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 lectures 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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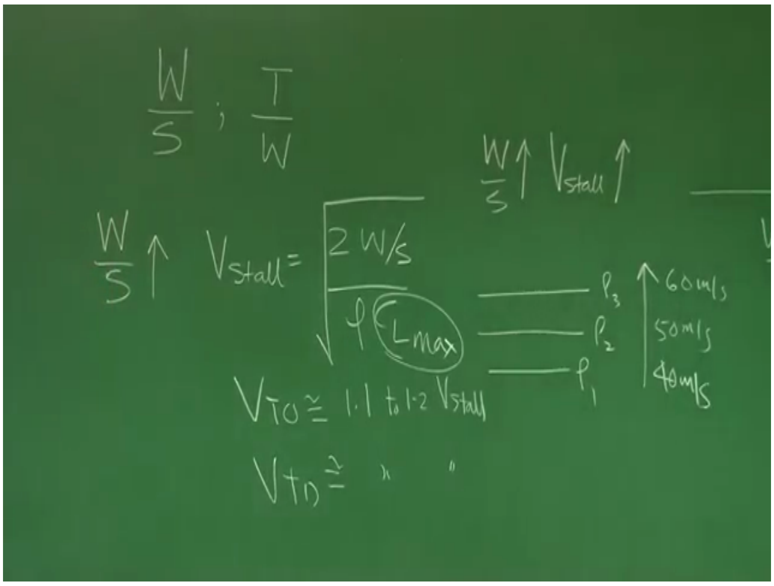

We have very loosely talked about wing loading, we have talked about thrust loading; very initial understanding why should we take a special look on wing loading, why should we take a special look on thrust loading and in an explicit manner. We will know as we progress it goes without saying that if 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 your 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 square root of two wing; wing loading by 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 that 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 rho one rho 2 rho 3 as I am going to 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, these a minimum speed in some sense and when I talk about V take off; V take off or V landing we try to designs such that we looking 1.1 to 1.2 times V stall. Similarly V touchdown is also of this same order therefore, as V stall increases V take off and V touchdown 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 I say 40 meter per second and as I am going high it may become 50 meter per second as further I go high it may become sixty meter per second.

This typical example is if I am trying to take off a machine in New Delhi for the keeping everything same that wing loading and C L max; 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 affect 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 of 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 the another observation you must have with wing loading.

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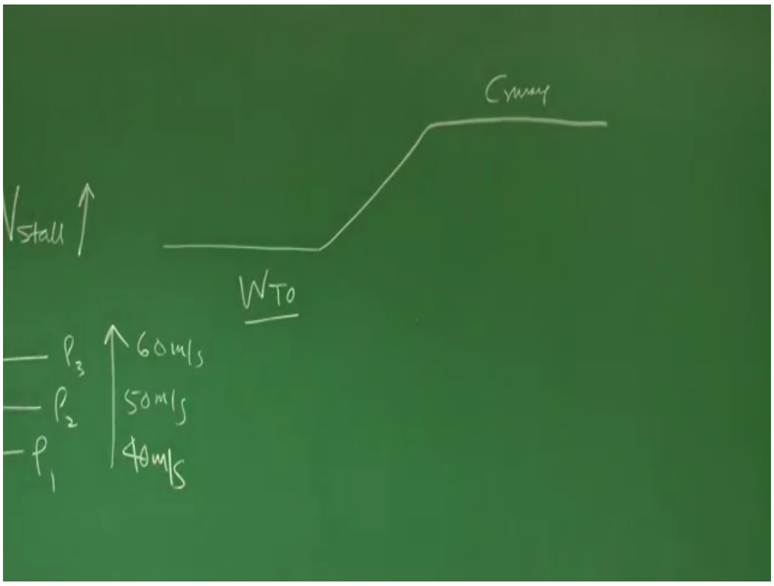

For example when I am taking off here a climbing and cruising here. So, here the weight of the airplane was w take off, but as I am climbing and start cruising here you could see that the weight of the Airplane will reduce because our fuel will be consumed. So the wing loading will reduce, although we 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 by 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 L max.

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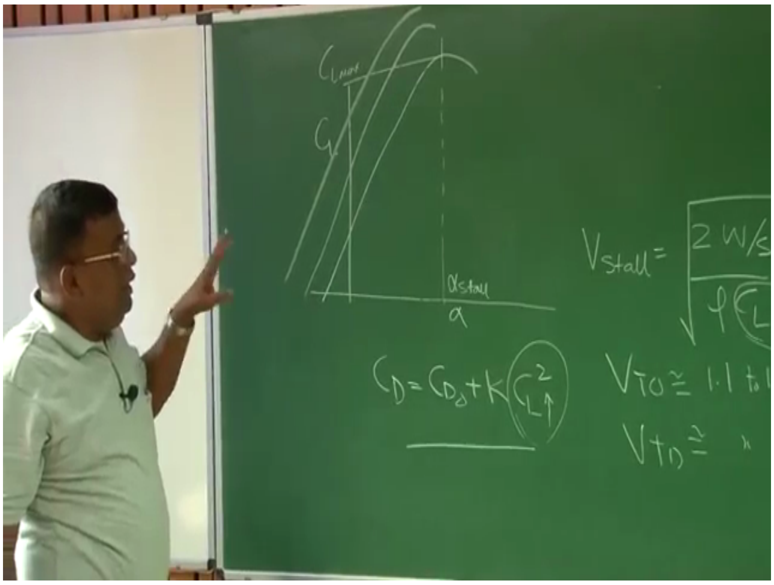

What is C L max? We will recall again performance course if this is C L and this is alpha is a particular angle which a alpha stall and corresponding to that this is C L max generally airplane will not fly here its fly somewhere here if at all, if we have to maximize the usage of C L max why do I want to maximize C L max, 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 L max locally why I am saying C L max should be increased locally, because I know from drag polar C D equal to C D naught plus K C L square 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 L max to be as higher as possible so that by V takeoff speed or V landing speed which is just 10 or 20 percent more than V stall is also low the question that how do I increase this C L max graphically if you see if we put some more shift this graph something like and this and this although the alpha stall will reduce.

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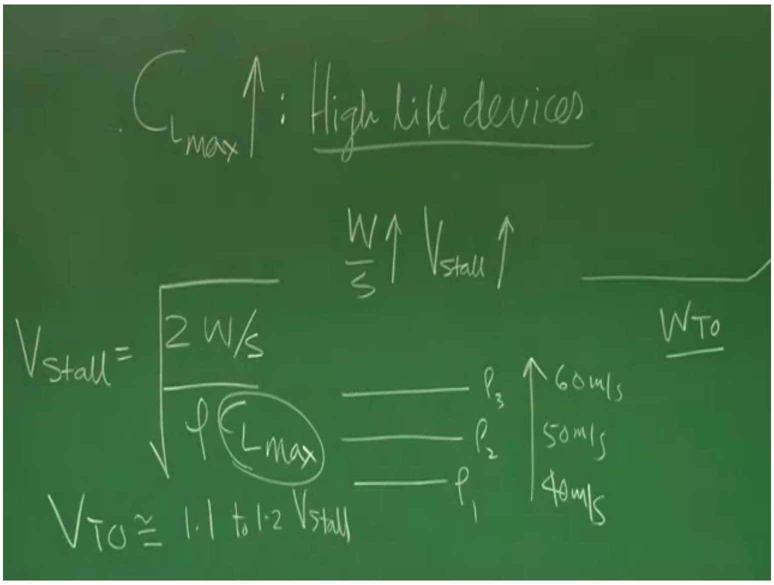

But, this possibility of increasing C L max and that is where we talk about high lift devices m is to increase C L max if high lift devices in the design course we will also put lot of understanding on high lift devices, how to select and high lift devices what are the advantages and what are the penalties we are giving for selecting or designing high lift devices will also be considered separately once we understand how to visualize wing loading is plus or advantages and disadvantages. Once I know what are the advantages and disadvantages of C L max 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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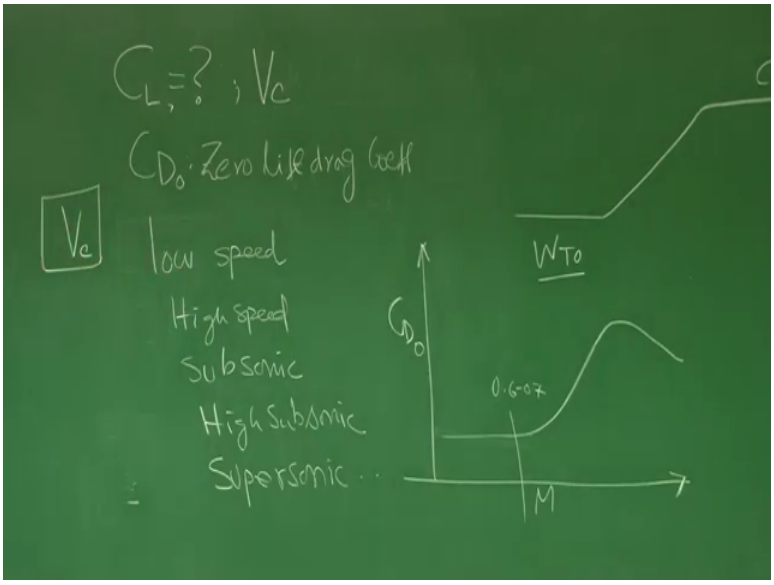

Since we are talking about C L question comes what C L should I fly and what are the considerations once I know the considerations I should know that how I synthesize this through different components so that really a in flight I get that C L. Second question comes to the mind what is the V cruises I want to fly which is the obvious question you cannot be as 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 a 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 D naught 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 I reflects on C L as well if you recall if I plot C D plus it is mach number it is something like this and typically here up to 0.6 to 0.7 if a this C D naught remains constant please understand we need to understand this is C D naught you are talking about the C D has drag give to lift as well right like the C D this is parasite and this is induced racket component now imagine if you want to design an airplane at around 0.85 you could see there is a sudden rise in the drags 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 a divergence mach number is little delayed we will talk about those things when you talk about high subsonic or transonic airplane this is just to refresh you that C D naught and mach number how it changes.

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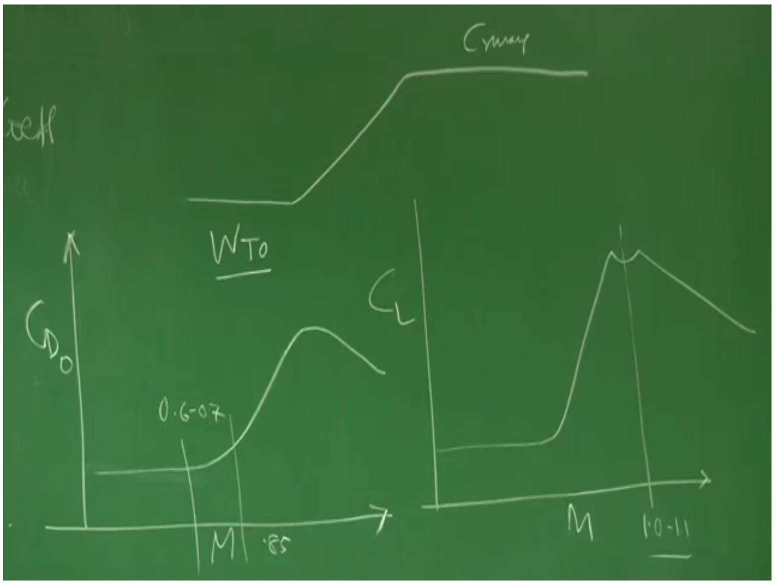

And also C L versus Mach number also have same similar train enacted on transonic it falls like this. So, depending upon which speed or which Mach number you are designing your airplane you have to be very careful about the type of C L and C D will be generating.

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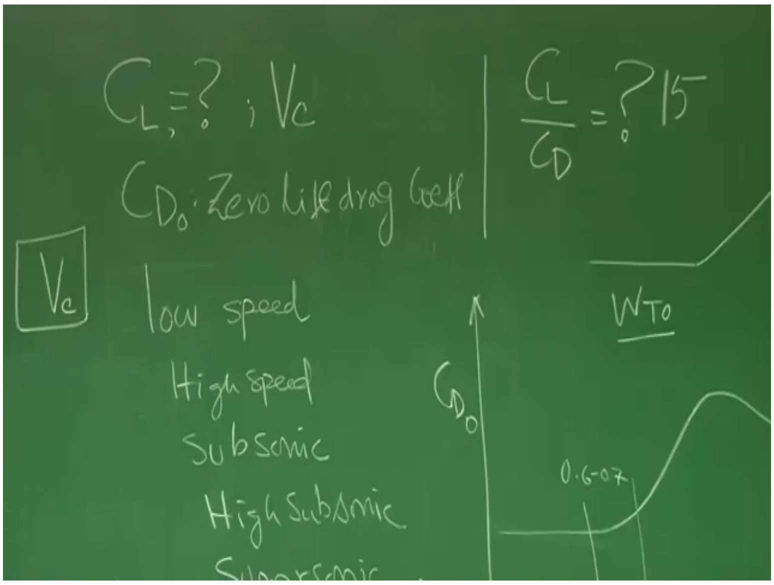

The finally, do not forget every time you will be actually looking for what is the C L by C D you are flying this is for the most important configuration for a designer perspective is this if from aerodynamic analysis it is said the C L why should the C D should be 15 for a particular efficient performance for designer. We will have to ensure that by displaying the wing tale fuselage in such a manner that indeed pilot should be able to generate C L by C D as and when required it should not happen that the airplane the way we have designed can never be able to generate C L by C D all of the order of 15.

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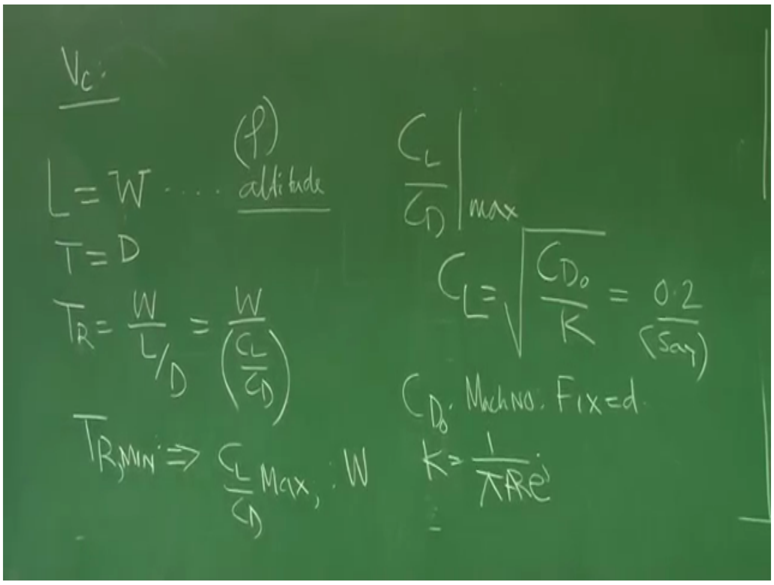

This is one consideration of V cruise another thing you understand. Suppose our mission is to fly as the lift equal to weight at a particular altitude I was a write like this I also understand thrust equal to drag because I am cruising and this just may thrust required which we have already done l by d or to w by C L by 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 C L by C D should be maximum for a given weight right its minimum is C L by C D should be maximum and- what is the meaning of C L by C D maximum C L by C D maximum. Means, wall of a performance course aircraft has to fly such that C L equal to C D naught by K and C D naught for an airplane at a given speed is fixed at a given mach number a fixed maybe typically point 0 to 1.0 to 3 of that order and K; K you know K is 1 by pi aspect ratio into e 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 the flies at the 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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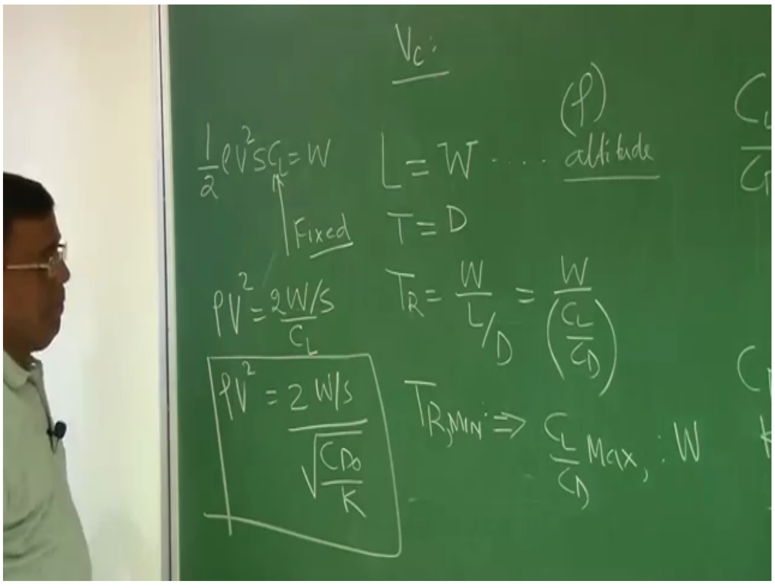

So, if lift equal to weight means half rho V square s C L equal to weight now C L we are fixed for this example since I am flying at thrust required minimum C L is fixed because it is under root C D naught by K and for just for example, we have taken it 0.2. So, what we will get will get rho V square is equal to w by s into 2 C L and C L is 2 w by s of course, C L is under root C D naught by K this is rho V square what is the message is if you want to fly a thrust required minimum for a given wing loading then you have to ensure that rho into V square should be fixed which is given by this number the airplane should have been designed in such a way that rho into V square should be 2 w by s under root C D naught by K as long as you maintain this you will be able to fly at thrust required minimum; now what is the meaning of rho V square to be a fixed number.

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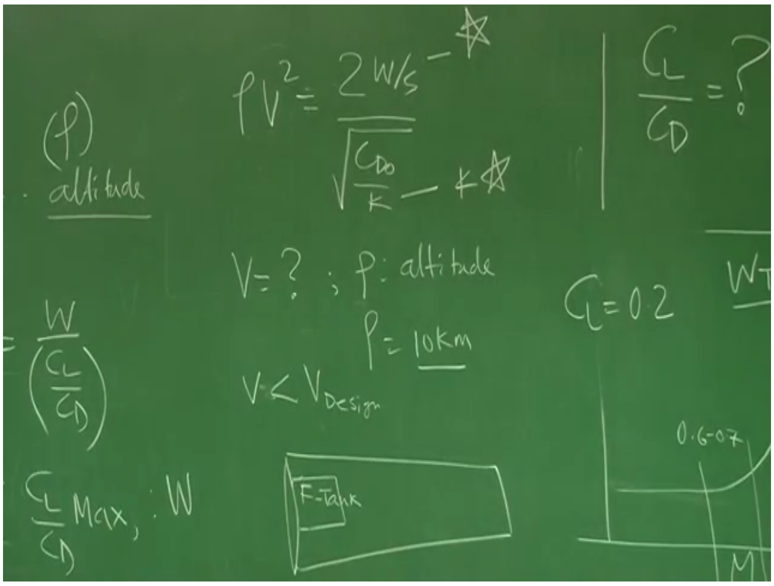

So, writing here rho V square to be equal to 2 w by s by under root C D naught by k, but we started the discussion we want to as a designer we asking a question what is the V and what is the altitudes I should fly these are my questions if you want to buy an airplane or design an airplane this question will come to your mind what is the cruise speed I want to design and then I want to do a altitude.

Now, see the fun if we have designing an aircraft with a jet engine and all typically you will like that from the engine requirement they will like to fly at tropo powers 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 rho into V square 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 kilometer.

And you are finding that for the given wing loading and given C D naught V is coming less than the V where you want to design possible we were a planning to design an airplane for V equals 150 meter per second, but under putting this condition for a given initial wing loading and K can be is aspect ratio we may find if I am the satisfy this condition V is coming lesser than V design. So, what do you do what is option it again come to this understanding there 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 meter per second right that is also.

You say I will fly at 120 meter per second then the way you have to manage is you have to retake this w by s you have to change w by s you have to manipulate K in have to manipulates to C D naught 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 y aspect ratio there is a possibility s also will change possibility, possibility of C D naught also will change.

So, everything goes you know they are interlude 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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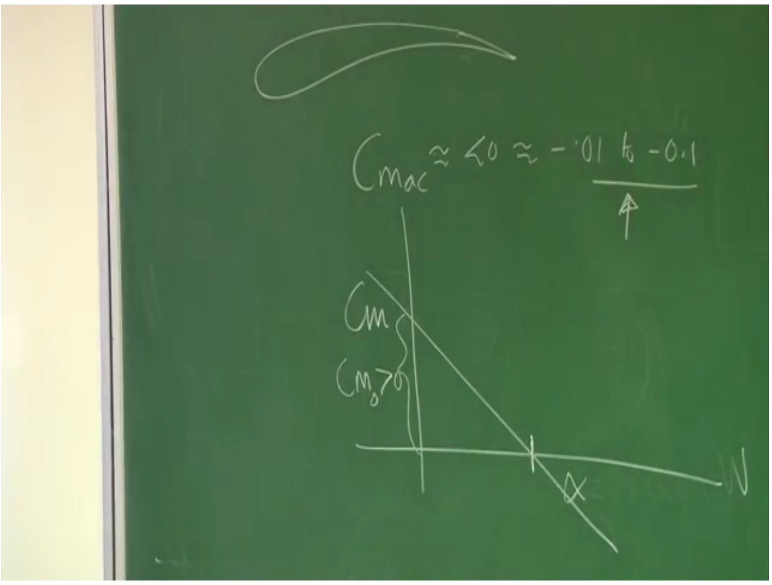

Aerodynamically we will pick up an aerofoil such that it is lift efficient and it does not give too much of C mac; you understand, C mac, remember we are consist with you know a cambered aerofoil. So, C mac value is typically which is after less than 0 is typically minus 0.01 to minus 0.1 is the order of values right, what is the meaning of C mac that because of camber whether it sees angular (Refer Time: 24:19) not angular there is not an issue, because of camber it will have a natural pitching pitch down moment it fixed pitch down moment. But when you on the trim the airplane you do not like this right; when you on the trim the airplane remembers C m and alpha if I draw like this if I want to trim it here at some alpha positive I need to have c m not greater than 0, but typically cambered aerofoil will give C mac less than 0. So, I have to also counter that. So, when I am selecting an aerofoil one condition comes.

The try to see that C mac is not unnaturally large negative, but more than that which is extremely important which we miss it we will got design I am get shifted to aerofoil and giving you a little bit of warm up understanding.

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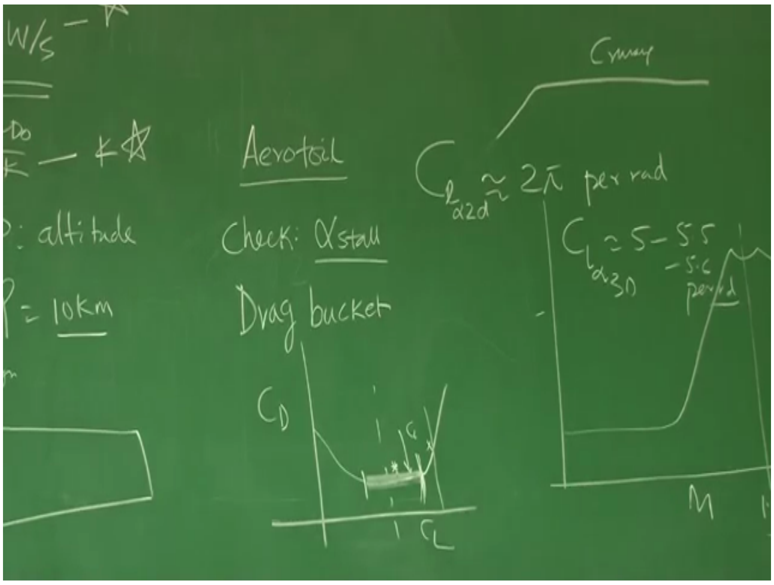

So, that we can progress systematically in couple of lectures when you think of aerofoil first of all we are picking let us says cambered aerofoil. So, you know it is a cambered the question comes how much cambered highly cambered moderately cambered or it is a reflects aerofoil and that sort of the question comes because yes you want lift efficient aerofoil. But same time you should be careful that unnecessary 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 if 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 in a 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 that 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 have flying at this C L most of the time and officially 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 a inefficient way of designing a wing. So, what is important when I have 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 of aerofoil, but do not forget the C L alpha 2 d value is restricted to 2 pi per radian is not it.

So, typically for a V whatever you do you will find the values of C L alpha for wing 3 d if I take it will be between 5 to 5.5 or 5.6 per radian. So, do not gave 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 the tragos make an airplane it may be smaller type which should be capable of flying right to immediately you know no problem and your lift equal to weight.

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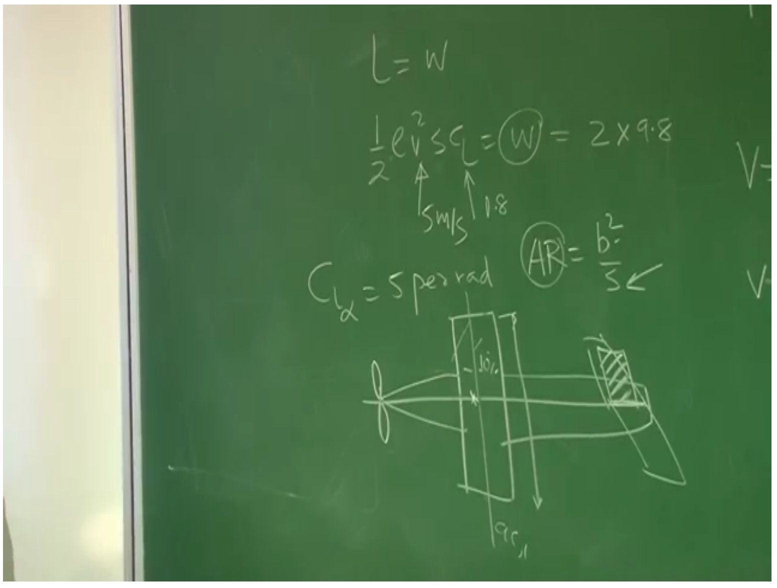

So, I will write half rho V square S C L equal the weight. So, I will take of a smaller aerofoil maybe 5 2 kg. So, 2 into 9.8 I know I will be able to flying at around 5 to 10 meter per second let us say 5 meter per second and C L. Let us say I will be flying at 0.8 because how do I right C L pointed because I know C L alpha is roughly I will take 5 per radian from there I will find C L pointed and from using this and rho as a C 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 by in your aspect ratio is equal to V 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 seventy percent it is not important to remember this number I am just telling the philosophy seventy percent then thirty 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 have taking a cambered aerofoil and you fly it; it will fly all there is a 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 we 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, but here anything any number will reporting 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 sort of a synthesis 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.