Aircraft Design
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Lecture - 17
Wing Design: Sweep, Twist and Taper Ratio

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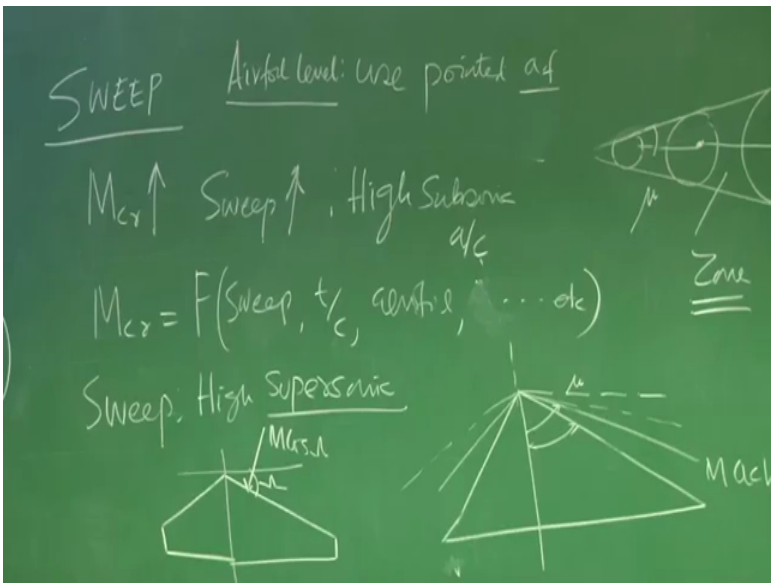

We discuss about sweep. Remember we talked about aspect ratio, then we talk about sweep. We talk about this parameter separately, but when you are doing a design you need to know, if they go together what is the effect. Whether is 1 plus 1 is become really 2 or it is becoming less than 2, in a symbolic manner that is whether we would have a right synergy or not. Because you may like to have a aspect ratio more to get lifting characteristic better L by D better, you will active a sweep mode because you want to increase the critical Mach number because this Mcr is increased if sweep is increased and I am talking about high subsonic airplane. Because for a supersonic airplane the free stream Mach number is already more than one, the critical Mach number has now mini right. Because what is critical Mach number it is that free stream Mach number for which for the first time they air plane at some point the Mach 1 has been achieved locally right.

So, as we increase sweep critical Mach number increases, and also you have seen this critical Mach number depends upon sweep t by C of the aerofoil ,aerofoil itself alright

the critical Mach number depend upon sweep t by C aerofoil etcetera, but when I talk about sweep in relation to high speed that is supersonic I am talking about supersonic, as I mentioned then the critical Mach number has no meaning the way interpret here because presteve already subsonic more than 1. There we give the sweep for distance reason. We try to see that the sweep angle is such that M cross lambda explains the normal component is less will have lesser drag, but it also cost you lift loss.

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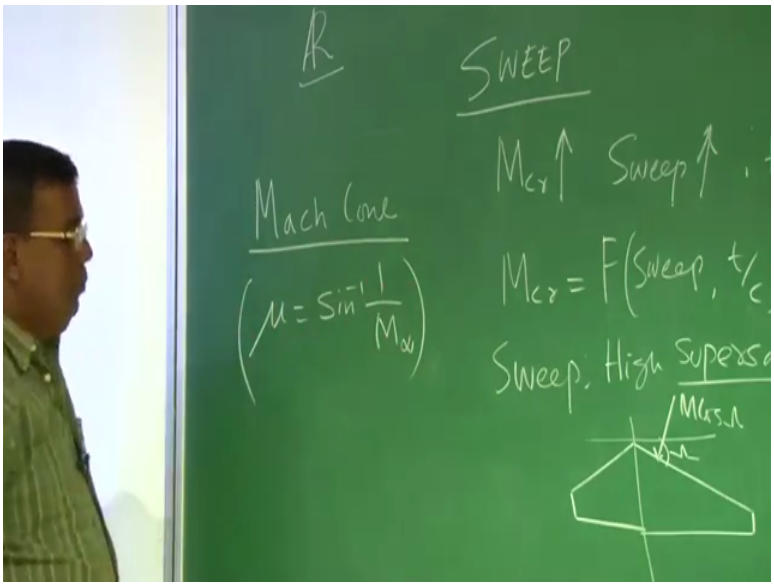

What is the systematic way of contouring the wing leading edge, you understand what is Mach cone right and Mach cone mu is given as sin inverse 1 by M infinity? Please revise from your book and try to understand what is Mach cone, I will just learns through it.

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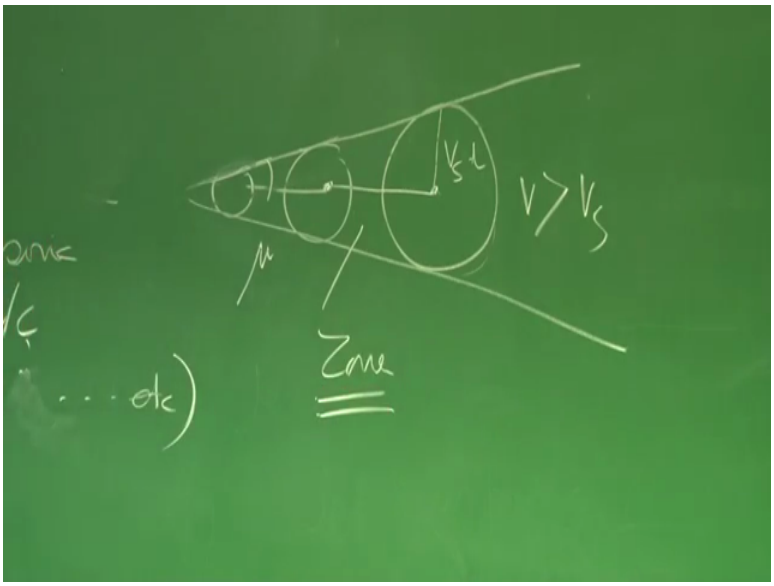

You know that if I moving with speed more than velocity of sound, in time t the disturbance which moves with the velocity of sounds, this is v s into t will be covered, but vehicle be more than the speed vehicle speed being more than the speed of sound. So, vehicle will be here. So, the another will come like this, you know, this time has relaxed to this we go larger and if you see this line if you do a tangent, at this angle if the Mach angel right. That is physically what we understand that disturbances are within confine within this zone right. And that relation mu is given as sin inverse 1 by M infinity and of course, a (Refer Time: 04:23) is more than 1 that is why that angle is oblique.

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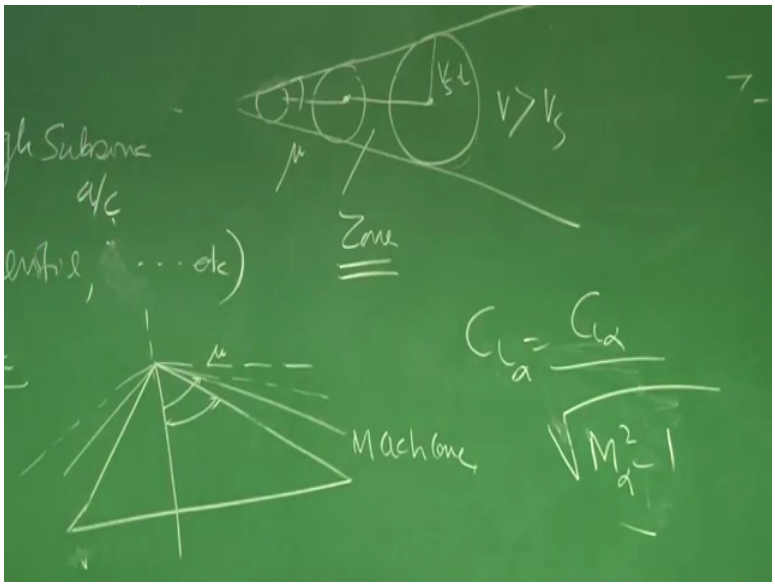

So, what is the best way to handle it is possible that, if we have a configuration like this, you calculate the Mach angles mu here. And this is could say if this is the Mach cone, and if you could manage the leading edge, within the Mach cone, then will have ugly possibility or you are having a subsonic leading edge, but it may not be all these possible. And in in contrast if you are leading edge is outside this Mach cone, then you will have supersonic leading edge supersonic leading edge the problem is there will be lift loss because you know C L e is C L incompressible by under root M infinity square minus 1. So, as you increase M infinity the C L or the C L alpha that reduces, one way is you try to put the leading edge within the Mach cone, but always not possible because this a distribute too demanding we have to really stretch the wing towards the central axis not possible all the time mostly not possible.

So, for the high supersonic case what is done is they handle it at a airfoil level. What is done is use pointed aerofoil, which a lose statement correct statement would be use supersonic aerofoil which have pointed nose, but it also creates it is own issues, but that is the direction. There are series of supersonic aerofoil, lot of base work is done database is available which was relevant. Since will not be focusing more on supersonic airplane, I will go back to soon I will try to go back to low speed and subsonic airplane, but I thought I must mention this. So, that you get inspired and read more. My lecture for this course level one is almost like showing you index of a book for a designer what they should know, what they should know, how to integrate right.

Now, since we are talking about sweep back, general portion come to young students mind, they always want to move forward. They do not like young people do not like to go back. You see it is a scenario has change go on are those days when a neighboring country apparently perceived higher number of military power, and dictate with us salute to our soldiers, was given right impression, that we have we have no knowledge or moving backward when it comes to defending our country. That is what is youth of today India's youth today.

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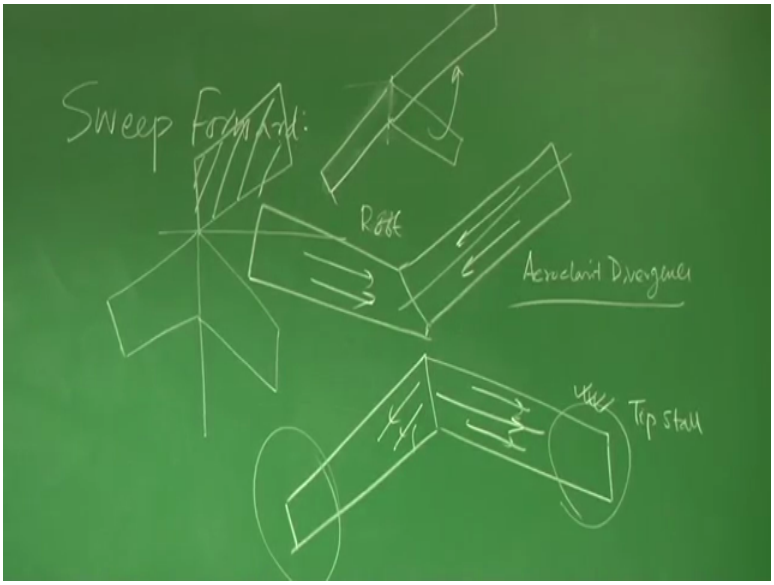

So, naturally they ask a question, you are talking about sweep back what is it forward. If this is sweep backward let us say this, I assuming aerofoil are appropriately. This actually forward will be something like this. So, instead of taking this back, you are taking it forward like this. Because as far as M cost lambda part is concerned that will be true here also the normal component will be less. The advantage one apparent advantage one would see is that for a sweep back is the flow has a tendency to go towards the tip. So, this tip area that boundary layer grows, and it is prone to tip stall one of the factors right.

So, the sweep back will ensure or encourage tip stall, but for a forward C b C the tendency of flow to comes towards the root. Here the tendency for root to stall first than the tip here. Root will encourage to stall first which pilot, will like it with that gives you a indication that you are entering into the stall area. This is one of the defense for a forward sweep because otherwise apparently did not make much of a difference. Then

there was a debates that for a former make for a face a problem of, they call it aero elastic diverges I will not going to detail, but I can tell you what does that mean in a very lemon sense. If something is forward someone is (Refer Time: 10:55) back and elastic axis is the axis about which if we apply the forces, then it will only do bending no torsion right, that is a that low cost of point is called elastic axis right.

The moment you do we forward there is a suspicion possibility, that this wing may infinitely go of increasing it is attitude by a twist, twisting the wing nose up nose up means angle of attack is increasing to stall and all this to happen and if may and just go out. Which is less probable for a sweep back wing? After the materials are there limiters are there. So, that is not an alien issue, but historically people are following a sweep back. You will find such thing being added in unmanned, aerial vehicle and then also you can expect one wing steps forward and another wing which is sweep back, or instead of both the wings are back this wing to be (Refer Time: 12:33) forward and another wing are back word, that combination is not theoretically possible.

There are see much of a difference right. Please understand why talk about the aircraft it is just not wing shape. You have to make sure the pilot maintenance visibility all this thing has to be integrated to say oh this configuration is configuration right; you will also see how feedback has been taken to advantage it came automatically.

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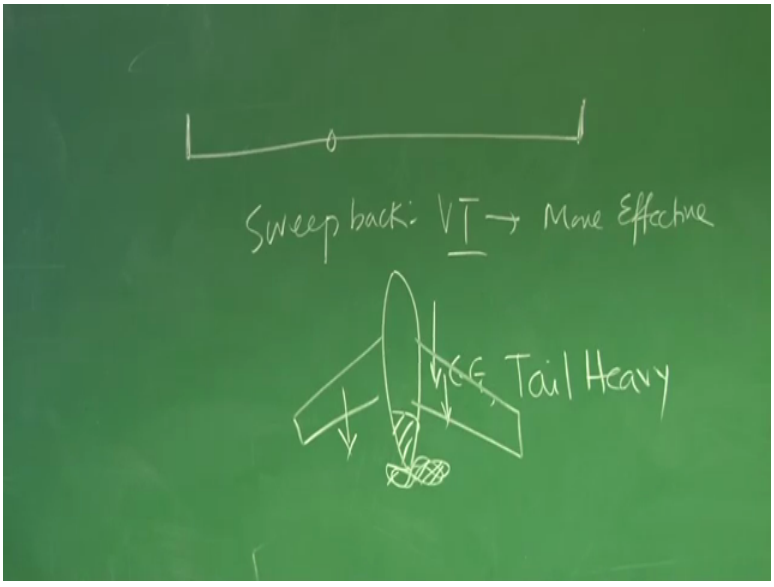

Imagine a situation if you are making a wing and putting a vertical tail here, this is the wing and vertical tail here. So, if you really want this vertical tail be more effective you sweep the wing.

So, if you sweep back vertical tail because more effective which vertical tail there are vertical domestics are putting over the wing right, but different combination you may do that also you see that, if this is the airplane and you were putting a pusher this engine is here. The moment, I put a pusher you see that the tendency of C g coming backward right. C g coming backward will say tail heavy right, to make it stable, we like aerodynamic center of the wing to come backward and that happens by sweeping the way. So, this speed may not be a criteria, the criteria is we want to draw the aerodynamic center at because the tail has become failure. The whole scenario of todays aircraft development has changed because today the focus is unstable does not mean uncontrollable if by making a unstable. You can control it and finally, it gives me a better objective fulfilled do that that is the philosophy.

So, all these concepts we are telling their stand alone is, but when they are integrated with different requirements, and different expectations, you will find at some point this concept is this point some point, this concepts is it is not a generic statement that this configuration will be better in a general sense.

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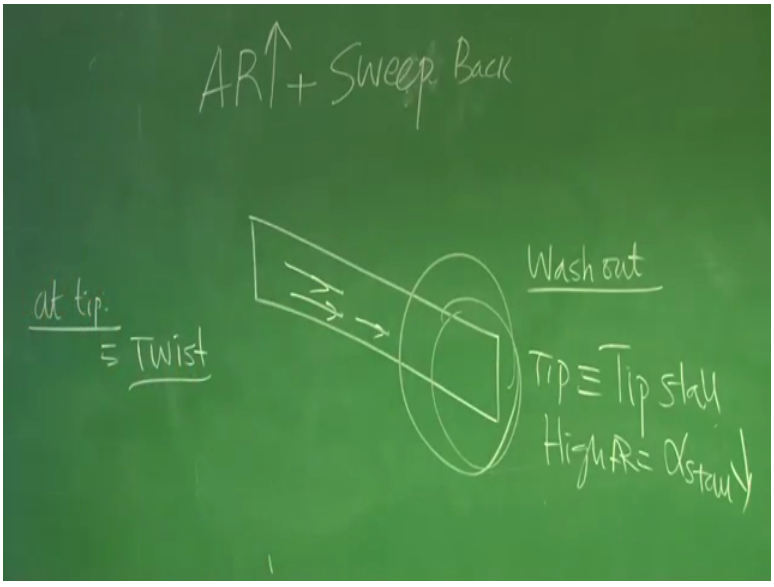

The other question which I was discussing, we have a natural love to increase aspect ratio which often troubles the structure group we have a (Refer Time: 15:53) making the wick look or the wing look we join by giving sweep back. If I try to add this what is the consequence, that is exactly where I has telling will 1 plus 1 always be 2 symbolically. Because will have to increase aspect ratio will have to have sweep back. What happens if sweep back is there, you know the tendency of flow to go towards tip. So, immediate worry tip stall, high aspect ratio again alpha stall reduces. So, sweep back and high aspect ratio this combination will lead you to get trouble. You understand sweep backflow will try to come towards tip high aspect ratio the alpha. So, reduces.

So, this settlement tip stall will get more elevated, but as human mind, if still you want some combination of aspect ratio and a sweep back, the best way to handle is you see that at tip, there is some twist. Twist the wing at the tip that is if is creating a problem of tip stalls, then you try to give a twist at the tip. So, that net angle of diag at that regionally is lesser by the amount of negative twist you have given to the wing and that is called all etymologies, use this concept washout.

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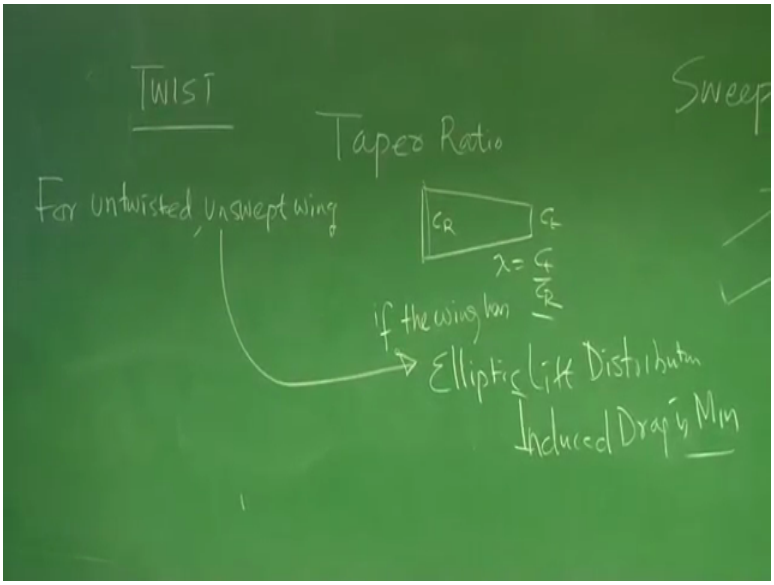

If you had increased the local angle of attack here, they save wash in. Just now I use the word twist, if I talk about twist, we need to first know about the live distribution over the wing that is very important. So, let us first discuss about the live distributions over the wing. And in that connection we will first talk about taper ratio, and you know taper ratio

is the ratio of tip chord to root chord, that is taper ratio C T by C R. And typically if the wing has elliptic lift distribution, and at a lower speed, distribution then induced drag is minimum. This we know from airplane performance one course, for untwisted unswept wing, this statement is should be valid for a low speed.

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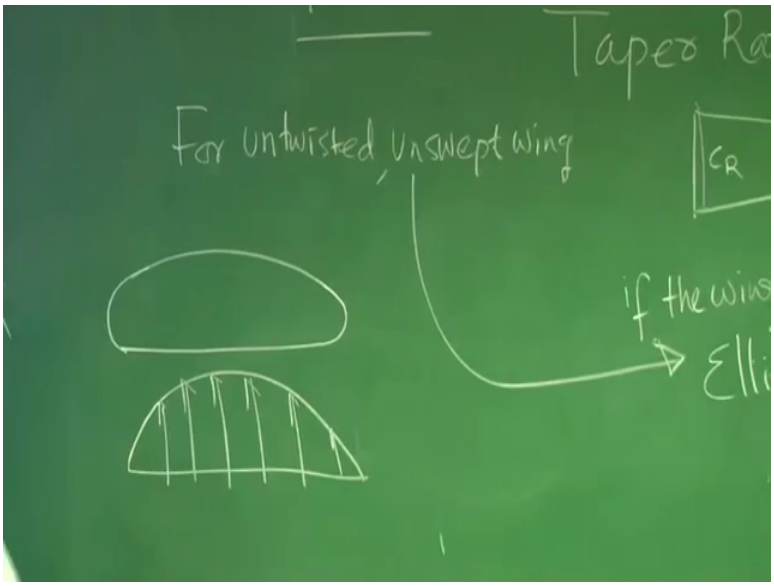

So, important untwisted and unswept wing. Typically, the wing platform will look like an ellipse, let me draw right practically. And I leave distribution is something like, you can refer any book, this things are available this is just part of revisions it is typically elliptic wing and you could see that it is not so easy to manufacture elliptic wing just to view a number.

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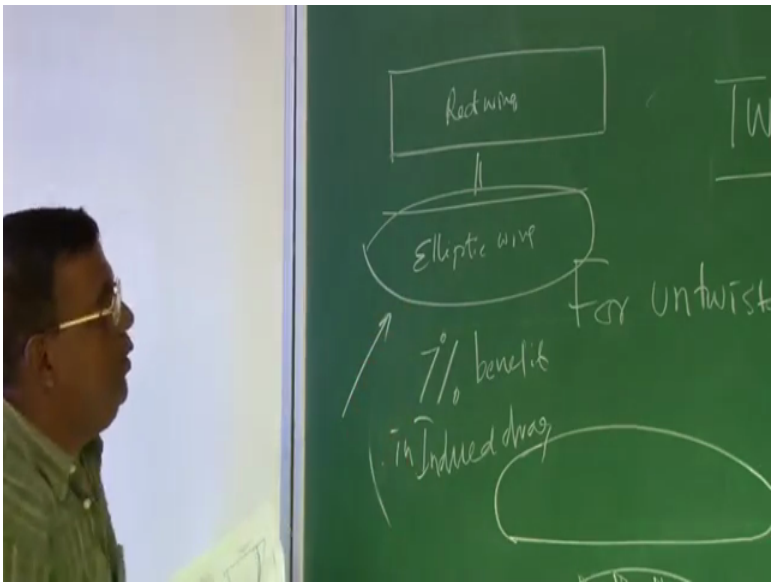

If I have same aspect ratio rectangular wing, and same aspect ratio if I am going for an elliptic wing, roughly 7 percent benefit in induced drag, in induce drag you get over rectangular wing when are using elliptic wing around 7 to 8 percent.

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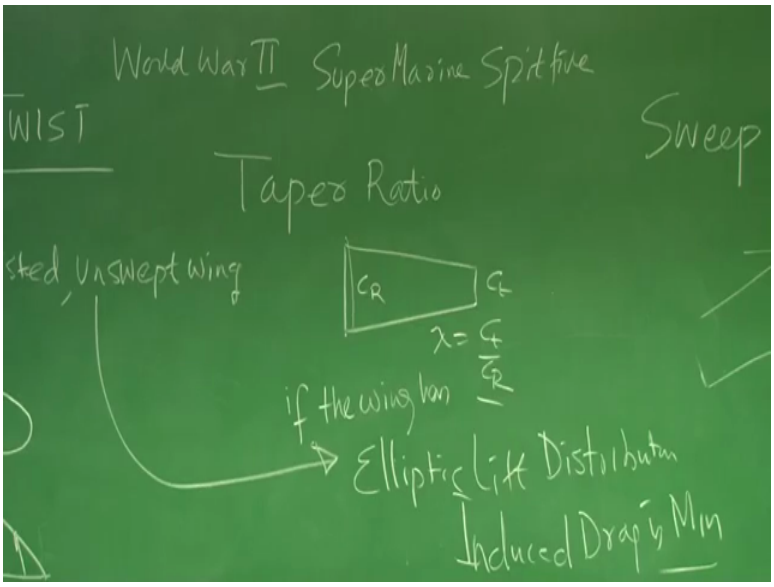

But the manufacturing of elliptic wing is not so straightforward. And if you see including world war I do not want to write this term world war 2, super marine, spitfire. Spitfire used almost elliptic wing. Whatever we are discussing understanding, we implicitly take both that our knowledge should be avoided or we should not create a scenario where our

knowledge should be used for destruction of humanity or universe. That character able to design and you to have of course, that does not mean if you are in trouble you only able to defend yourself right.

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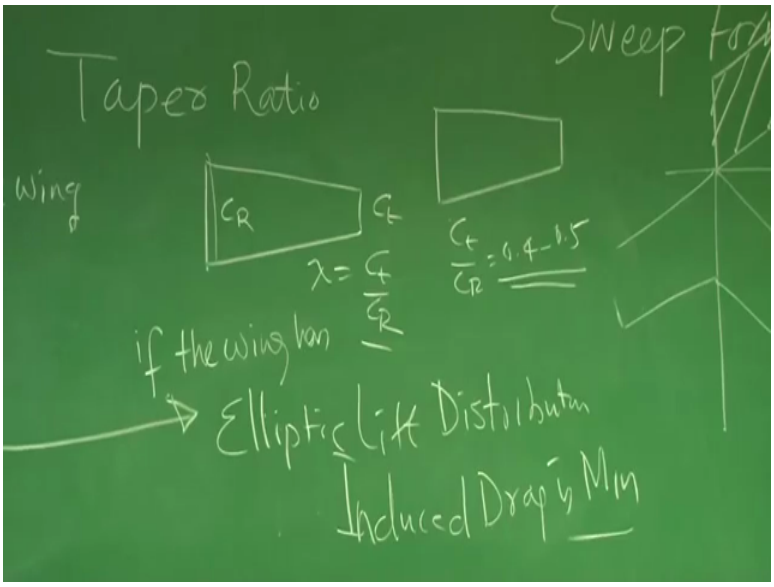

Typically, it is seem that if you take rectangular wing and taper ratio around 0.4 2.5, if you keep almost you get similar advantages as per lift distribution is concerned as you can have through elliptic wing.

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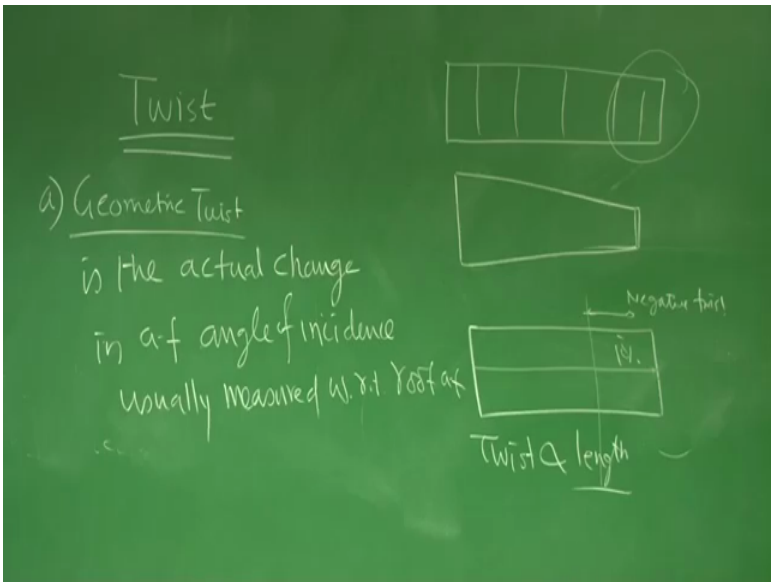

Since we talk about twist, how can you use the twist aerodynamically. Fundamentally we know if I have a wing, for a constant chords right. And a wing having taper chord. The moment I put a constant chord, I am unnecessarily making lift near the tip large. As I put more lift at the tip, I am nearing to us more vertices gross, structurally more bending moment, but since we are talking about elliptic distribution, I will talk in terms of if the constant chord we are unnecessary loading the tip. Instead reduce the load here one is we do taper ratio we actually this is the chord here. So, lift this load at that portion is reduced.

If you have rectangular wing only, do not want to go for taper then that is some portion here we have to give a negative twist maybe 10 percent. So, that you are this area is not as loaded in terms of load as this, was because you want to avoid induced drag because induced drag is depending upon the pressure difference on the top at the bottom surface. So, I am reducing it right. So, I have to give a negative twist. So, here aerofoil was like this. I will give like this see this was aerofoil I am negative twist I have given like this. For something percent (Refer Time: 24:35) then what is twist geometric twist is what I explained, was geometric twist. So, little bit height, it is the actual change in aerofoil angle of incidence, usually measured with respect to root aerofoil right. How much I have to studied is measured with respect to the root aerofoil. I can do a twist like this down negative, which I call wash out I can also increase which call washing right. That is geometric twist. I can also give a twist which is proportional to the length as length is increasing twist is proportional to the length, local distance where I am giving.

So, twist could be proportional to the length. So, linear twist, but you see on blackboard it is. So, easy to tell wash out wash in, think of way these have to manufactured in the workshop, how much you are bothering the person who are manufacturing. First of all whatever twist they are giving they have to manufacturing process, they have to be process to measure it validated it. So, much of effort goes on. So, use all these twists and all absolutely when required, do not do it for fancy. If we are bothered about stall you going to avoid tip stall there is another way of handling, it is what we call is aerodynamic twist. When we talk about aerodynamic twist the designer is more focused he wants to ensure that the stalling property improves or in a sense.

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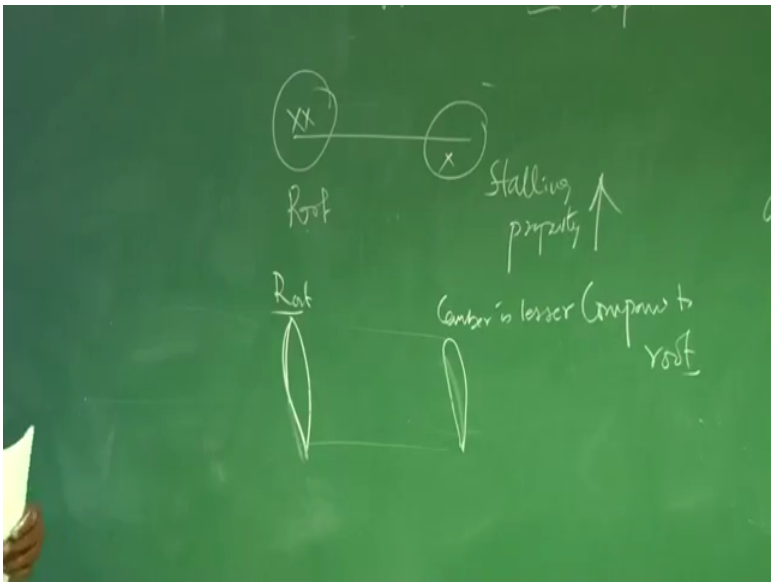

He wants this man to root to stall first than the tip because his alone are etcetera working there.

So, what is the best way to do is, use in the aerofoil particular camber here. Lesser camber you use here. So, here the camber is lesser compared to route aerofoil. And you know as you increase the camber the stall angle reduces. So, at the root I have put highly cambered aerofoil and getting a scale max also, but at the tip I am putting a aerofoil with lesser camber. So, the stall angle here is more. So, for a angle near the stall angle this gentlemen this area will stall fast, but again black board it looks fine. How do I maintain continuity on the wings a face when you are putting different aerofoil, having different camber? Theres a construction issues constructor smartness is required. If I get a chance I will definitely demonstrate how we do in our lab when you design our unmanned aerial vehicle of nowadays, we are designing forty k g unmanned aerial vehicle.

So, you could see almost similar things are happening right you could appreciate that what I am trying to do initially I am I am trying to give you some idea about physical phenomena. And then try to drag you towards designers perspective through numbers. For example, if somebody tells me, how do I get an average number for what sort of twist is there simple rule is you take the average of them at the designer to start with if, somebody asked with what aspect ratio I should start conceptualizing as design, I say if it

transport the airplane takes 8. What is (Refer Time: 29:27) a C L alpha take 5.5 per radian, but when somebody asked me what sort of wing loading, I say hold on.

Will be talking about wing loading, I mean next later lectures, but we are very close to coming to finding our thrust requirement thrust loading requires wing loading requirement which are extremely important part of it designing of an aircraft. I am my sincere advice please revise airplane performance one and performance 2 whenever you find some connected material being term read textbooks google, approach google uncle and get your queries use forum. And finally, you will understand that from blackboard to your field, the design consent must stay should have stay on the blackboard or your notebook you should stay with him then only you are designed.

Thank you very much.