NOC: Introduction to Airplane Performance
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Lecture - 46
Design Basics: Wing Loading and Thrust Loading

Good morning friends, when I am talking today we are all certain demise of Dr Abdul Kalam. He had been a real source of inspiration for all of us, who is to have very close interaction with him. Recently also he was her, I am sure that this is right occasion that whole of this course, we dedicate it to Dr Abdul Kalam and make sure that, whatever dreams he had also become your dream and that is the best way to pay homage to Dr Abdul Kalam.

I am sure, he will be around and watching all of us, how sincerely we are working hard to take our country to an extreme high. Coming back to our effort to understand airplane performance and as we agreed that, we will be in this course in the manner that, at the end of the course you should get some idea, how to design an aircraft. Because, we may often another course on stability and control, purely on stability and control and third course on aircraft design subject to the response I get from all of you. If you really think it is helping you, we are here to help you out, but if you think books are sufficient fair enough, no issues. So, let me try to recapitulate, what we were doing from the perspective of designing an aircraft.

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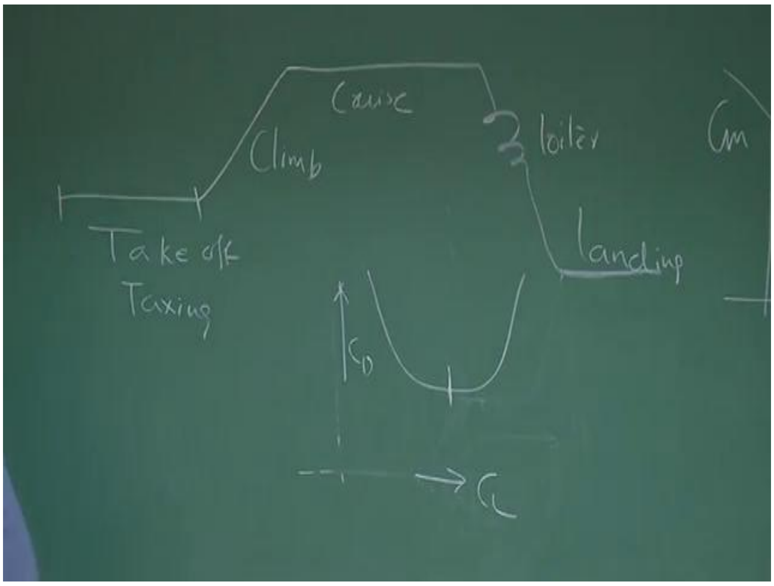

When you want to design an aircraft, you know that there are phases. Typically, I can draw it like this; here it is the takeoff and taxing. In fact, it start taxing and goes at a particular speed, then put the front wheel up, then climb. So, this is a climb phase and this you know the cruise, then this is lighter and landing. These all we now know, what are the primary characteristics for these phases and how do I related to aerodynamic parameters, geometric parameters, inertia parameters of an airplane. To see that, really pilot can achieve all the things that is, design has a bandwidth where pilot can extract depending upon the requirement.

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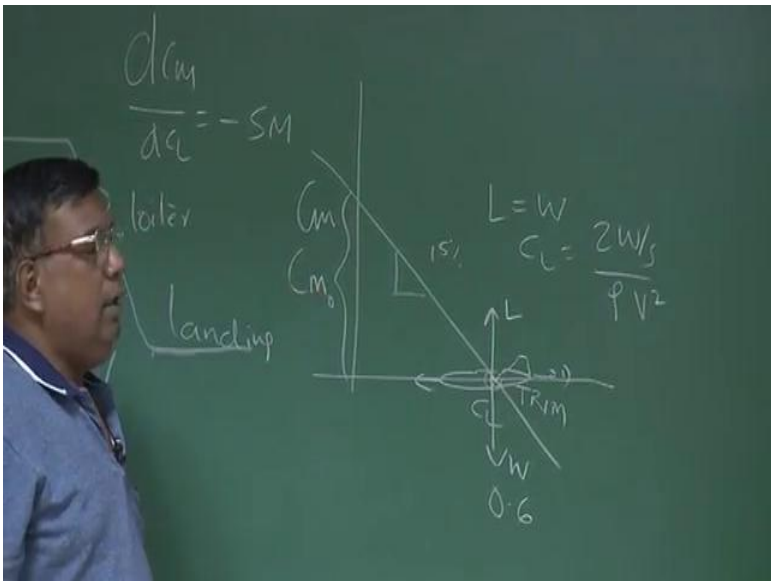

Now, since we are focusing on design aspects, we also discuss something on stability C m and C L. Remember, we talked about trim point and that is the point, which is the trim point. Well, I can trim the airplane at this C L, meaning thereby I can fly at this C L with lift equal to weight and there are no unbalanced moments. So, moment is zero that is, why C L is zero at this point and the C L is typically is...

If I am concentrating on cruise, then C L corresponds to lift equal to weight and C L is 2 W by S rho V square that is C L. So, now, if I see this, this point and if I decide, depending upon my requirement if I decide I will ensure that, this C L is such I have decided. So, that if I slightly change the C L, there should not be large increase in the drag, because you know, because of C L there is a induced drag also.

And because of C L, even if there is no induced drag for aerofoil, still C D will increase C L, because of flow separation. When I talk about C L, a wise designer ensures that he appropriately fixed up the C L somewhere here with value of a drag bucket. So, that even if there is a change in C L, there is no large change in the drag coefficient. Also we know by now that, most of this transport airplane they are designed for a static margin should be between 5 to 10 percent or 5 to 15 percent. So, I know also the d C m by d C L is nothing but, minus static margin, so static margin is 15 percent.

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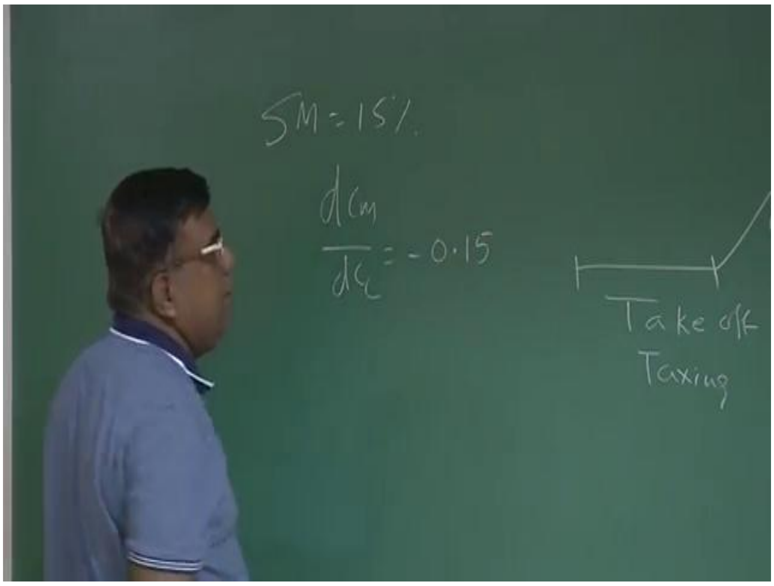

Let us say 15 percent, the slope will be… If static margin is 15 percent, then the slope d C m by d C L is minus 0.15. Because, I know d C m by d C L is minus static margin ((Refer Time: 05:56)), non dimensionalized with the mini aerodynamic chord. So, once I know 15 percent is my static margin that is, I know the slope I know what C L I am going to fly. Let say this C L is 0.6, I am going to fly ((Refer Time: 06:05)).

Then, I know how much C m naught the airplane should generate. Well and good, if it can automatically generate without defecting elevator and that also we know, it is possible by giving tail setting angle and also locating the wing, such that a c of the wing is ahead of c g of the airplane, all these things we have done. I will be now highlighting few small, small things which are very relevant for designing an aircraft very preliminary, but yes. If you understand this when you do design course, you will be ready for it, let us see first V stall.

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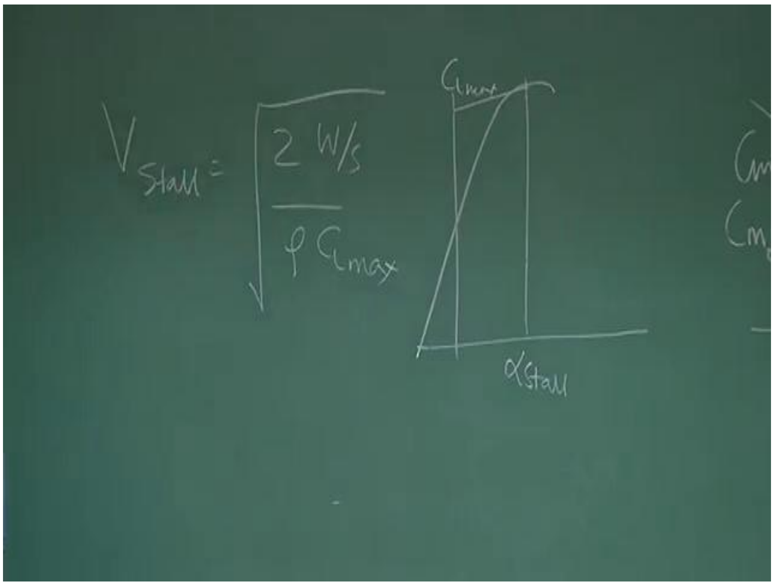

What was V stall? V stall was 2 W by S rho C L max, you are all now expert. What was the interpretation of V stall? That, this is the minimum speed with which the aircraft can maintain lift equal to weight at a given altitude. And what was C L max? There is a maximum C L I can get from the airplane at a particular angle of attack. If this is angle of attack, this is alpha stall and this point is C L max, you all know this. As a designer, what do you want, V stall should be high or low.

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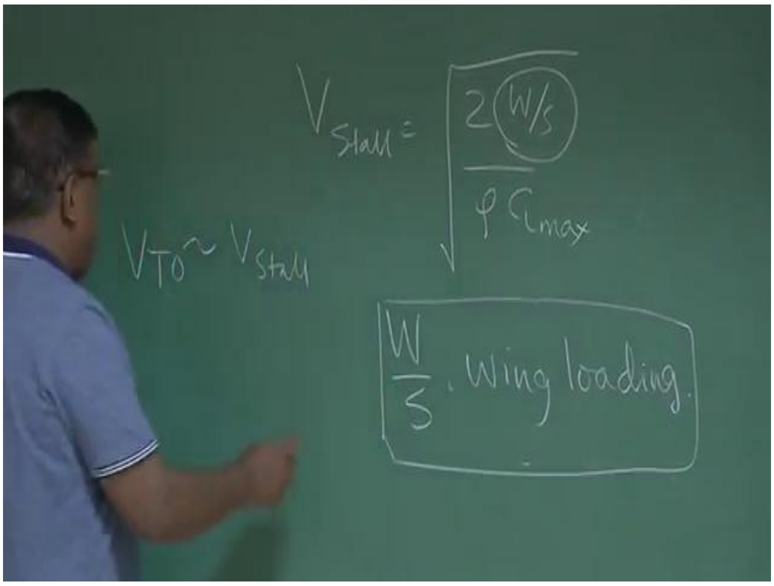

Remember, if V stall is high that means you need larger takeoff distance, because you know V takeoff is proportional to V stall. It is 10 to 30 percent or 15 percent of, within that rate range of V stall. So, V stall is high, V takeoff will be high, so there are two possibilities. I have to put a bigger engine, so that it can attain accelerate to that speed within shorter takeoff distance or if I am not able to increase the engine to a power, then I lead larger takeoff distance.

So, who plays the vital role for a given altitude and given aerofoil? It is the W by S and W by S is called wing loading. You could see from here, if W by S is large, V stall also will become large. What is the meaning of W by S large means, relatively the S is small that is, why W by S has gone high. Or in other way if I say, if you want to reduce V stall keeping other thing constant, I must have very low value of W by S.

Low value of W by S means what, a c is relatively high and which is correct. If S is high you get larger lift, so you will be able to takeoff earlier, but there is a problem. If I increase S to large size, the drag will also increase, the moment drag increases engine power required to maintain the drag also increases, so that again increases the weight. So, this W by S goes on an iteration cycle.

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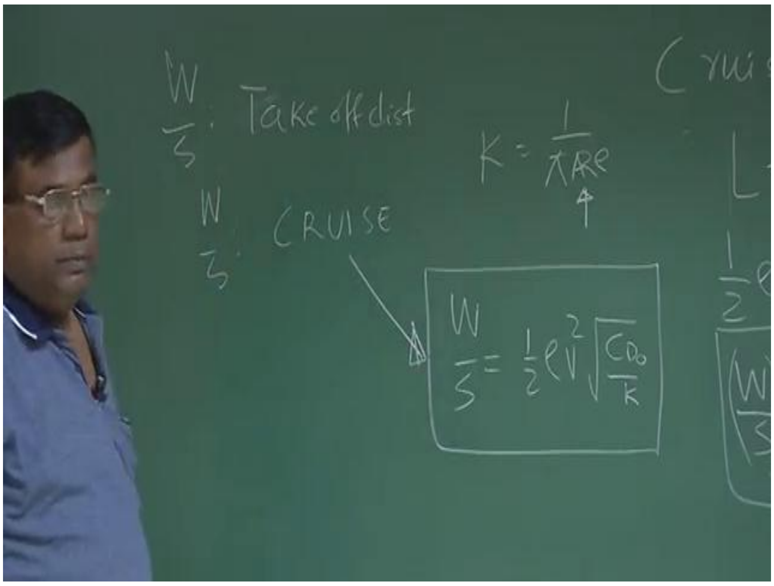

So, one thing you should understand, the wing loading is very important, so I have to select wing loading from takeoff distance point of view. So, we understand here, I have to select W by S, keeping in mind takeoff distance required. We always try to ensure that takeoff distance is as low as possible, this is one.

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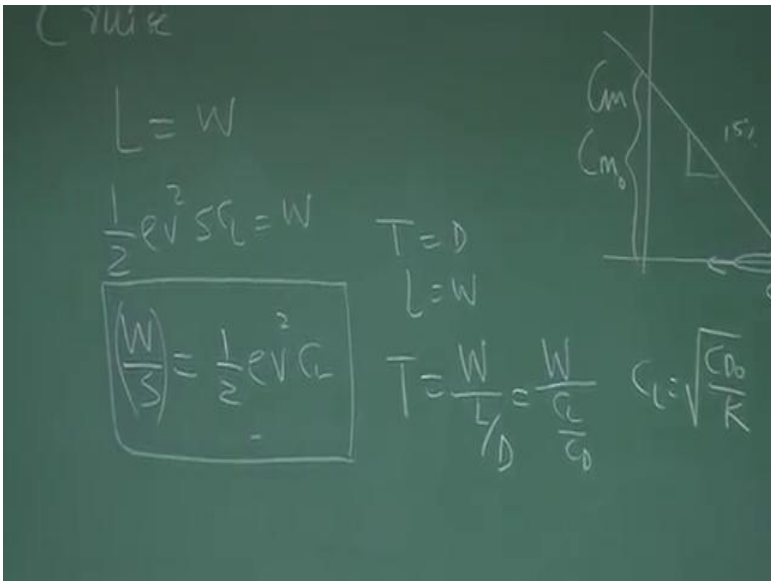

Now, second part you see. If I come to cruise, what do you see in cruise, lift equal to weight or half rho v square S C L equal to weight or W by S equal to rho v square C L, this is one expression we get. Also please understand, see thrust equal to drag and lift equal to weight, I know thrust equal to W by L by D equal to W by C L by C D. What these two relationships telling us? This telling that, if we have decided what will be the C L cruise and for a given altitude, I should have this much of W by S to maintain lift equal to weight.

Please understand, if we have decided, what is the altitude we are going to be flying most of the time? Let us say for jet engine, you will prefer to fly at around 11 kilometres, where engines are efficient, relatively more efficient. And suppose, you have decided what is the cruise speed, then this C L design is also decided from other criteria. So, this also tells you, how much wing loading you require to maintain lift equal to weight, so this is also W by S from cruise.

The story does not end here, you know that if I want to fly at a C L, where thrust required is minimum, then I have to fly at a condition C L by C D is maximum, you all expert now. This means, I have to fly at C L equal to under root C D naught by K. So, now this expression becomes W by S, I can now write half rho v square to C D naught by K. So, this is another requirement that aircraft must have been this much of wing loading, so that it can manage lift equal to weight as well as it will fly at a thrust required minimum.

You could see that, I can manipulate W by S for given rho and V by altering the value of C D naught and K. What is K? K is 1 by pi aspect ratio e, so I was flexibility in altering the value of aspect ratio and also C D naught. I can make the aircraft smother, I can reduce the skin friction for depending upon requirement, again I find there is restriction on W by S, because of cruise.

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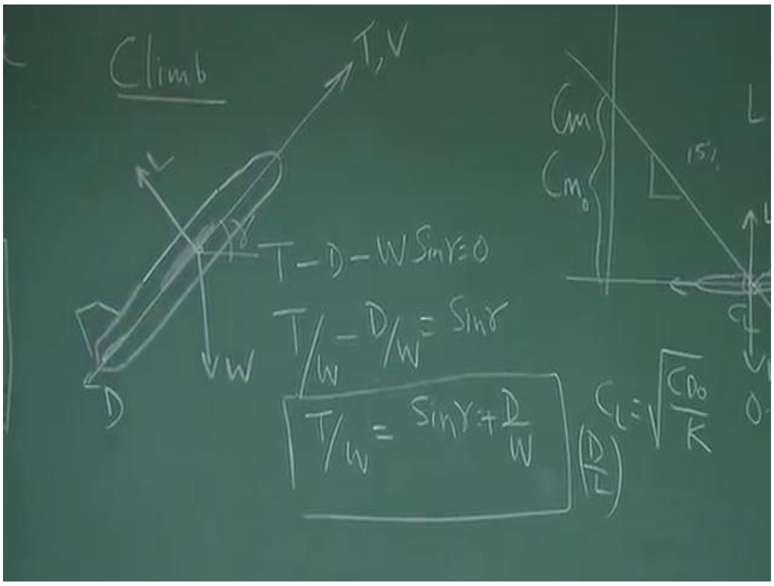

Let us see, what happens during climb. Check for climb, this is drag, this is lift. So, I know T minus D minus W sin gamma equal to 0 for a steady climb. So, what I am seeing here? I am seeing T by W minus D by W is equal to sin gamma or T by W is equal to sin gamma plus D by W. So, if I am really going for the climb, please understand the designer when I am climbing, the thrust has a duty to lift the weight, carry the weight which is thrust that is why T by W becomes another important parameter.

And here you could see, if I want to climb at a particular angle gamma, then T by W I can get an initial estimate by just taking the sin of that value. Because, D by W, if I approximate it as D by L, because W equal to L, W although we climb W equal to, W is not equal to L, L cos gamma equal to L. You know, for gamma small I can replace W by L.

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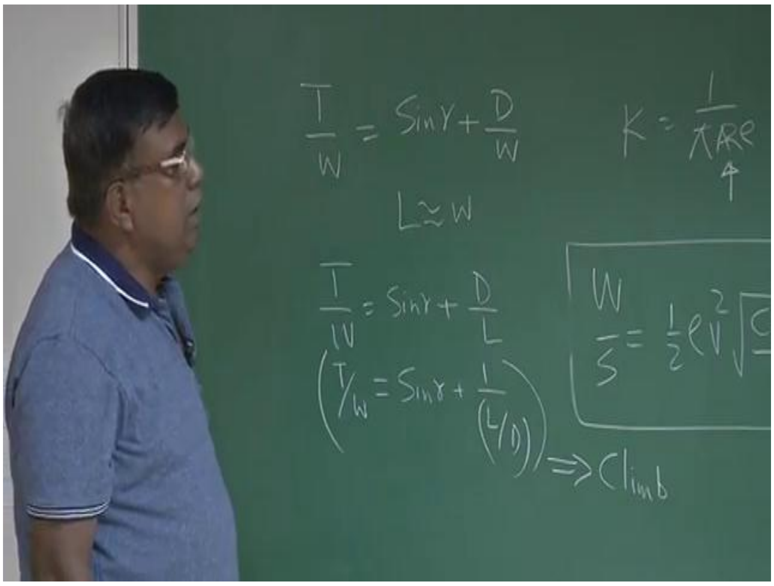

So, I get the expression T by W is equal to sin gamma plus D by W and if I assume, I is roughly equal to weight. During climb, please understand lift is not equal to weight, lift is actually equal to W cos gamma. Since, gamma is small I am taking as a approximation, as a designer I always do that. So, I do this, then I get T by W is equal to sin gamma plus D by L or this is equal to sin gamma plus 1 by L by D, this is during climb. So, what was T by W during cruise?

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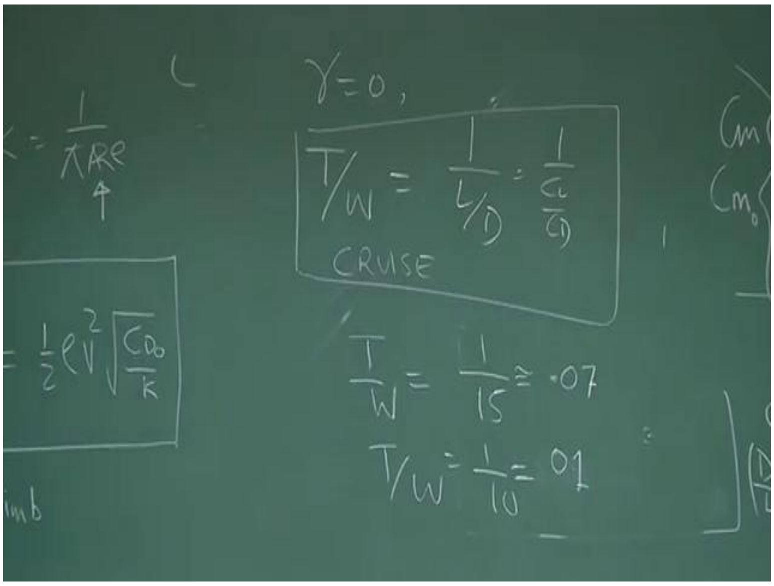

If I try to find out, how much thrust is required during cruise, so I can always get that expression by put gamma equal to 0 in that expression. So, I will get using the same expression T by W equal to 1 by L by D, which is equal to 1 by C L by C D, which you are not surprised. You know that, this is already we have derived many times, we are trying to see estimate the value of T by W for cruise, this is for cruise and this was for climb, see here.

Typically, T by W should be how much for a cruise airplane? You could see that for a cruise, what I required T by W should be. Let us say C L by C D I am flying at 15, it is a good number most of the time, so it will be 1 by 15. We are looking for rough estimate of T by W during cruise. If I say L by D or C L by C D is 15, which is realistic number, then T by W will be around point roughly 0.07. Suppose, if you are flying at a C L by C D of 10, then T by W will be 1 by 10 and that is 0.1. This is a requirement in the cruise. You could see that, these values are pretty less. If and we will appreciate it more, if I come back to T by W of climb, the requirement of T by W during climb. Let us see, how much it happens.

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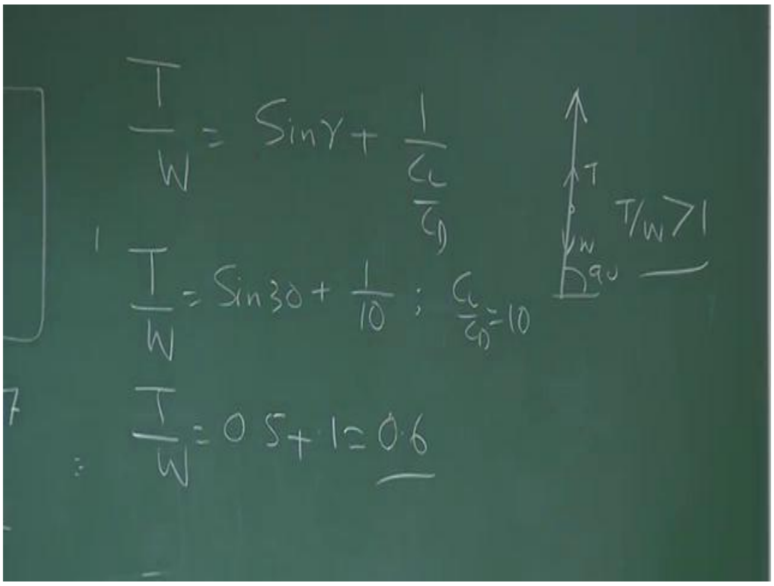

You have seen T by W I can write as sin gamma plus 1 by C L by C D, let us say I am climbing at 30 degree. So, T by W equal to sin 30 plus 1 by, let say C L by C D is 10, this is C L by C D is 10, then how much it is. This T by W is coming to 0.5 plus 0.1, 0.6. You see the difference, for taking the mass through a climb phase that T by W requirement will be predominant. You will not decide T by W from the requirement of the cruise, we will decide the requirement of T by W for the requirement of a climb.

You could see that, if I change gamma to a lesser value, the T by W requirement will be less. So, depending upon what gamma you are flying, the T by W will be the deciding factor and remember, this where we are assuming that it is going and climbing at a steady speed, no acceleration. So, this will give you an idea about, how to select T by W for airplane depending upon requirements. Suppose, you are designing an airplane which you want, it should just go vertically like this, then definitely you understand that T by W should be more than 1. Am I correct?

Suppose, if I am flying like this, I am climbing like this 90 degree, then naturally T by W should be greater than 1, the huge engine is required, huge power thrust is required. So, the two important parameter, one you have seen the wind loading W by S and T by W thrust loading are extremely important parameter to design an aircraft. And you have a fairly idea, how do get an initial estimate of wing loading, you can find out the wing loading also by taking into account, what is the V max, maximum speed required, what is acceleration you want.

Because, you know as I increase S although lift increase, drag also increase; that means, if I want to read it to high acceleration, the largest aspect ratio wing are not in demand, because that is our lot of drag and lot of power has to be dissipated. That is why for a high speed airplane, we will find the aspect ratios are small. Is it clear now? If I have understood about T by W and W by S and while discussing, I am talking about high speed.

Let us also have few gleams, few understanding of what is the high speed airplane and how wings plan forms are configured. When I say high speed, we are meaning thereby in today's context mach number greater than 0.3 or typically 0.7, 0.8 or supersonic. It could be depending type of airplane; you can go up to 2 to 2.5. The moment you are increasing the speed of the airplane, you will find there is a change in the configuration of the airplane.

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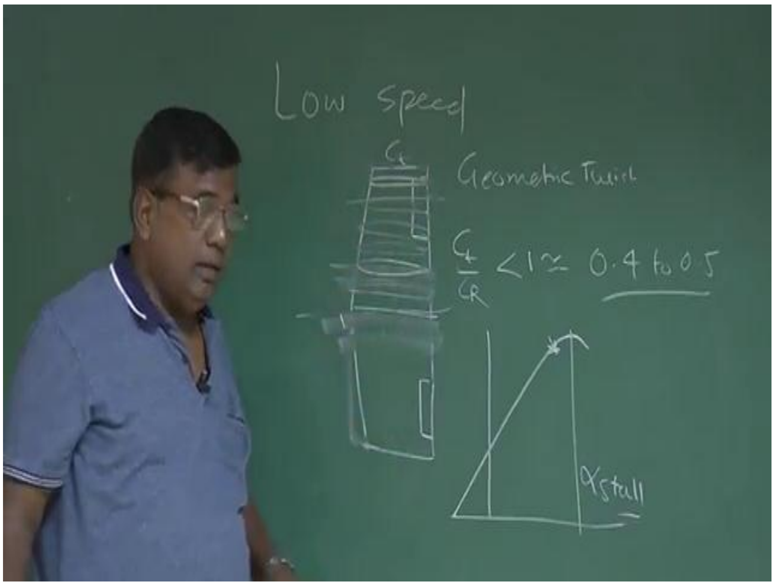

For example, for a low speed we will find mostly it is rectangular, it will like elliptical also, the base is rectangular. You will find for low speed also some sort of a tapering is done like this. Tapering means, if this is tip chord and if this root chord, the c t by c R is less than 1 and typically, this value will find around 0.4 to 0.5. The low speed will find, the airplane is given that much of taper ratio and that helps in bringing the wing plan from closer to an elliptic wing type, you know not exactly, but yes it helps.

Also you see that very important please understand this, one of the major challenge for flying is, there is natural tendency to fly at a higher angle of attack if possible at a lower speed. So, there is engine part requirement is less and you get a lot of lift from the interaction with the medium. As we try to fly at higher angle of attack, I have a danger, I should not cross alpha stall, also we understand suppose I am flying here, although I am not in alpha stall, but because of some upwards gust, local angle of attack may change and the airplane may got into a stall.

Suppose, the airplane has gone into a stall and you know, this is the elevator, what will happen. If the airplane goes into a stall, then the elevator will not have that much of sensitivity, it is effectiveness will reduce. So, if the airplane goes into a roll or yaw, combination of that, the spin, the elevator will not be effective enough to bring it back. So, what is the voice we are handling it? What we do is, we ensure that if at all stalls we are approach in accidently, the late the route portion stall first, then let that tip portion stalls.

So, that the moment there is a stall in the route, there will be a warning to the pilot and that time aileron is not installed. So, it will be effective, it will take care of the adversities. But, how do I do that? If everything is similar here, then naturally all the parts will stall almost equal at the same time. So, what is done is, some geometric twist is given to the aerofoil at the tip around this region that is ((Refer Time: 24:35)), there is a deliberate in negative angle is set on the airfoil, so which are near the tip.

So, that even if there is 12 degree or 13 degree stall angle, this portion will see less than 12, 13 degrees. So, the route will stall, but this gentleman will not stall, this is one way which you call geometric twist. Another way possible, you put different airfoil, you put a airfoil here and here, because this is completely the contours controlled by the airfoil shape. What we do? We do not give geometric twist, but we put airfoil here, which has a characteristic of stalling earlier than the airfoil here, that I can easily decide by selecting the airfoil through the nose radius or T by C etcetera, etcetera.

For example, if T by C is higher, it will likely to stall earlier than airfoil, where T by C is smaller, same thing will be true for nose radius, I can design that. So, what is the second step? I put airfoil here, here the route which has the characteristic of stalling at an angle, let say it is 13 degrees and we select aerofoil here, which has the characteristic of stalling at let us say 14 degrees. So, the moment it stalls that 13, this man has not stalled. So, this effectiveness is available and you can do correction, so this is one aspect.

Thank you very much.