Aircraft Design
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Lecture - 23
Thrust Loading and Wing Loading

Good morning friends. We will continue discussion on Thrust Loading.

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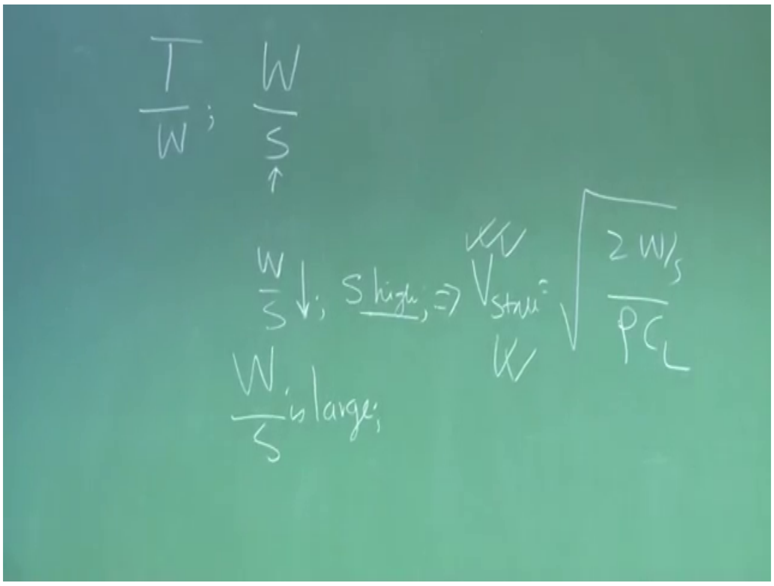

Please remember when I am talking about thrust loading T by W I should keep in mind another parameter wing loading will also play an important role. And a good designer will select the right combination based on what is the final mission requirement, right. If we recall one as a designer I want to perceive wing loading I know that if W by S is low; that means lots of area is available to generate lift to balance the weight so naturally your minimum speed required to maintain lift equal to weight will reduce your takeoff speed also will reduce. But at the same time we should know that as I am being low wing loading area of the wing is relatively large.

So, large suspicious area, more thin friction, more drag, so more power. So, that is a conflict. You could see for a designer there will be many times a conflict to arrive at a combination of T by W and W by S. For simple reason: I want W by S to be low; that means S is relatively high and this amounts to my V stall which is 2 W by S rho C L will be low or lower. If W by S is less from designer perspective if large area of wing is there so that will produce larger lift for a given dynamic pressure and angle of attack.

So, the moment W by S is low we have this advantage, we have advantage of V stall or any operational requirement which is based on V stall. For example, takeoff, landing, they also will get the advantage of V stall being low. WE will have lower takeoff speed, lower landing speed. But we know that because W by S is low so S is high, so larger area, larger thin friction so larger drag. And again to comprehensive that we need to have higher thrust: it goes without doing much an effort that if W by S is large; that means area is relatively less if I assume both the configuration having same weight; area less means less V stall will increase. But the advantage one I could see that area being less skin friction drag will be less. So, my thrust requirement may be lower.

So, the high speed airplane you will find W by S will be large, if you are going to accelerate fast W by S will be large. Of course, as you have larger area and if you club it with larger aspect ratio then structural problem also comes. I am not going into those details now. But whenever I am talking about T by W; thrust loading you should keep back of your mind the wing loading W by S which will be dealing exhaustively after one or two lectures, right.

So, let me come back to thrust loading some salient points.

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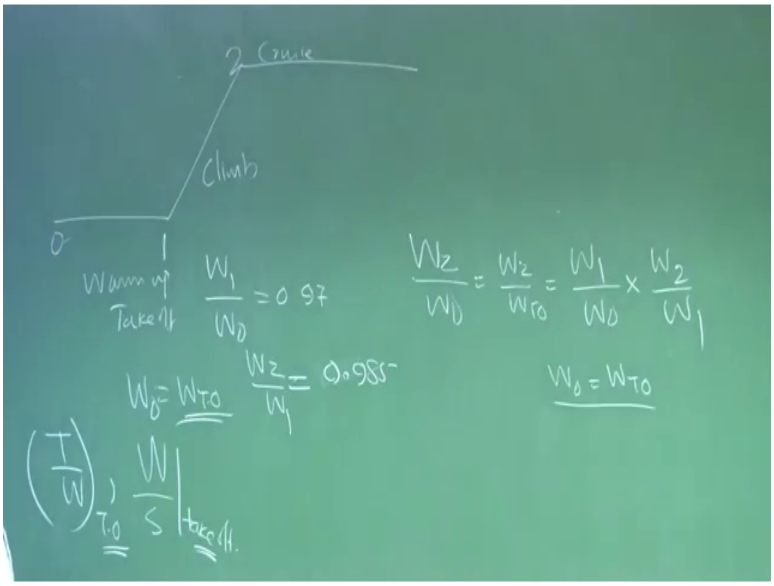

If you see this is power warm up warm up and takeoff, and this is climb and this part is cruise, this is the machine profile. And if I put 0 1 and 2 we have seen that W 1 by W naught; in this case W naught which is W takeoff. For a designer it is important to arrive at some number W takeoff ,because that becomes a weight and then he is tries to find out what is W by S takeoff .If that is the basic parameter with which he starts designing the airplane.

Similarly, just now we will be talking about T by W takeoff is that is understand this takeoff conditions why this is important if I give a simple example with W by S takeoff you know this W naught is W takeoff. So, W 1 by W naught this value could be let say 0.97 let me some fuel as been consumed in this sector in this segment and then W 2 by W 1 which is climbed. And let say that ratio is 0.985 because to climb up to 0.2 this ratio W 2 by W 1 is less than 1 because of fuel is consumed.

But if I want to know what is W 2 by W naught which is equal to W 2 by W take off that will be what that will be simply W 1 by W naught into W naught to W 2 by W 1 I repeat W 2 by W take off or W naught they are same. It will be W 1 by W naught into W 2 by W 1.

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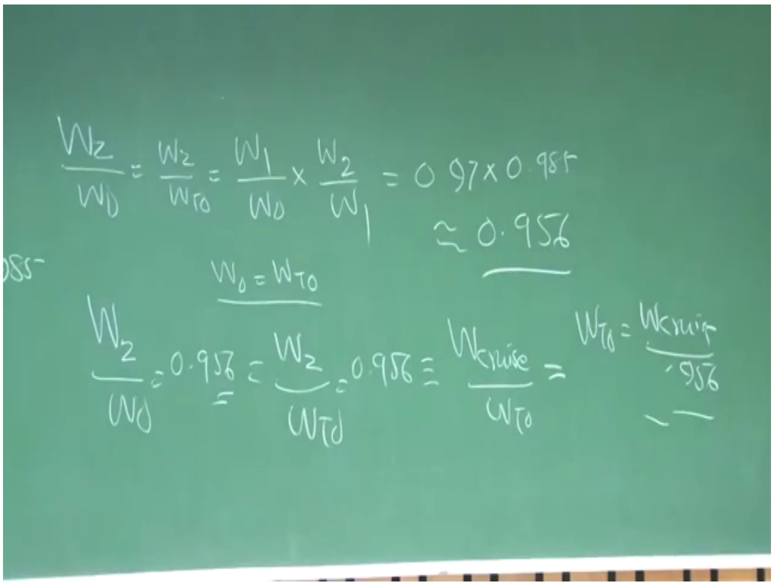

Because please keep in mind W naught and W take off are same and if I do this, this will give me 0.97 multiplied by 0.985 and that may be approximately 0.956 please check yourself what is the message? Message is W 2 W naught is 0.956 or I write it like this. W

2 by W take off is 0.956 and then I also understand W 2 here I am talking about W cruise at the beginning by W take off this value is 0.956.

So, if I am interested in W take off by S. So, I should translate this W cruise to W take off that is what should have been the W take off. So, that I made this conditions and from here you understand you have to simply W take off will required would be W whatever cruise divided by this 0.956 factor. So, this is even common mistake we do in the class and this is just not a numerical mistake that is why I am stressing it when you are designing an airplane this points.

This 0.2 will tell you at the start of the cruise it is expected to have W 2 by W 1 0.985; that means, this much 1 minus 0.985 whatever number comes that much into whatever weight airplane had if I multiply I will get the weight at cruise or I say if I really want W to be that much for many requirement I should ensure that W take off is sufficient enough. So, that after this operation W cruise is what you are aiming for right that is why all the data I should convert into the take off conditions you will also see that interesting that when you are cruising from here to here.

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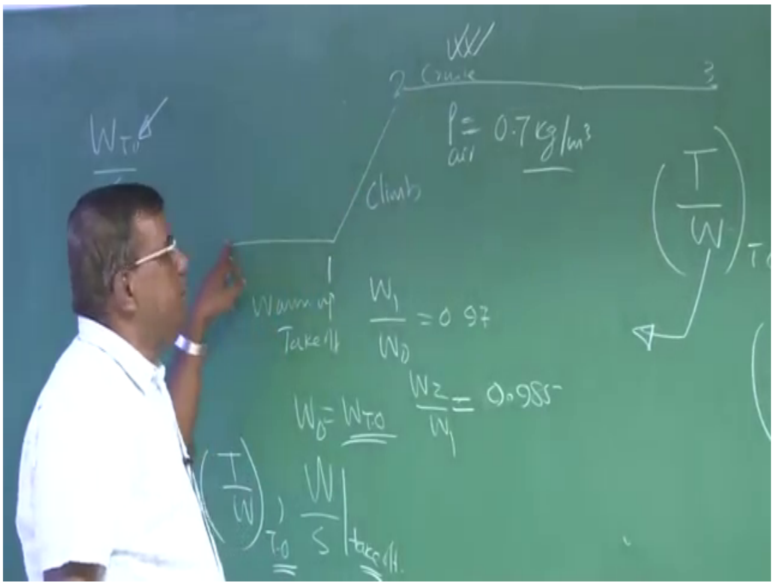

Let say 3 point; number 3 again the fuel consumption will be there. So, which W by S take off should we take?

So, you take the average what is that designers approach this is fairly simple to understand now if I go backward again from here I switch over to thrust because I told you will be talking little more about W or T by W take off and since I told you should not only see T by W separately whenever you are thinking of T by W think of W by S as we will make it a practice right. That is why I am also moving from T by W to W by S again coming back to T by W just to give you a feel that never commit a mistake of thinking T by W separately always T by W immediately check what is W by S I am looking for like C L the moment you think C L do not think C L separately in C D also.

So, C L by C D you should see. So, that is that will help a designer to be confidence and in that is right approach in my opinion right.

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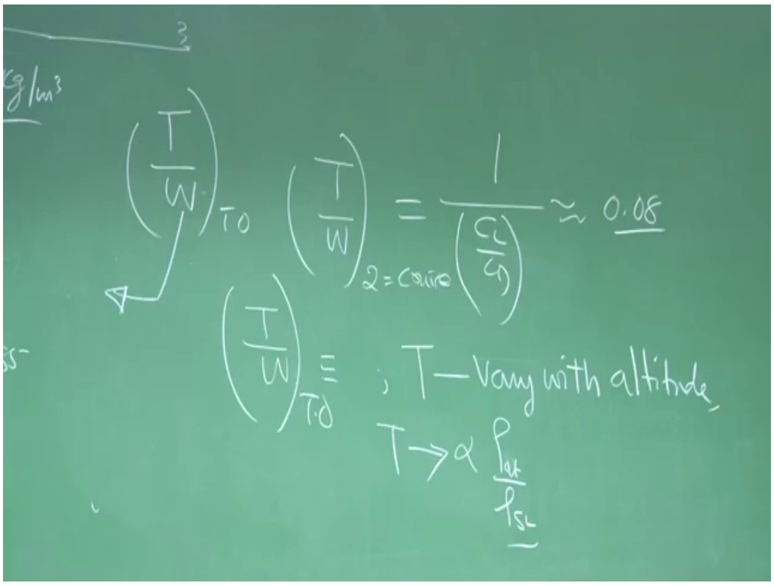

So, if I similar thing if I do for T by W take off now we have understood how to correct W take off because you will have W cruise here some value convert it into W take off here you have some thrust at the sea level. So, you know T by W is how much, but T by W recall that 2 T by 2 require that 2 which is nothing, but cruise equal to one by C L by C D and this value may be around 0.08 if I flying at C L by C D more than 10 around 0.08, 0.09, 0.1 whatever the number could be. So, that is the requirement prescribed at this point.

But what will be T by W take off as I was telling you have to convert all this requirements into a T by W take off or W by S take off what is the understanding is this thrust will vary with altitude. So, you need to see the engine and see I want T by W some number I see that T by W cruise is at an altitude let say rho equal to density of air at 10,000 feet; it may be 0.7 kg per meter cube around that and you know the thrust available at that altitude will not be the thrust which is available at the sea level.

So, you have to again convert that taking the altitude effect from here to the sea level. So, when I am talking about T by W take off I am all talking at to refer the sea level right for example, if you are if you design an airplane T by W take off, but you are going to take off from lay or some places you have to correct it. Because that is not sea level conditions right. So, what do you do you correct the thrust seeing the chart generally it follows density at altitude by density at sea level because as you go higher and higher the density of air reduces ad hence your thrust also changes there are calibration chart engine manufacture will give this chart and those things are available, but these are I know roughly it will follow that right.

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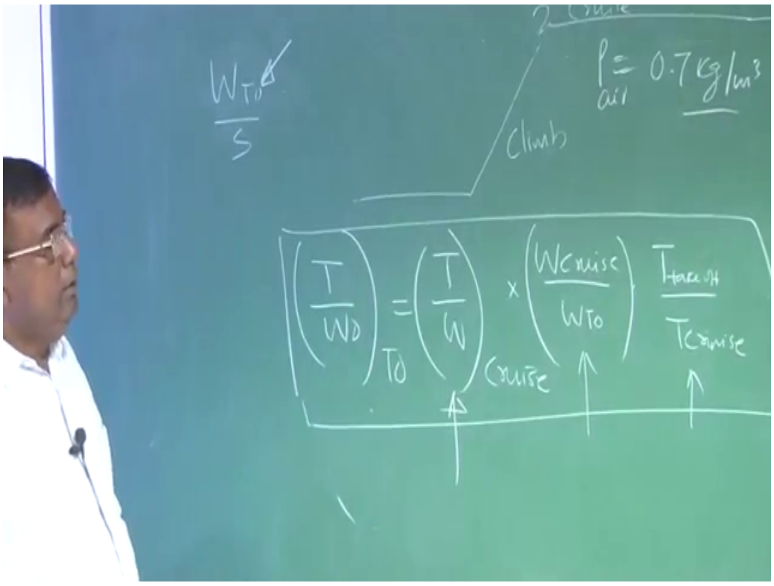

So, you pick your initial concept conceptual design based on this and then always see the chart which are available right. So, in a net shell if I try to make it little more formal with this understanding, I can write T by W take off is equal to T by W cruise. If I am talking about cruise, I am converting cruise to cruise T by W to T by W take off because I know both thrust and W at cruise needs to be translated to take off conditions. So, this will be this multiplied by W cruise by W take off into T take off by T cruise this should be back of your mind and it should have some number for this at the designer some number for this and you know how much T by W take off the engine should be able to deliver at C level conditions.

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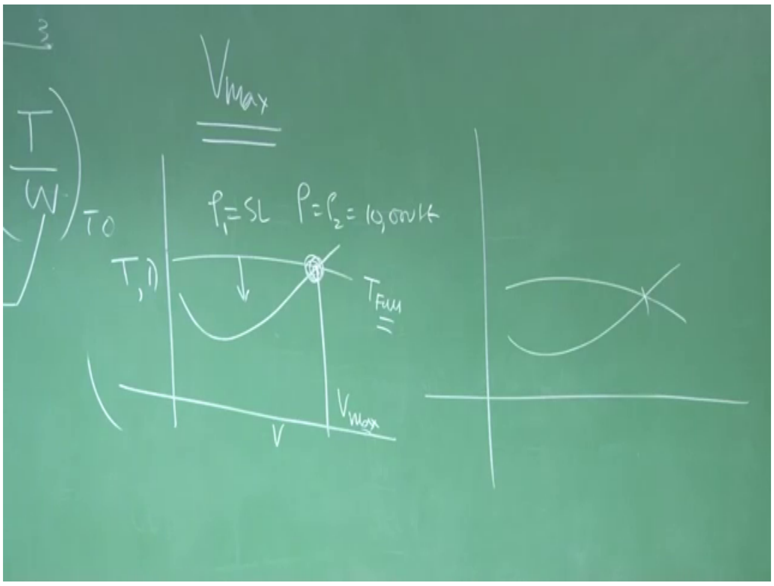

This is one; I thought and the second thing the last class I did mentioned in the last class we are talking about V max. We are asking a question assuming that the aircraft is strong enough to fly at V max meaning there by the aircraft is strong enough to withstand the dynamic pressure and forces which is the combination of the altitude at which it is flying as well as the speed right. So, we found that fundamentally we know that if this is thrust and drag and it goes like this and the thrust is constant almost I am assuming with V thrust is not changing.

Typically jet engine behaviour then this is the point where I say this corresponds to V max full throttle. So, assuming that thrust is full throttle I have given, but remember if this is at an altitude rho equal to C level rho 1 if I want to have a V max for rho equal to rho 2 which is let say 10,000 feet in that case what will happen both this as well as this will change this man will try to come down and this will try to shift this way because density of air is less density of air is less means the drag part will be less; however, same time thrust available from the engine also will be less it will come down. So, this point will change.

So, those are the silent things you should carefully see and you know that if you want to fly at same C L then you know the expression; how to get what is the equivalent speed what I am; I was telling the last class I want to come back to that immediately once we were trying to see how do I find out you said thrust equal to drag.

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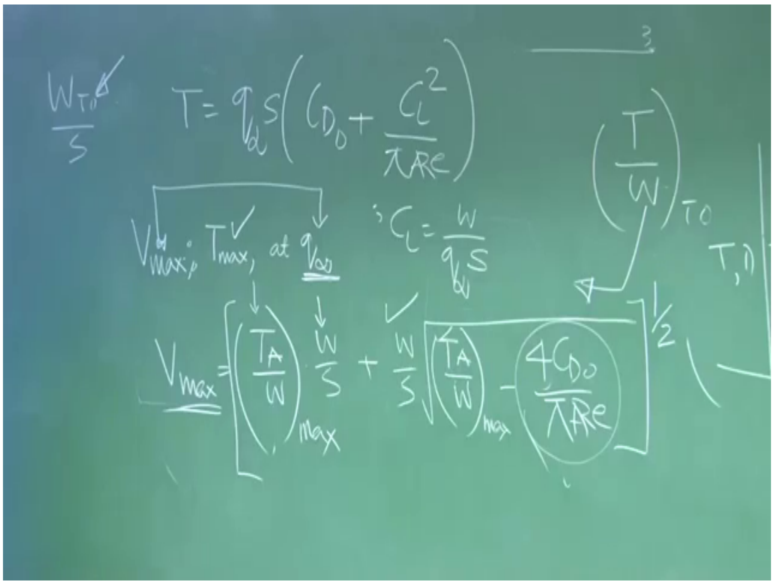

So, that is C D naught plus k C L square. So, C L square by pi aspect ratio e right and C L you know equal to W by dynamic pressure half rho V square into S by now you know that once you write it drag polar expander drag polar like this I have made some assumptions and their low speed plane the wing is struggling to be near elliptic wing and definitely it has a lower speed, but when I want to see what is that speed at which this drag and this thrust their matches this equation gives. So, for V max I ask a question I have given T max full throttle at a given q infinity that is dynamic pressure which is I always think whenever I am talking about V max high speed. Immediately it should be careful enough you should start thinking in terms of dynamic pressure because structural limitation comes from dynamic pressure, right.

So, I do this then we have shown that that expression comes is something like this T by a W max into W by S plus W by S T a by W max minus 4 C D naught b y pi aspect ratio e and this is to the power half as I have told you can refer and there is an book introduction to flight. In fact, you do not require it you can also do it from here.

When I was discussing this it is very obvious that V max if you want to increase V max T a by W should increase right and also you see W by S should also increase W by S increase means what S is less. So, drag is less naturally V max will increase. So, this is consistent this is also consistent we were bothered about what is this term for simple reasons we are talking about T by W we are talking about W by S, but where is that aerodynamics, where is that aerodynamic efficiency which will also dictate how do I achieve V max conceptually if drag is low then you can accelerate fast right.

So, somewhere that C L by C D has to play role somewhere it must be hiding let us see any aircraft design any expression L by D max will be present is their explicitly or implicitly and the designer takes maximum advantage of that. So, whenever you designing whenever you see an analytical expression try to look for where is L by D max what is W by S they are hiding those are initial design parameters which I am designer can easily pick right remember in the initial part we decided how to get roughly the value of L by D max right.

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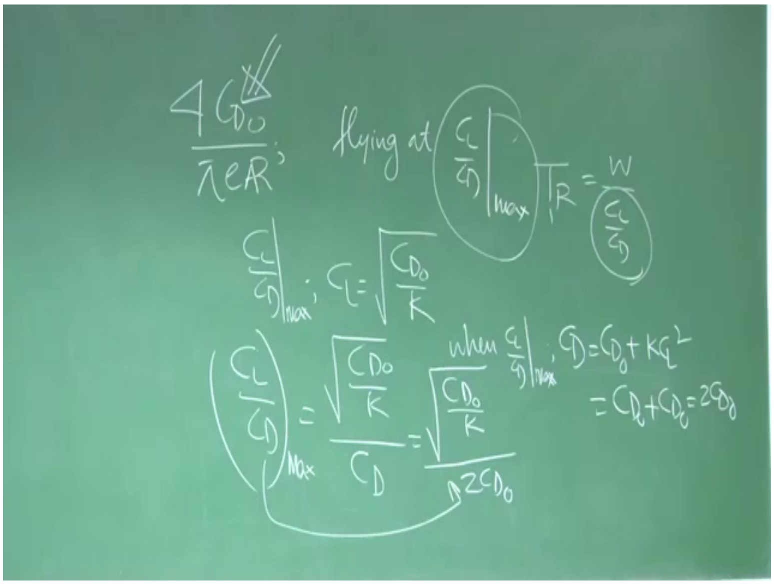

So, that exercise I told you to do I do not know how many of you have done it, but let me do it if you see this expression 4 C D naught by pi e aspect ratio suppose I am flying at flying at C L by C D maximum what is the meaning of C L by C D flying maximum if I am cruising I know T equal to thrust required equal to W by C L by C D. So, when I say I am flying at C L by C D max; that means, I am talking about thrust required minimum right and you say aerodynamically most efficient configuration when C L by C D is maximum aerodynamically and you know that for C L by C D to be maximum you need to fly at C L equal to under root C D naught by k all this thing you have done and you are performance course also which essentially means you fly at C L such that your induced drag coefficient and once I drag the half equal magnitude.

So, for C L by C D max C L equal to C D naught by k and I see what is C L by C D max that will be under root C D naught by k by C D and you also know that when C L by C D is maximum then I could see that C D equal to C D naught plus k C L square. So, this is equal to C D naught plus C D naught that is 2 C D naught right. So, I now write it like this under root C D naught by k divided by 2 C D naught see this.

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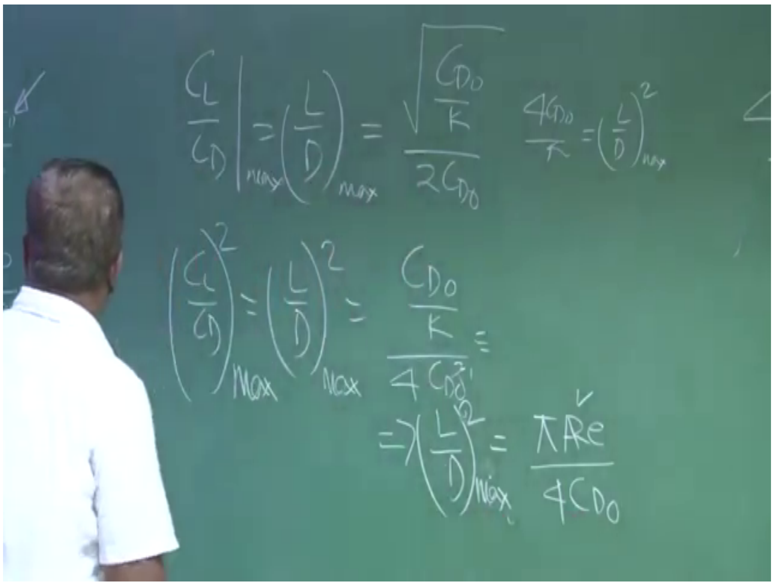

And keep your focus here we want to see what this bunch of number tells us aerodynamically.

So, now; so, if I write C L by C D max which is nothing, but L by D max which is equal to under root C D naught by k by 2 C D naught. So, if I take C L by C D square which is max of course, which is equal to L by D max square will be equal to C D naught by k divided by 4 C D naught which is equal to 4 C D naught square yes right.

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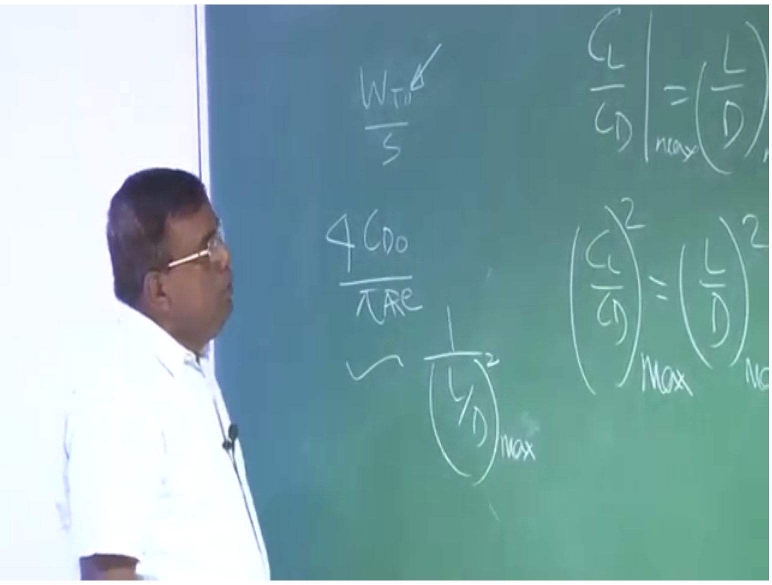

And also what is k? So, k is one by pi aspect ratio e please do not forget that term what we are looking for which I have erased here 4 C D naught by pi aspect ratio e. So, if I do this I get C D naught goes up. So, this implies L by D max square will be equal to pi aspect ratio e by 4 C D naught let me check this.

This becomes one force C D naught. So, this is 4 C D naught by k equal to L by D max square or L by D square max you see that C L by C D square equal to L by D max square C D naught by k by 4 C D naught square you C D naught get cancelled S I get L by D square max L by D square max; max equal to pi aspect ratio e by 4 C D naught, but we are looking for 4 C D naught by pi aspect ratio e. So, that is 1; by L by D max square sorry L by D square max.

So, in that expression now if I come here we have derived this expression we where looking for this term and this term you see is nothing, but reverse of this. So, it varies inversely with L by D max square and see this is a negative term. So, as you increase L by D max influence of this term go down.

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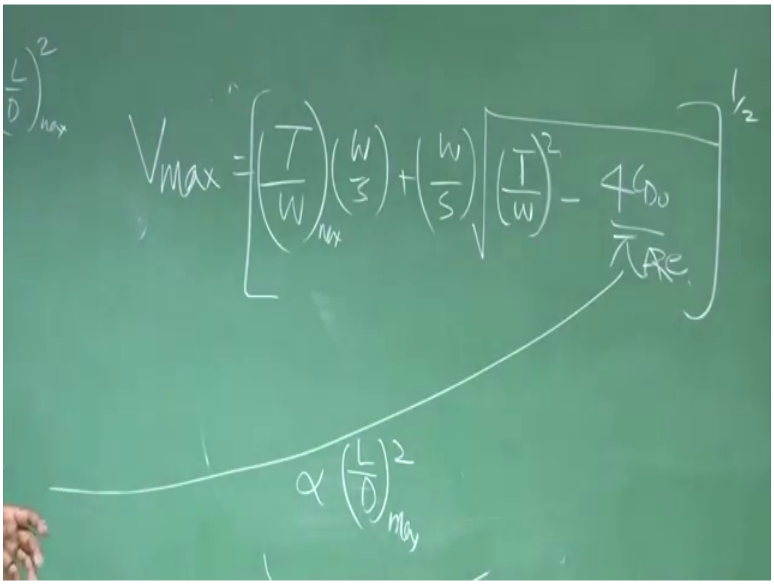

So, it helps in having higher V max. So, now, that puzzle is over S for V max and T by W as large as possible W by S as large as possible. So, wing as small as possible and also I want from this L by D max should be as high as possible. Analytically it looks very very nice, but achieve a configuration which will satisfy you all this 3 things to your desire may not be always possible and that is where a designer as to play the important role; how we optimizes this. That is why whenever you are seeing this expression just do not solve an assignment problem the moment you want to increase T by W ask yourself what it means for increasing T by W means you are going for a bigger engine bigger engine will also increase the weight cost will increase maintenance may be difficult W by S if I want to increase lesser wing area; that means, I need higher speed higher V stall to balance lift equal to weight and L by D max can I really fly at that L by D max all the time for a given aspect ratio is it possible.

So, all this thing you have to ask your question and also silently you see here this C D naught value if you do not try to relate to L by D max square. You may start wasting time on C D naught, but please that moment is leading. So, it is always better whatever analytical expression you are using you please see what is inside what sort of information you get right; I taught I must mention this to you, let us see how a designer should play around with this analytical expressions let me do an give an example if I talk about rate of climb let us see rate of climb right for a conventional aeroplane and let us take a example of a jet driven aeroplane.

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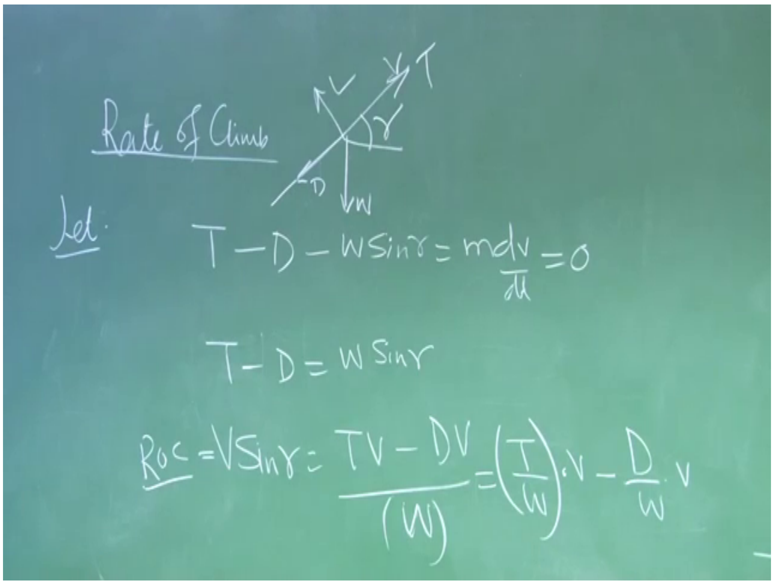

Rate of climb when you say it is if you write this equation if this man is going like this, this is a drag you are all familiar with sort of expression this is flight path angle and this is left. So, I write T minus d minus W sin gamma is equal to m d v by dt, this is acceleration along V direction and these are the active forces right and I am saying simply thing I am going for a steady climb that is with constant speed rectilinear motion I put it 0.

So, I say T minus d is equal to W sin gamma and we know that I can write it as V sin gamma equal to T V minus d V by W this is nothing, but rate of climb this expression does not tell me about anything T by W; W by S although T by W you could see here right we could see that yes if you want to increase rate of climb this expression I can visualize as T by W into V minus d by W into V. So, T by W is more rate of climb will be more it would climb faster all fine at a given speed V.

But where is W by S hiding because I say told you whenever see T by W look for where I W by S right.

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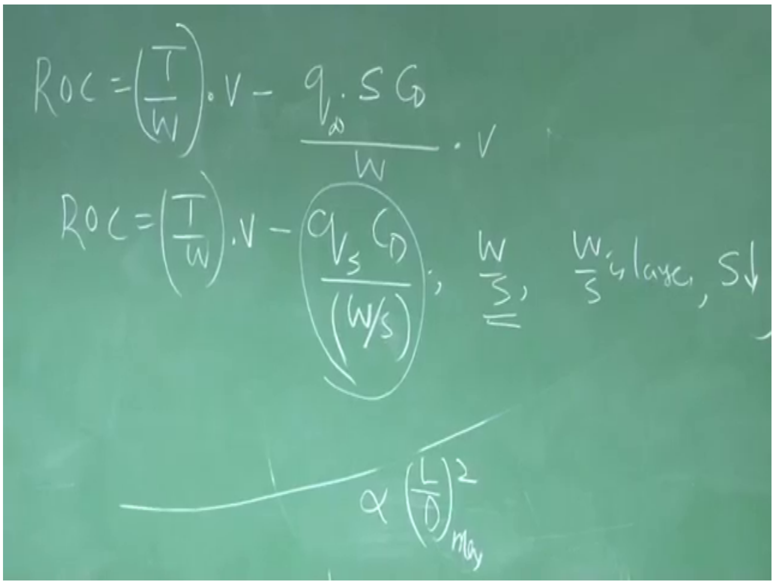

So, now, I see here rate of climb equal to T by W into V minus q infinity dynamic equation into S into C D by W into v. So, immediately I could see the rate of climb. So, equal to T by W into V minus q infinity C D by W by S this is now if you want to see what is the effect of W by S what is the message you are getting if W by S is large; that means, W by S is large means what area is less area of the wing is less T hat is why W by S is large for a given W.

If W by S is large; so, this term will be less. So, your rate of climb will improve if W by S is small the larger wing this term will become more negative and rate of climb will all will reduced we see the connection. Now designer will see this a designer should be able to extract meaning full information for e synthesis; it should not just depend upon equations then writing program code and looking for numerical methods you cannot be a designer with a minimum manipulation here and their arrangement you should get the maximum information that is where you say this man as a intuition this man as that amount of smartness to manage all those conflicts because he understands with minimum effort, yes, this is going to happen order of magnitude he gets an understanding.

The story does not end here, if you want to see in this where is aerodynamic efficiency playing a role the as I told you T by W, W by S always check the third friend where is this aerodynamic efficiency because after all it is a aerodynamic vehicle. So, aerodynamic efficiency has to be there hand holding our mission of flying from one point to another. So, we must try to see even if we it is hiding in a disguise try to; I get it you may get more information if I see this expression q I am just doing a an exercise to give you a feel how a designer should try to get maximum information right q infinity S C D V by W and that is this expression I am talking about here because here T by W into V is there and here C D is there.

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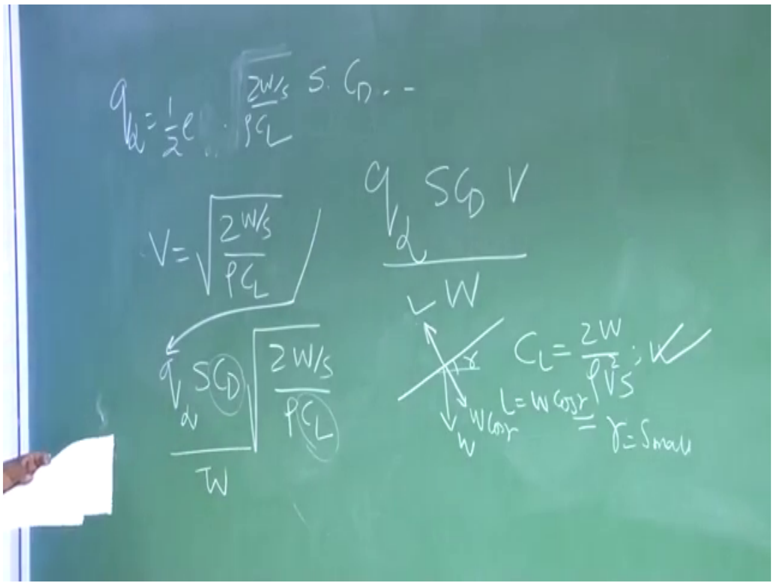

So, I am first attacking that term and during climb I am assuming that C L equal to 2 W by rho V square S that is lift equal to weight, but you understand that lift is not equal to weight this is lift. So, lift is actually equal to W cos gamma I am assuming gamma small or small climb. So, I am taking liberty of writing C L as this correct this is lift and this is the weight sp this is W cos gamma. So, if it is flying rectilinear path constant speed. So, the lift should be sufficient enough to balance the weight and this lift will be less than the weight for a as compared toward cruise. So, we say induce drag in climbing also less all this things you know.

So, if I use this expression then I can write V equal to under root of 2 W by S rho C L and that V I use here. So, q infinity S C D into 2 W by S rho C L by W that immediately you start seeing C L and C D appearing right from that expression C L was not seen. So, you do not get the relationship C L by C D that feel. So, you can start putting this number here you can also can put for q infinity you can write half rho V infinity into again 2 by S by rho C L and then S into C D and this term here let me what I am doing for q infinity I am putting half rho V infinity into V; V I am writing like this.

I can do also I can write q infinity as half rho V infinity square. So, I release this I can see like this another C L term comes here right. So, that is from where you have to pick what is the C L by C D combinations right in it should not be surprised that you get something very very interesting. So, keep it a habit like this of expanding it rationally and try to see where is C L by C D or C L 3 by to C D all this things finding; I leave this exercise to you and see from this expression can I comment anything on C L by C D or C L 3 by 2 by C D from aerodynamic ratios which will inspire and designer to maintain. So, the rate of climb is maximum right.

So, I hope you will do that in any case I will do in the next class, but I will always prefer before I come for next class we do some home work and get some expression there we get we get connected very well right.

Thank you very much.