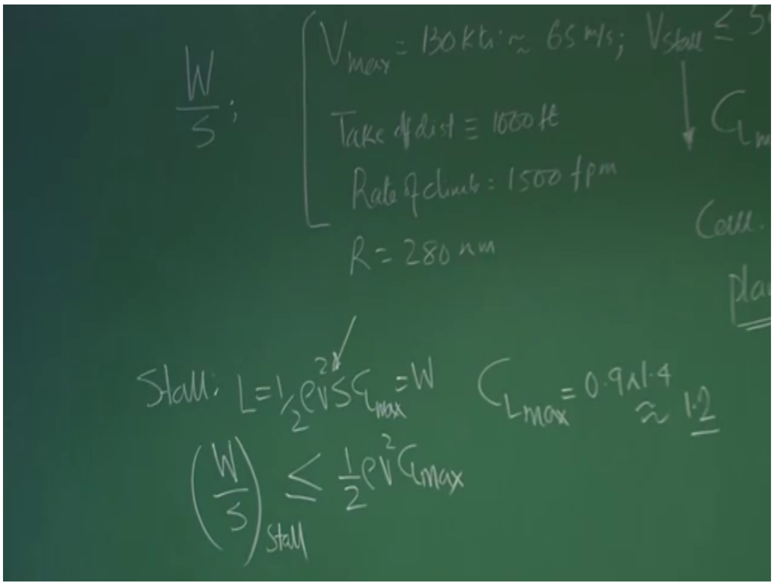

So, if CL max is 1.2 then I know for stall lift equal to half rho V square S CL max that equal to w. So, W by S stall if I have to maintain that V stall should be less than 50 knots then I can say W by S stall should be less than equal to half rho V square CL max and let us say the density of air in FPS I am taking for a particular altitude is closed to c level if I it is c level.

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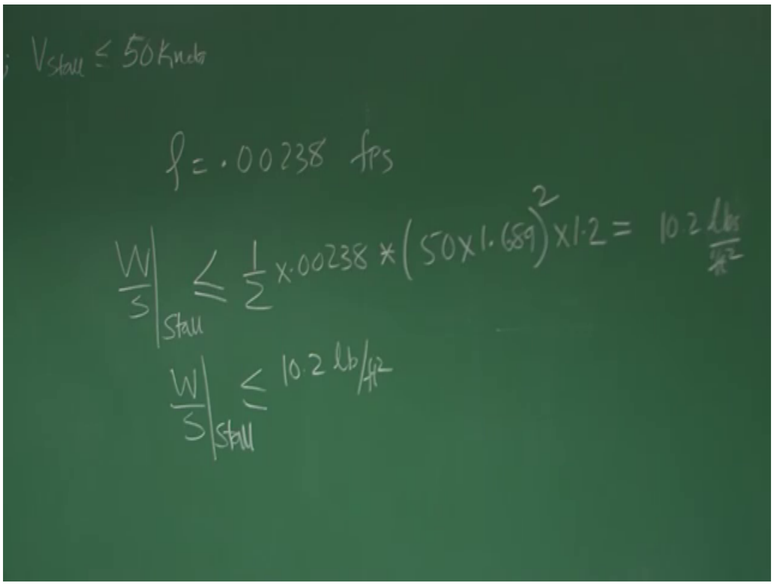

If I take a rho equal to 0.00238 in FPS unit V stall is 50 knots and rho is in FPS unit that is 0.00238.

So, I can directly use this W by S stall will be less than equal to half rho is 0.00238 up to V square V is 15 knots. So, we have to convert into feet per second. So, I multiply 50 into 1.689 is to convert into feet per second into CL max which is 1.2 and this we will give you around 10.2 k G per sorry 10.2 pounds per feet square. So, what is the message? Message is W by S stall should be less than equal to 10.2 pounds per feet square. If I want to maintain V stall less than 50 knots right 50 knots I am converting into feet per second multiplying by multiplication factor.

Same thing if I want to get a feel in terms of k G per meter square is not difficult. So, what do I, do I know W by S.

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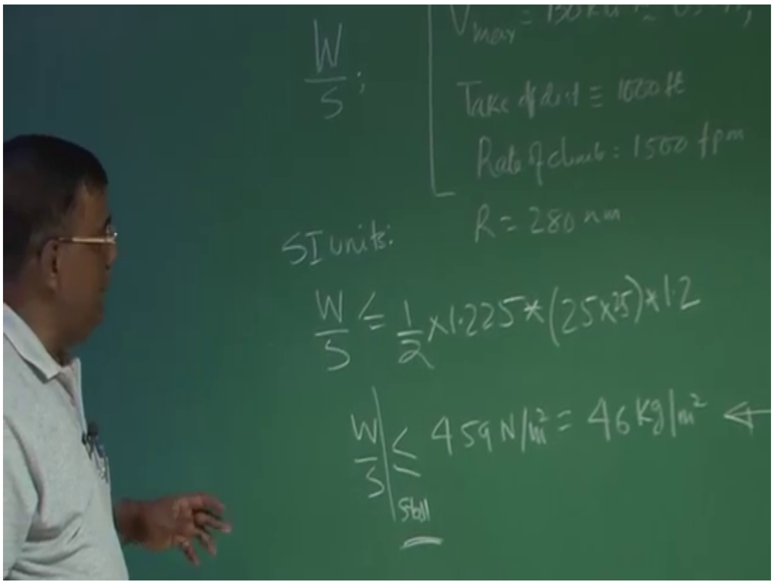

I am not doing in s I units equal to half let us say it is CL level. So, half rho is 1.225 into V square V is 15 knots V stall 15 knots means roughly 25 meter per second, which is roughly 25 meter per second. So, half rho V square which is 25 into 25 into CL max is 1.2. So, that will give me W by S less than equal to around 459 Newton per meter square which is equal to 46 roughly k G per meter square.

They see this and whether you work in S i whether you work in pound per feet square this is the condition you get, I am doing in FPS unit because the examples of sort in I FPS unit, but you should not get worried you know how to convert them and get a feel for number. So, this is W by S stall to maintain to establish satisfy the stall condition of V stall less than equal to 25 meter per second, I need to ensure W by S as 46 k G per meter square or 10.2 pound per feet square assuming that CL max is 1.2 right this is clear and you could see here.

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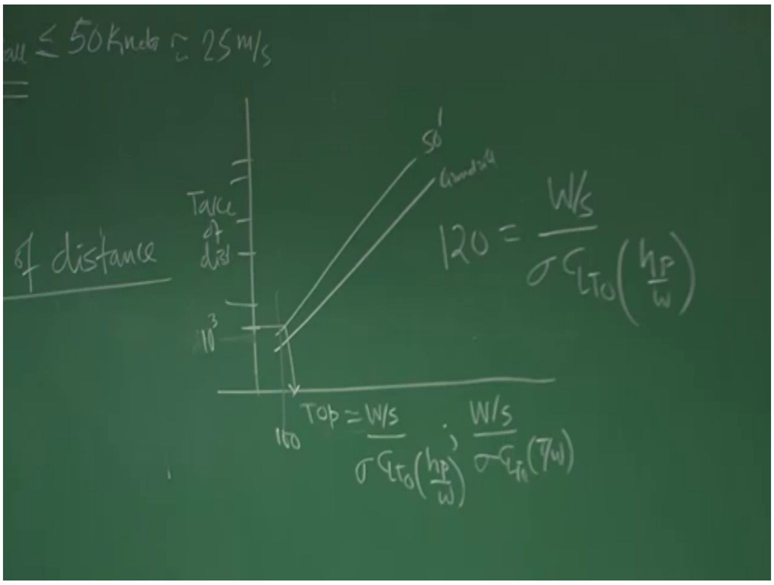

Why I am writing less than equal to because this V stall is the maximum limit. V stall is less than equal to in low case V stall can be more than 50 knots, and why this sort of a condition is prescribed? Because I know take off speed as well as touchdown speed or percentage more than V stall.

So, V stall place extremely important role then we come to second case takeoff distance you remember for takeoff distance this is one chart which gives you this is takeoff parameter and this is equal to W by S a sigma CL takeoff into h p by w for a popular aircraft or this is equal to W by S sigma CL takeoff into T by w for a jet driven the aero plane and here it was takeoff distance. Now we have seen to the chart this number is around 100 around 10 into 10 to the power 3000 feet it goes like this you see the chart and this number here is around 100. So, if you required thousand feet if cross plot here because this is for 50 50 feet clear this and this is normal that is ground role land role or ground role we are looking more for 50 50 feet clearance, because that is our takeoff distance. So, I see what is the takeoff distance one thousand feet I go here and try to draw line and see what is the takeoff parameter.

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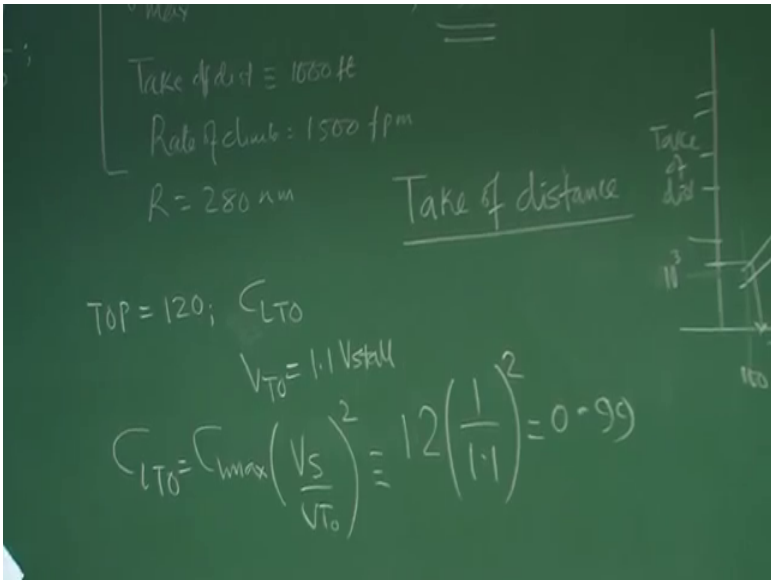

For this case you will see that take off parameter we will come out to be 120. This purely mechanical we have to see their chart takeoff parameter is 120 and that means, what do I do now I need to know what is CL takeoff because what I will do? I will write 120 equal to W by S by sigma CL takeoff into h p by w, if you are solving this case for a popular driven aero plane. So, I need to know what is CL takeoff and you know all know V takeoff is taken as 1.1 V stall. So, I can easily write CL takeoff is equal to CL max into V stall by V take off square which is equal to 1.2 by 1 by 1.1 square and this is equal to 0.99 that is CL takeoff. This is clear V takeoff equal to one point one V stall I am mechanically putting this numbers here.

So, CL takeoff a CL max V s by V takeoff square which comes down to 0.99 and we know T of P takeoff parameter equal to W by S divided by sigma CL take off into hp by w.

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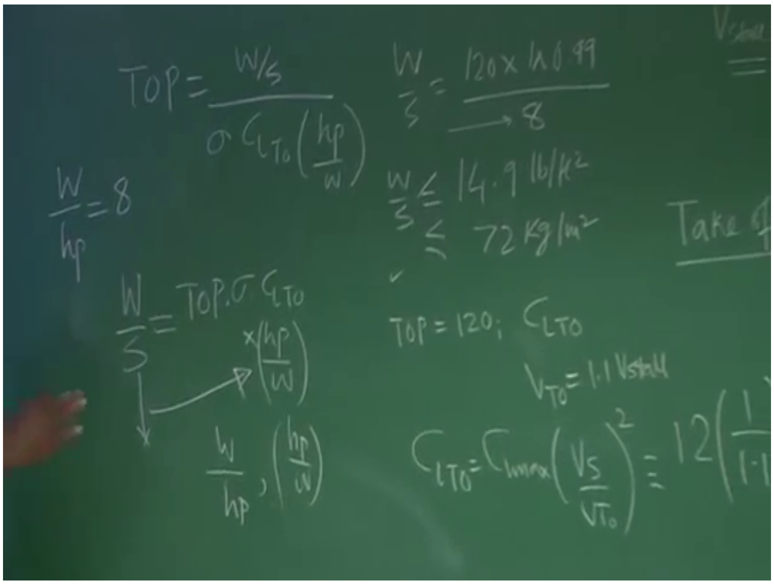

So, W by S equal to T of P into sigma into CL takeoff into h p by w; So, W by S if I am to calculate for takeoff I need to know the value of h p by w, actually power loading is w by hp now what is that value I should take an conceptual stage? As I told you which is your mission requirement we need to identify a base line aero plane of that weight class similar performance, same type of engine properly to be an engine and historical data I will find for such aero plane the value of h p by w we will be available to you, and for this case what we do is W by S equal to 120 into 1 into CL takeoff 0.99 divided by 8, that is h p by w is 1 by 8, power loading you defined at w by h p what you required here is hp by w get value is what now put it here, and if I do that then I get W by S equal to around 14.9 pound per feet square or which is again less than equal to 72 roughly kg per meter square.

This 8 you should not get confused please understand when you have identify the base line aircraft, they are the w by h p which is defined as power loading is 8 for a such similar aircraft, you are using h p by w. So, I put 1 by 8 right generally there are shall where we are commit this mistake. So, I am purposefully making sure that you understand that the they every possible chance of just multiplying reverse way, in a reciprocal manner it should be careful because thrust loading is defined as T by w, but power loading is defined as w by correspond that should be clear. Now after takeoff distance we come to climb takeoff then climb.

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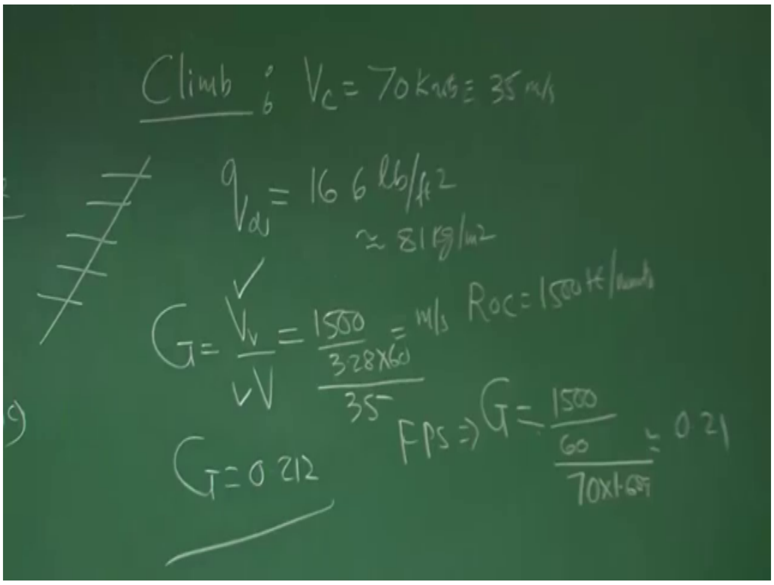

So, the question is what should be W by S for climb. So, we are looking for W by S, but you know very well that in during climb the T by w is more important right. T by w decided by climb and takeoff right.

So you will see that when you analyzing climb how many information you get. So, one you once you are talking about climb the first question we will we will come to a mind what is the claim speed, at what speed you want to climb. Again let us say that is 70 knots I think based on type of aero plane you are designing which is roughly equal to 35 meter per second. Not a bad number and the problem is when you are talking about climb as its climbs the density of air changes. So, your even if your claim is speed is 70 knots your dynamic pressure we will change because density we will change.

So, we will calculate for one dynamic pressure. In fact, you should calculate for different different dynamic pressure and you see that there will be a variations right then you take a draw a matrix and drag you find out let us for a example we are saying that we are trying to calculate is the wing loading performance at a dynamic pressure, which is 16.6 pound per feet square, which is roughly equal to 81 kg per meter square. Let us see how to use it we know G which is the climb gradient which is given by V vertical speed by the total speed and that is already written that of climb, we want have 1500 feet per minute that is that was the requirement.

So, vertical velocity we have to convert into a particular unit consistent unit. So, I can write this has G equal to 1500 feet per minute base divided by 3.28 divided by 60 that you will give me meter per second right. Feet divided by 3.28 because meter and minute towards 60 milliseconds. So, the value of G this is divided by of course, we are getting G V is 70 knots which is roughly 35 meter per second. So, I have calculated this G in S i unit please understand I can do it in FPS unit as well right. Just to make you comfortable I will be switching of the units its nothing you just question a multiplying a dividing by some factor understanding the G is ratio of V v by total plus d v and I have put in appropriate unit, and if I do that I get the value of G has 0.212. It could see that if I work it in FPS then how do I use it? G equal to vertical velocity in feet per second this is one 1500 feet per minute to 1500 feet per minute means divided by 60 right.

So, this becomes 1500 feet per second divided by the total velocity V which is 70 knots 70 knots to feet per second you have multiply it by 1.689, this also we will give around 0.21. So, what there are you do in FPS or it should be handing when you are a designer most of the data we will be in FPS unfortunately right, that is why you need to be very conversant right should not commit any conversion error that is why I am purposefully I am doing wherever possible both in FPS and S i units right. So, if G is that as I told you when you do climb T by w will be dominating the climb.

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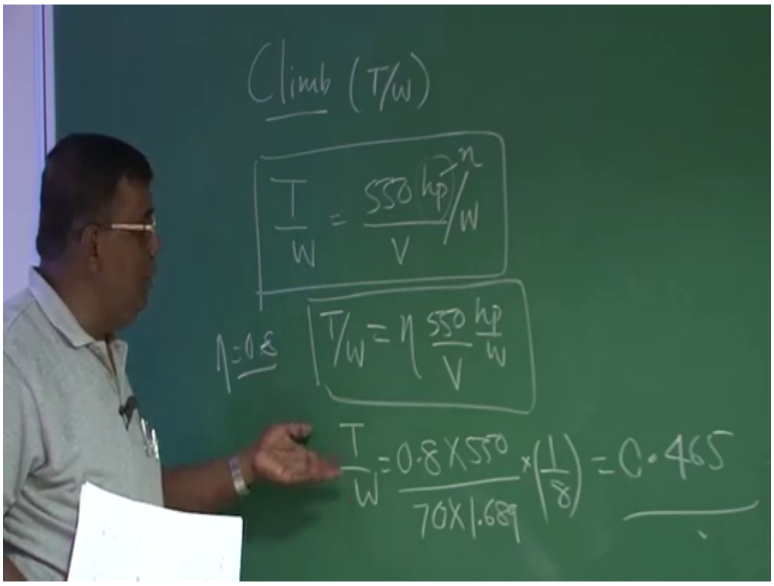

So, you need to know what is the T by w we are looking for and you know T by w I can write it as T by w equal to 550 hp by V, hp by in w and the V this and of course, you know this is the horse power at the break. So, you have to multiply by neta. So, this expression is neta 550 h p by w divided by V this is T by w. This is nothing new I am writing its already we have explained earlier. So, if I now put the value here it could see T by w we will be equal to neta if I take 0.8, which going to be a bad number with designer you can always take neta 0.8.

Generally it is we around that value will change when 550 into let me write this 0.8 into 550 correct, then 70 is converted into feet per second 1.689 and hp by w. So, I have to write it has 1 by 8 because w by h p is eight. So, I have to put hp by w which is 1 by 8 and this gives me a value of T by w around if I have not mistake a point 0.465. This is important, this takes cares of what speed you are climbing what is efficiency and what should the power setting you have to do.

So, this T by w during climb and also understand is the thrust is going to change with the altitude w is going to change with the altitude because. So, in foil is consumed as I told you when you are talking in terms of T by w takeoff, you have to give all those correction back right we have to bring back the corrections, which earlier you have told, but this gives you a pretty good number and this will tell you for that climb.

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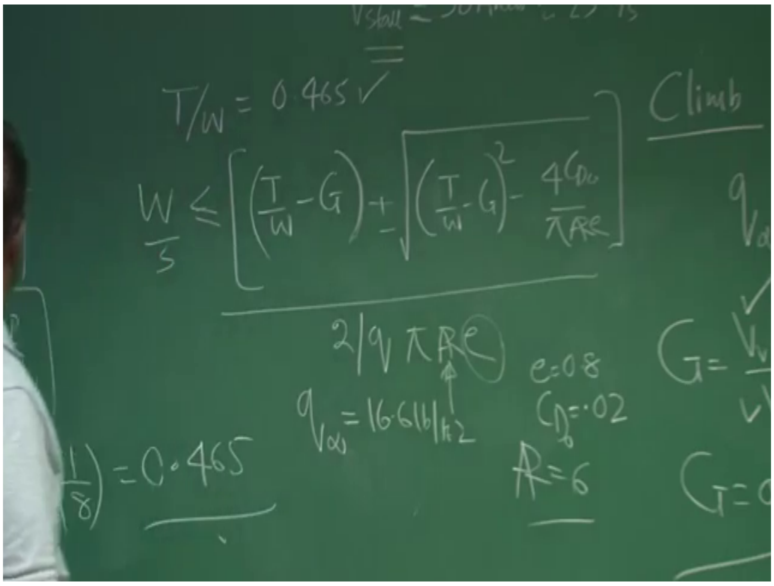

T by w is 0.465 no issues and I need to know W by S and that will be to that we have already derived that will essential T by w minus G plus minus under root T by w minus G whole square minus4 C D naught by pi aspect ratio e divided by 2 q pi aspect ratio e.

Now, as the designer you will you will have fairly good idea about A R aspect ratio. Because we have done the initial what estimate and you have assume. So, value of aspect ratio next question be how much e I should take, to initial conceptualize design you can take e equal to 0.8 and I have been telling every time C D naught 0.02 is the good number various very stable. So, D naught of course, it was a third decimal, but a conceptual stage you can always start why CD naught equal to 0.02 and we are calculating this as you agreed for dynamic pressure of around 16.6 pound per feet square. If you substitute all this thing here we can now all the numbers you know T by w you know G you know C D naught you know aspect ratio you know then you get for this calculation let us say we have taken aspect ratio is equal to 6 and then you will find should be less than equal to 62 pound per feet square or there is an equal to 33.3 k G per meter square.

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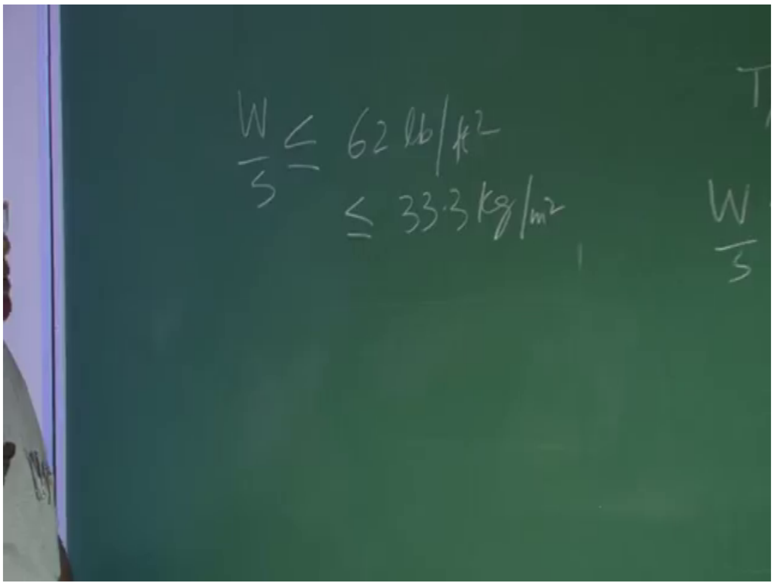

Please doing you know. So, this calculation conversion do not relay too much on me on conversion, you should do yourself and if there are mistakes you must tell me. But here as a designer please see that this value depends upon aspect ratio. So, at this stage what you should do in automated way, you should generate data for different value of aspect ratio for a particular C D naught when you generate this number for different combination of C D naught and aspect ratio. Similarly for different combination of T by w G all those data should be available with you so, that you can select. So, creating a data base and he using the data base rather using all the type formula is a write way for a designer to get a field, do not leave everything to the computer at least at the conceptual stage right.

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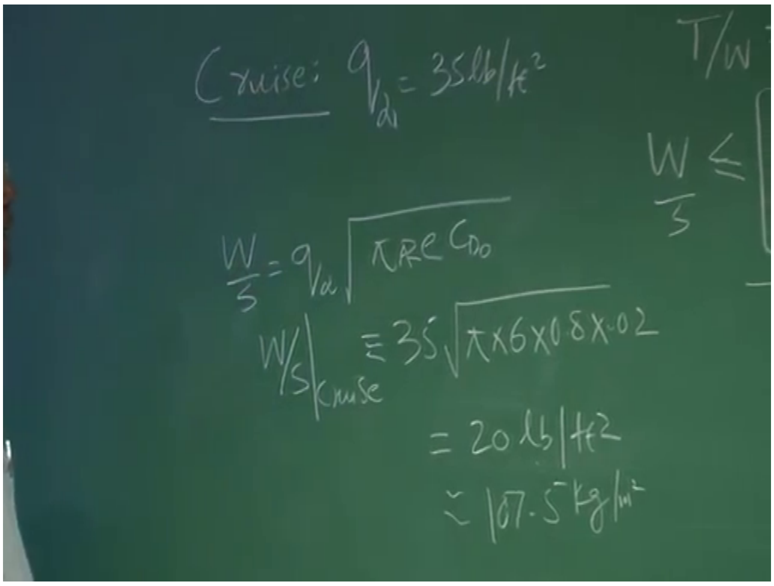

Then comes the at most important thing, Cruise again when you are cruising you need to know at what altitude you are going to cruise or what will be the cruise speed, because type of aircraft you are designing again the baseline aircraft helps you then what is generally the cruise altitude. So, you have enough idea of what sort of dynamic pressure because you are going to fly and let us say that (Refer Time: 27:41) pressure is 35 pound per feet square, you can generate numbers for various dynamic pressure.

These calculations are demonstrated here to tell you how to use this expressions right. The designer we will generate values or cruise are different different any equation then you will check what is that altitude and what is that altitude at what speed I should fly. So, that drive is minimum sometime that is not desirable because it will be take longer time. So, what is the prescribed speed, so, all those things goes into the design instead of talking altitude and splits up readily, dependent to talk many a times in terms of dynamic pressure.

So, this is that dynamic pressure and you know W by S from the two's formulation is q under root pi a r e into C D naught, which will be W by S cruise definitely this coming because of one condition that I am trying to get W by S for a best cruise, and if I put those number I felt 35 under root pi that aspect ratio 6 e have taken 0.8 C D naught I have been 0.02. So, let us say this is equal to 20 pound per feet square or at approximately equal to 107.5 kg per meter square.

In wing loading we may time create problem by writing a by actually getting the value is neutral per meter square and then writing it has kg per meter square. So, you have to multiply divide by value of G, be careful we will conversions right. So, what is happened by mechanically using this for at least you know clearly the road map, what I am getting that is important please see that whatever I have so, many days we have been talking about wing loading, thrust loading etcetera one important thing you have realize here for a climb, the wing loading has a meaning provided you have preselected thrust loading. Because unless you have this you cannot climb that is the more dominating factor.

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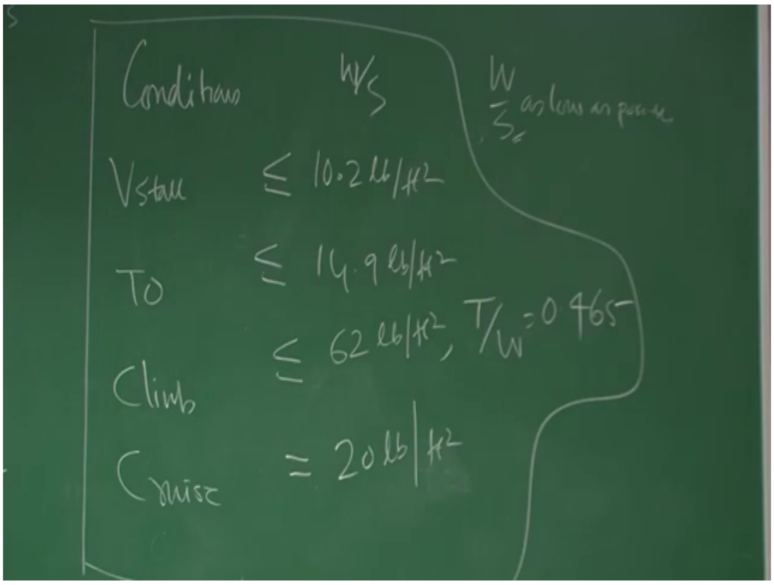

So, now what we are seeing, you are seeing the conditions and I say W by S, if it is based on V stall then the answer is wing loading requirement less than 10.2 pound per feet square, if I am satisfied takeoff then less than equal to 14.9 pound per feet square. If it has satisfied climb then annotation will less than 62 pound per feet square roughly, and of course you have to maintain T by w equal to 0.4 something 0.46 or let me put the exact number 0.465 and if it is cruise satisfy cruise this is equal to 20 pound per feet square.

So, let me check whether the numbers are or not for stall I got 10.2 pound per feet square right for takeoff it is 14.9 pound per feet square, for climb T by w point force is 5 and W by S is 62 pound per feet square, for cruise it is 20 pound per feet square. Now the question is which W by S I should take. It is always fine for an aircraft if you general tendency not obvious, but I like to have W by S as low as possible meaning there by that for a given weight wing area is large. So, I get a lifting will be easier takeoff will be easier, but do not forget it will cause drag penalty lot of skin friction drag, then if large wing area structural weight also may vary I took may go to a higher size sometimes.

So, then how do I select? If I put the criteria I take the lowest then naturally out of these thing this I will pick right, but if I pick this I would not be able to satisfy cruise condition. So, how do I handle such situation? So, that will be my next class and that is where from mechanistic approach to a designer approach it begins here only numbers will be there for different different combination and then you have to select keeping all your mind that what finally, you want and those who are believing in optimization, there will be computerize it automate it they use those understanding at the part of algorithm.

But at a conceptual stage dear friend software will not help you, unless you understand unless you know how to visualize and then feel for numbers you can never be an engineer designer in particular whatever softwares are given to you. So, I will we that is why I am putting lot of stress in understanding getting feel for numbers, I hope you appreciate it and you learn and build your own conceptual aircraft.

Thank you very much.