Aircraft Design
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Lecture - 03
Design Basics: Lift and Drag

Good morning friends. We were discussing about Aircraft Design, and as I told you the initial few lectures will be a warm up lecture so that we know what direction you should take to make aircraft design approach very specific. And to be specific, we need to understand that aircraft design is a synthesis process. So, we should know what exactly; what are the components we are going to synthesize.

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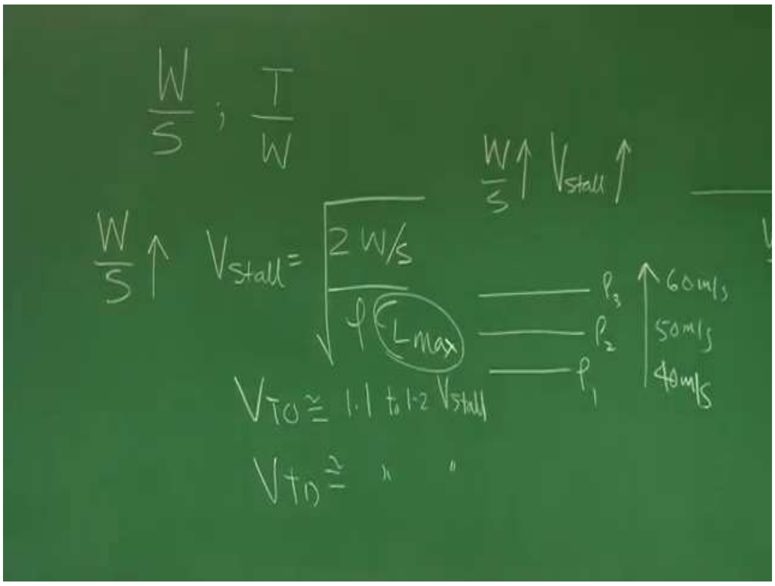

We have very loosely talked about wing loading, we have talked about thrust loading; very initial understanding why should we take a special look on wing loading, why should we take a special look on thrust loading and in an explicit manner, we will know as we progress. It goes without saying that if I am trying to design an airplane where there is a requirement of high wing loading, it has direct impact on the strength of the airplane; specially the wing because high wing loading means relatively the area is small. So, larger weight you have to distribute over a smaller area. So, the stress level generated on the wing will also be higher this is one structural aspect we should keep back of our mind because as we are going to reinforce structure the weight will go on increasing generally. So, again wing loading will increase.

Also, we know that V_{stall} is very very important parameter and which we have seen and we express that:

$$V_{stall} = \sqrt{\frac{2W/S}{\rho C_{L,max}}}$$

It also gives us few careful observations: one is of course, you can see that if wing loading goes on increasing then V_{stall} also goes on increasing if other things are kept set. Even for a given wing loading for a constant wing loading, you could see that as I am trying to take off at different-different altitudes let us say ρ_1, ρ_2, ρ_3 as I am going like this the density of air goes on decreasing. So, the V_{stall} will also go on increasing.

What is so important about V_{stall}? V_{stall} by definition is that minimum speed at which you can fly such that lift equal to weight. So, this is a minimum speed in some sense and when I talk about V_{TO}; V_{TO} or V_{land} we try to designs such that it is between 1.1 to 1.2 timesV_{stall}.

Similarly, V_{TD} is also of this same order. therefore, as V_{stall} increases V_{TO} and V_{TD} also will change, will increase For example, if I am trying to take off the airplane at sea level which is rho one here let us say for that V_{stall}will be some speed let us say for number let us say 40 m/s and as I am going high it may become 50 meter per second as further I go high it may become 60 m/s.

This typical example is if I am trying to take off a machine in New Delhi for keeping everything same that wing loading and C_{Lmax}; same aircraft we want to take off at some higher altitudes Bangalore may be at Leh, Ladakh, the V_{stall} requirement will increase and as the V_{stall} requirement increases what does it mean? means the speed has to increase. So, you need to have more power and more power means bigger engine bigger engine generally bigger engine; bigger engine means again wing loading will increase. So, we see that wing loading has direct or indirect so many affects that is why we pick wing loading as one of the parameters.

We will also see for rate of Climb, for maximum range or for different ton rate how wing loading is playing a role or if is not playing any role we will have to see those things because for an airplane when you are designing it will have different mission it has a takeoff, it has a Climb, it has a cruise, it has a maneuver, landing an everywhere we need to see that the aircraft is properly designed as far as wing loading is concerned. There is another observation you must have with wing loading.

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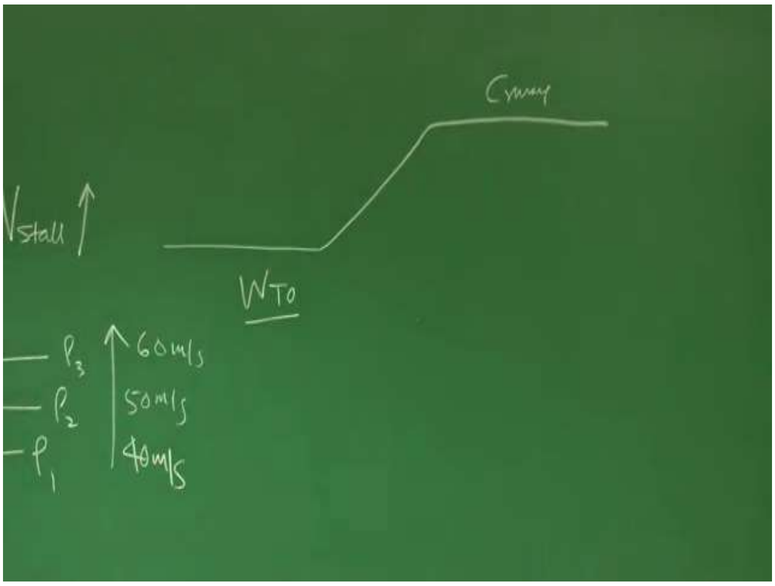

For example, when I am taking off here and Climbing and cruising here. So, here the weight of the airplane was W take off, but as I am Climbing and start cruising here, you could see that the weight of the Airplane will reduce because our fuel will be consumed. So, the wing loading will reduce, although we need in we will reduce please understand another thing that the density will also reduce. So, it will try to increase the minimum speed to maintain lift equal to weight although same time W/S will be reducing. So, you have to see how do I budget these things appropriately so that my design is an efficient design and another very critical parameter which a designer should look for and the whole technology has come to handle this issue C_{Lmax}.

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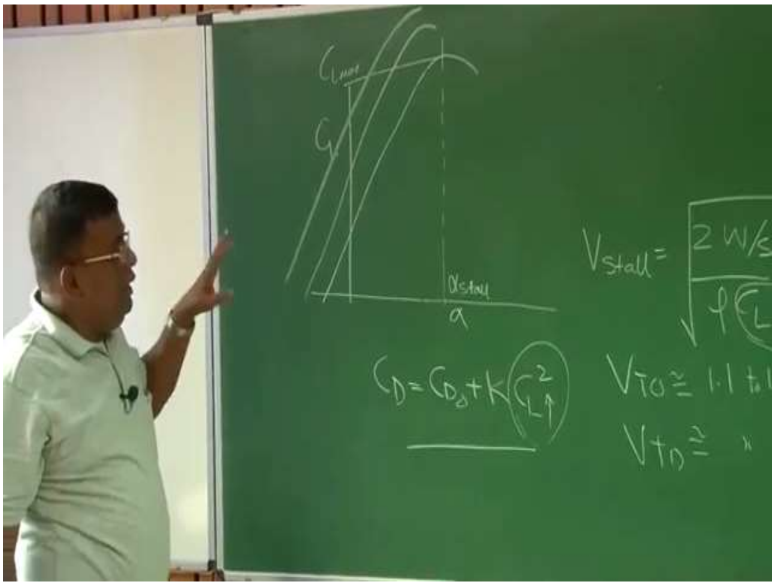

What is C_{Lmax}? We will recall again performance course if this is C_L and this is alpha is a particular angle which is alpha stall and corresponding to that this is C_{Lmax} generally airplane will not fly here, it will fly somewhere here if at all, if we have to maximize the usage of C_{Lmax}. Why do I want to maximize C_{Lmax}? because I want to fly such that my or I want to design airplanes such that the V stall is as low as possible.

So, what is the best way to do that that I increase the C_{Lmax} locally why I am saying C_{Lmax} should be increased locally, because I know from drag polar:

$$C_D = C_{D0} + KC_L^2$$

If I am flying at a higher C_L, if this goes up then total drag also will increase, which will not be advisable. But for some time, some part of the operations especially when I am taking off or landing for the short duration, I would like C_{Lmax} to be as higher as possible so that by V_{TO} speed or V_{land} speed which is just 10 or 20 percent more than $V_{stall}$is also low. The question that how do I increase this C_{Lmax}? Graphically if you see if we put some more shift this graph something like and this and this although the α_{stall} will reduce.

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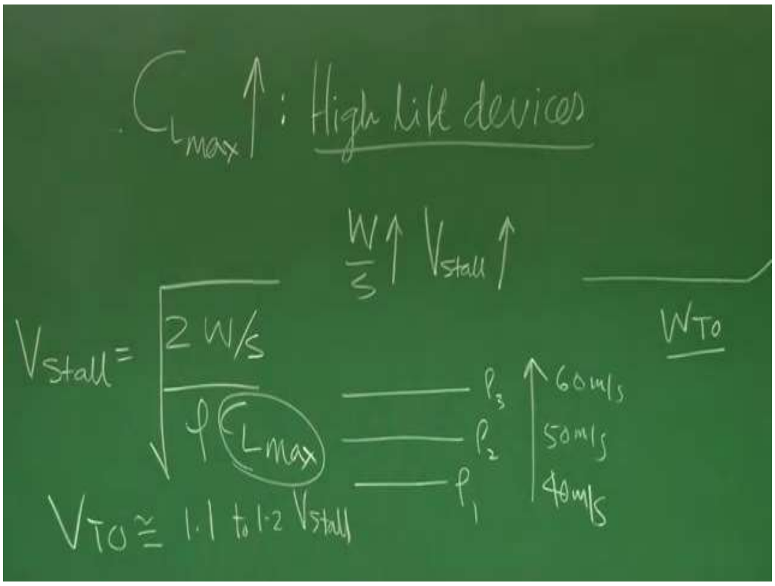

But, there is possibility of increasing C_{Lmax} and that is where we talk about high lift devices, aim is to increase C_{Lmax} if high lift devices. In the design course we will also put lot of understanding on high lift devices, how to select high lift devices? What are the advantages? and What are the penalties we are giving for selecting or designing high lift devices will also be considered separately. Once we understand how to visualize wing loading its plus or advantages and disadvantages. Once I know what are the advantages and disadvantages of C_{Lmax} through high lift devices now as a designer, I would like to synthesize those concepts so that we have finally, we have benefitted right. Another important question for a designer comes.

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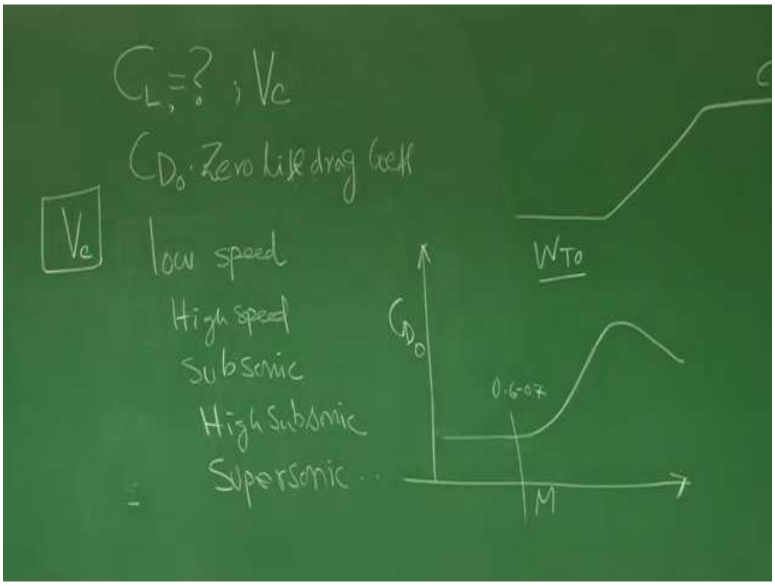

Since we are talking about C_L question comes what C_L should I fly? and what are the considerations? once I know the considerations, I should know that how I synthesize this through different components so that really a in flight I get that C_L. Second question comes to the mind what is the V cruises I want to fly? which is the obvious question you cannot just go like this you always try to go faster the problem is which a designer should understand that if I am trying to see, I want to fly at higher and higher in speeds because the airplane is moving in a medium, so, there is an interaction between the aircraft and the medium which is air in this case. So, we have to see carefully what happens as the speed increases and all of you know we have this interaction characterized by low speed, high speed, different nomenclature subsonic, high subsonic, then supersonic and so on.

Very important observation one need to have when you talk about cruise speed that depending upon what is the flight regime, the interaction between the aircraft and the medium is going to be different especially in terms of C_{D0} which is 0 lift drag coefficient. As you know as I am going higher and higher the flow will be really visibly compressible then there may be a shockwave at high subsonic or supersonic or transonic. So, this gentleman will play role.

And then it reflects on C_L as well if you recall if I plot C_D versus Mach number it is something like this and typically here up to 0.6 to 0.7, we say this C_{D0} remains constant. Please understand, we need to understand this is C_{D0} we are talking about because C_D has drag due to lift as well right like the C_D this is parasite and this is induced drag component. Now imagine if you want to design an airplane at around 0.85 you could see there is a sudden rise in the drag value C_D value.

And accordingly, we will talk about divergence Mach number right. And one has to be very very smart in seeing that you design an airplane, high speed airplane so that divergence mach number is little delayed. We will talk about those things when we talk about high subsonic or transonic airplane this is just to refresh you that C_{D0} and Mach number how it changes.

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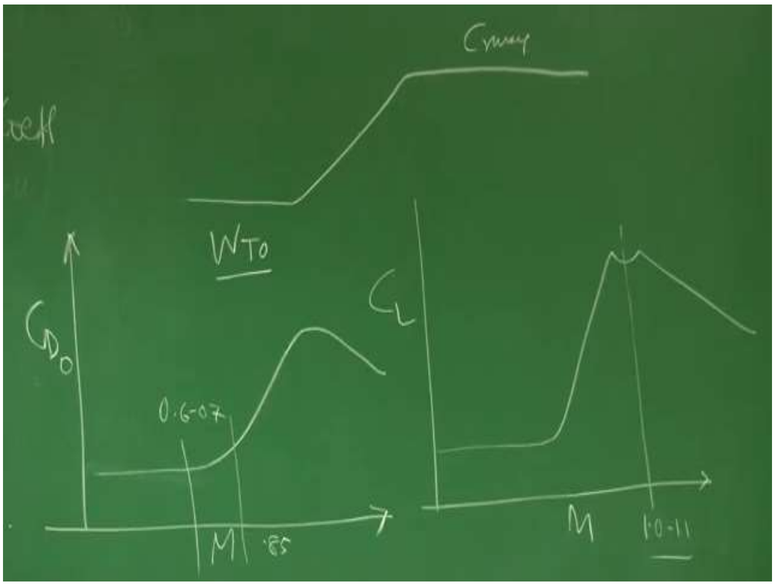

And also, C_L versus Mach number also have same similar trend and later on transonic it falls like this. So, depending upon which speed or which Mach number you are designing your airplane you have to be very careful about the type of C_L and C_D you will be generating.

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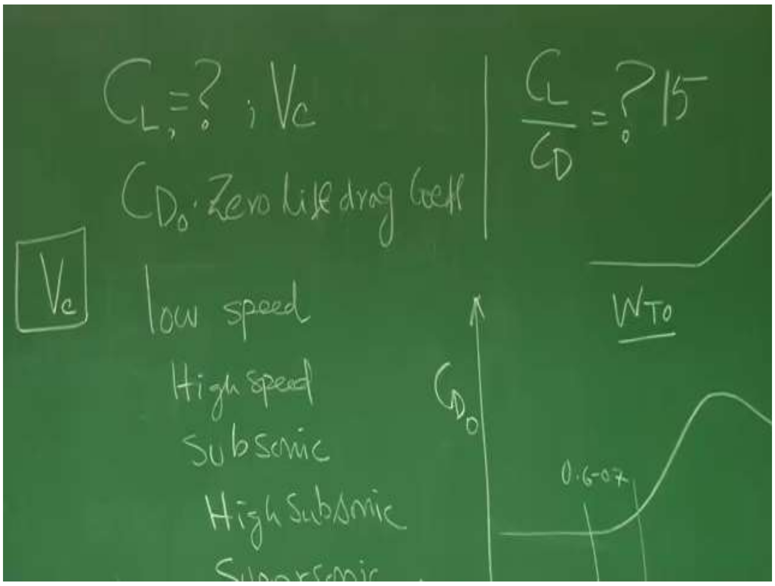

Because finally, do not forget every time you will be actually looking for what is the $\left(\frac{C_L}{C_D}\right)$ you are flying this is for the most important configuration for a designer perspective is this if from aerodynamic analysis it is said the $\left(\frac{C_L}{C_D}\right)$should be 15 for a particular efficient performance the designer will have to ensure that by displaying the wing, tail, fuselage in such a manner that indeed pilot should be able to generate $\left(\frac{C_L}{C_D}\right)$as and when required it should not happen that the airplane the way we have designed can never be able to generate $\left(\frac{C_L}{C_D}\right)$ all of the order of 15.

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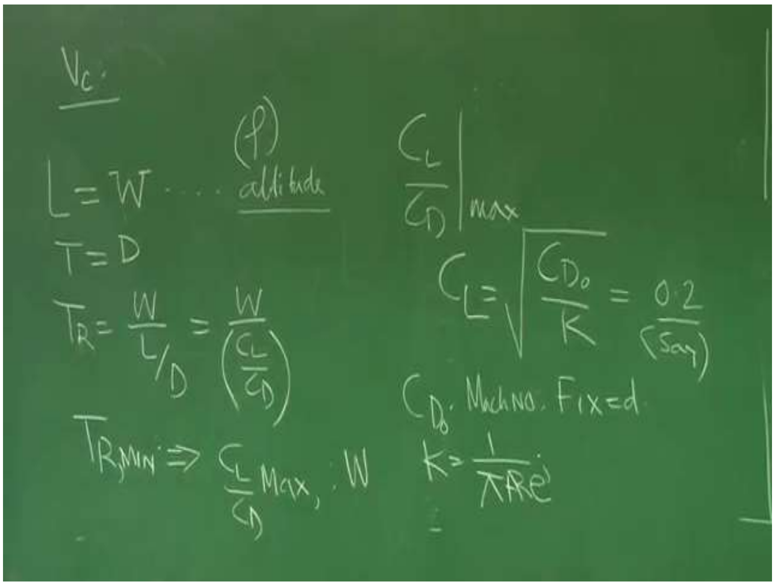

This is one consideration of V_{cruise} another thing you understand. Suppose our mission is to fly such that lift equal to weight at a particular altitude I also write like this I also understand thrust equal to drag because I am cruising and this just mean thrust required which we have already done:

$$T = \frac{W}{L/D} = \frac{W}{\left(\frac{C_L}{C_D}\right)}$$

Generally, what is our aim? We want to fly such that thrust required is minimum.

And if I try to understand from here thrust required minimum it implies that $\left(\frac{C_L}{C_D}\right)$should be maximum for a given weight right its minimum is $\left(\frac{C_L}{C_D}\right)$should be maximum and- what is the meaning of $\left(\frac{C_L}{C_D}\right)$maximum? $\left(\frac{C_L}{C_D}\right)$ maximum means, as you all know from performance course aircraft has to fly such that:

$$C_L = \sqrt{\frac{C_{D0}}{K}}$$

and C_{D0} for an airplane at a given speed is fixed at a given mach number is fixed, maybe typically 0.021-0.023 of that order and K; K you know:

$$K = \frac{1}{\pi eAR}$$

this is also fixed once you have chosen the aspect ratio of the airplane. But, if I want to fly at a given altitude same time thrust required should be minimum; that means, C_L is fixed let us see that C_L fixed value is 0.2 let us say let me repeat I want to fly at a given altitude rho such that thrust required is minimum.

And just for an example I am taking let us that value is 0.2 what does it mean? the question is yes, it is true I want to fly such that thrust required is minimum for the C_L is 0.2, but the basic thing is it has to maintain lift equal to weight.

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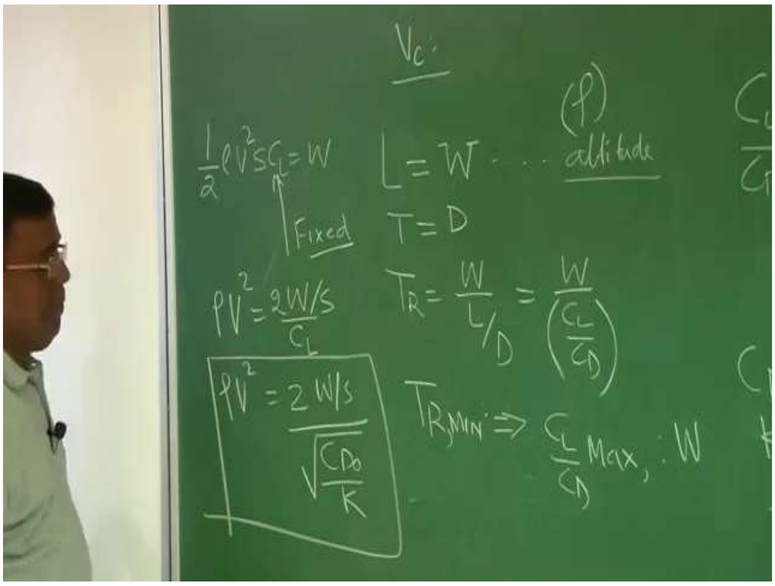

So, if

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

Now, C_L we are fixed, for this example since I am flying at thrust required minimum C_L is fixed because it is:

$$C_L = \sqrt{\frac{C_{D0}}{K}}$$

and for just for example, we have taken it 0.2. So, what we will get will get:

$$\rho V^2 = \frac{2W/S}{\sqrt{\frac{C_{D0}}{K}}}$$

What is the message? Message is if you want to fly at thrust required minimum, for a given wing loading, then you have to ensure that ρV^2 should be fixed, which is given by this number. The airplane should have been designed in such a way that

$$\rho V^2 = \frac{2W/S}{\sqrt{\frac{C_{D0}}{K}}}$$

as long as you maintain this you will be able to fly at thrust required minimum; now what is the meaning of ρV^2 to be a fixed number?

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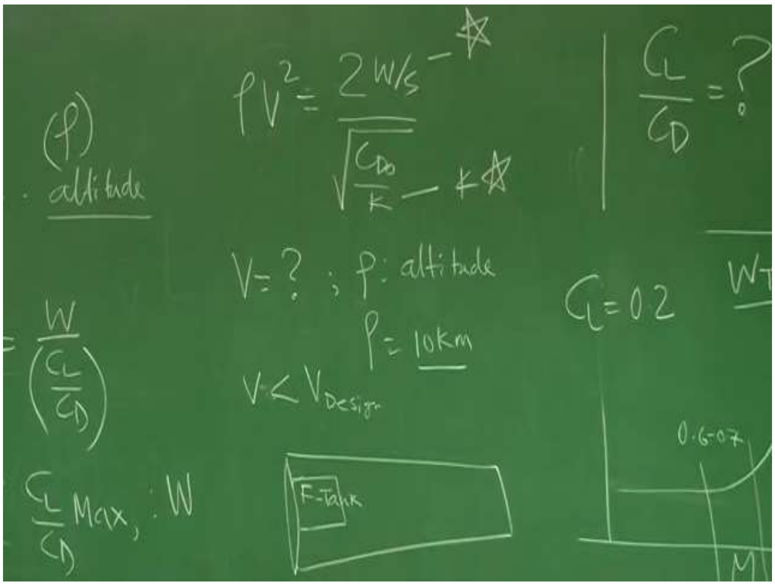

So, writing here

$$\rho V^2 = \frac{2W/S}{\sqrt{\frac{C_{D0}}{K}}}$$

but we started the discussion we want to, as a designer, we asking a question What is the V? and what is the altitudes I should fly? These are my questions if you want to buy an airplane or design an airplane this question will come to your mind what is the cruise speed I want to design? and then at what altitude?

Now, see the fun, if we are designing an aircraft with a jet engine and all typically, you will like that from the engine requirement they will like to fly at Tropopause around 10 to 12 kilometers because of temperature being constant and it helps the engine to maintain its efficiency. If this gentleman is fixed, then since ρV^2 is also fixed, then you do not have a control over V, but you want to design an airplane so, that the V is under your control. So, that is where you have to do designing you understand? this sort of a conflict you have to manage. For example, if you want to fly at 10 kilometers.

And you are finding that for the given wing loading and given C_{D0}, V is coming less than the V where you want to design possible? You may be planning to design an airplane for V equals 150 m/s, but under putting this condition for a given initial wing loading and K means aspect ratio we may find if I am satisfying this condition V is coming lesser than V design. So, what do you do? what is option? it again come to this understanding that rho into V square has to be constant. So, one way to design if I have selected rho to be at 10 kilometer corresponding 10 kilometer altitude, I know this value if I selected any case I want V to be 150 m/s right that is also.

You say I will fly at 120 m/s then the way you have to manage is you have to retreat this W/S, you have to change W/S, you have to manipulate K, you have to manipulate to C_{D0} as well please understand why design is so important and design is not just doing something some computation unless you have a philosophy because you want to synthesis. Please understand if I change K aspect ratio there is a possibility S also will change possibility, possibility of C_{D0} also will change.

So, everything goes you know they are interlinked also you understand when I am talking about design if I go little away from aerodynamics. Finally, in a wing you will be putting the fuel tank, which I have shown you in the first Class, particular volume of fuel will be housing inside the wing if somebody says sir what is the problem C_L suppose this gentleman some C_L, I am getting it 0.2. Now I have to select what type of aerofoil I will be using he says sir no problem.

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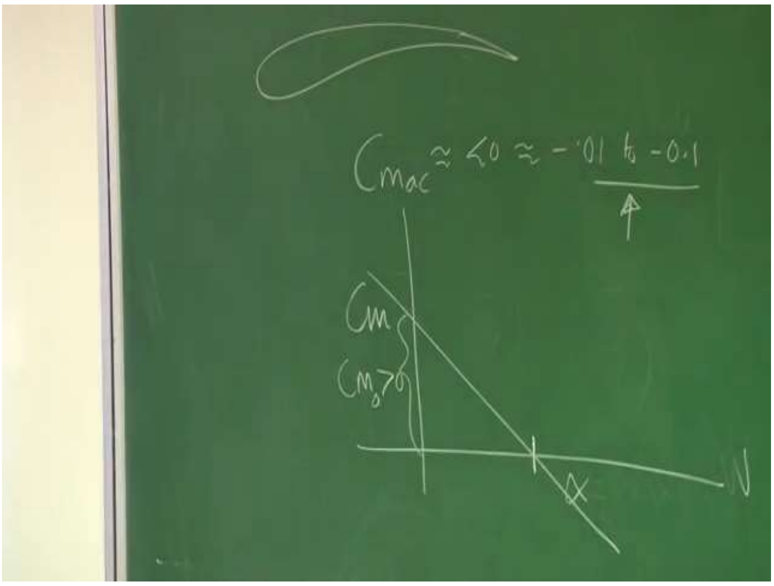

Aerodynamically we will pick up an aerofoil such that it is lift efficient and it does not give too much of C_{mac}; you understand, C_{mac}, remember? We are with you know a cambered aerofoil. So, C_{mac} value is typically which is also less than 0 is typically minus 0.01 to minus 0.1 is the order of values right, what is the meaning of C_{mac}? that because of camber whether it sees angle of attack or not angle of attack, that is not an issue, because of camber it will have a natural pitching pitch down moment a fixed pitch down moment. But when you on the trim the airplane you do not like this right; when you trim the airplane remembers Cm and alpha if I draw like this if I want to trim it here at some alpha positive, I need to have C_{m0} greater than 0, but typically cambered airfoil will give C_{mac} less than 0. So, I have to also counter that. So, when I am selecting an aerofoil one condition comes.

Try to see that C_{mac} is not unnaturally large negative, but more than that which is extremely important which we miss it during our design I am just shifted to aerofoil and giving you a little bit of warm up understanding.

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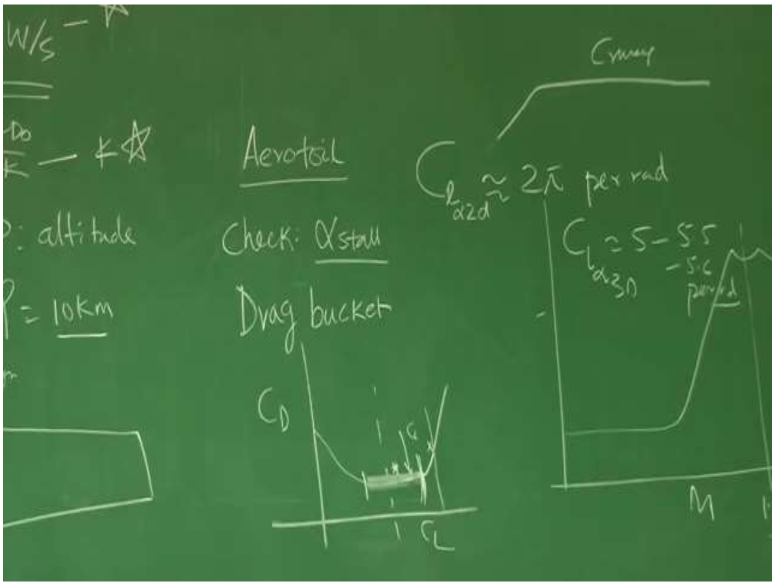

So, that we can progress systematically in couple of lectures. When you think of aerofoil first of all we are picking let us says cambered aerofoil. So, you know it is a cambered the question comes how much cambered? highly cambered, moderately cambered, or it is a reflects aerofoil and that sort of the question comes because yes, you want lift efficient aerofoil. But same time you should be careful that unnecessarily in the C_{mac} should not be negative and apart from that there is another important point which you should not miss that please check for cambered aerofoil what is alpha stall what is the stall angle? With the cambered you will find stall angle will have a tendency to reduce you should not select an aerofoil because it is lift efficient. But it stalls too early because for an airplane, the stalling angles are different whether you take wing tip or a root or a horizontal tail, we have been very very careful in selecting the stall angle criteria for an aerofoil. Also, you will find something called drag bucket, this also you have studied, let us say it is something like this.

This is C_D and C_L. So, there will be a flat portion if I plot C_D and C_L and let us say your $C_{L,design}$ is somewhere here for most of the time, but there will be time when you will be flying here as well. So, what this ensure that if it is a flat like a bucket that if I am even if I am flying at this C_L the drag penalty is not large from the airfoil right, but suppose you have selected an aerofoil that you are flying at this C_L most of the time and occasionally you fly at this C_L then what is happening? the moment you have to fly at this C_L there is a large increase in the drag. So that is an inefficient way of designing a wing. So, what is important when I am talking about a wing I select an aerofoil keeping in mind that drag bucket, keeping in mind the stall angle, and keeping in mind C mac and also remember there is a recall rush for designing different types of aerofoil I do not stop you from rushing to design different aerofoil, but do not forget the $C_{l\alpha,2d}$ value is restricted to 2π per radian does not it?

So, typically for a wing whatever you do, you will find the values of $C_{L\alpha,3d}$ if I take it will be between 5 to 5.5 or 5.6 per radian. So, you do not gain much most of the wing will be giving the values, but do not waste too much of time in customizing the aerofoil, but for alpha stall and drag bucket these are important for a low subsonic airplane. So, we will be talking about aerofoil selections also in detail. We have talked about wing loading, we have talked about aerofoil. If I am doing an aero modeling let us say somebody ask Dr. Ghosh make an airplane, it may be smaller type, which should be capable of flying right. To immediately you know no problem and you know lift equal to weight.

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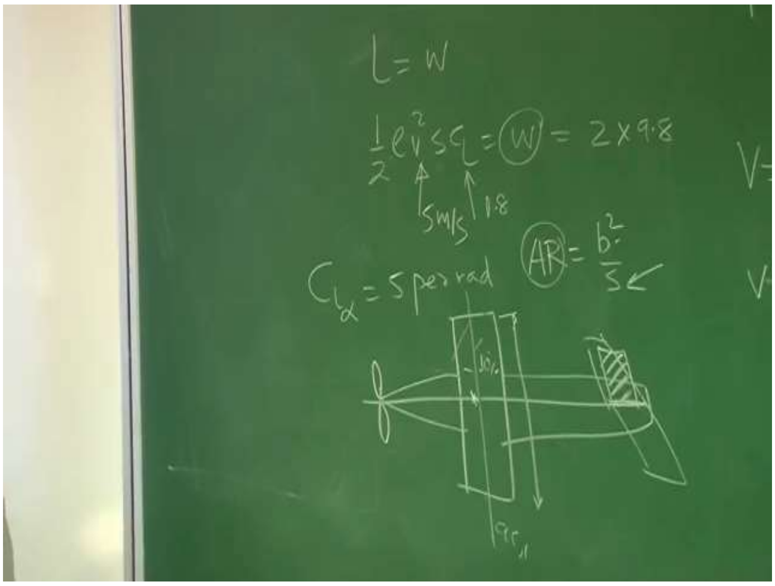

So, I will write

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

So, I will take smaller aerofoil maybe 2 kg. So, 2 into 9.8. I know I will be able to flying at around 5 to 10 meter per second let us say 5 meter per second and C_L let us say I will be flying at 0.8 because how do I right C_L 0.8 because I know $C_{L\alpha}$ is roughly I will take 5 per radian from there I will find C_L 0.8 and from using this and rho as a sea-level condition I can get what is the area required right and then I make a wing of that area and I put a propeller here and I see that total length whatever wing area I have taken let us say wing area is some meter square I feel for this type of wing aspect ratio 8 or 9 is good.

So, I distribute this, I know aspect ratio is equal to b square by S I know S I know aspect ratio. So, I can have span. So, I make a span and this then I decide this length will be almost equal to this length and this is 70 percent it is not important to remember this number I am just telling the philosophy 70 percent then 30 here and you configured like this then you ask a question how much should be the tail area? Oh, tail area will be around 15 percent of the wing area. So, you put a tail 15 percent of tail you put here see and half of this one of this you take and put as a vertical tail and ensure that if this is the A.C of the wing C.G should be within 10 percent ahead of C.G if you are taking a cambered aerofoil and you fly it; it will fly all the aero model are like that it will fly it will have a particular speed to fly, but we will not be doing this that is my point.

So, once you are attending to this lecture if you have some experience in aero modeling please keep in your house do not bring along with you. If you are bringing that, this course will not be useful at all. Here anything, any number we will be putting, will justify will cross question and we will put them in a bucket you are qualified, but whether they are going to be used or not that will be decided at the end I may have 6 sets of aspect ratios. But at initially see I will not know which aspect ratio I will pick, but in my data bank there will be 6 to 8 sets of aspect ratio data and those sorts of a synthesis is possible if you clearly understand Why you are doing this? and How we are going to use this? and that is what is design Why? and How?

Thank you very much.