Introduction to Aircraft Design
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Lecture – 32
Wing Geometry Definitions

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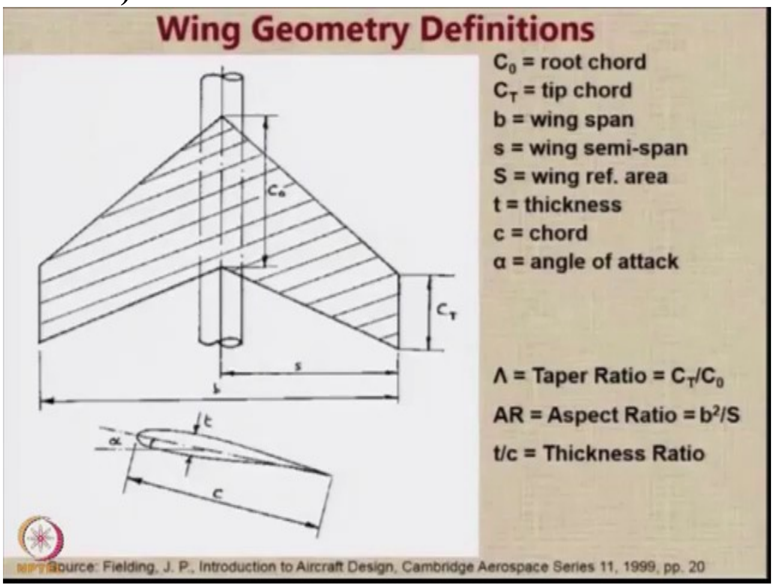

Let us have a look at some wing geometry parameters. Now, the basic geometrical configuration of a wing is supposed to be a trapezoidal wing and these are some of the important geometrical parameters. The first parameter is the root chord, which is the chord of the wing not at the place where it attaches with the fuselage, but at the location of the extended center line of the fuselage.

So, this is a very common mistake, sometimes many people take the root chord as the location where the wing and the fuselage are physically meeting, but, the root chord is defined theoretically as the chord of the wing when it meets the theoretical extended center line of the fuselage. You also have tip chord, which as the name suggests is the chord of the wing when it is at the tip. The distance between the 2 ends of the wing is called as the span b and half of it is called as the semi span s.

S is normally reserved as the parameter wing reference area, which is the area of the wing as viewed in the top view, including the part that is submerged inside the fuselage. Though the hatched area in this figure is the definition of wing reference area, it is a reference. So, as long as everyone understands what it stands for, there will be no confusion. So, it is important to remember the definition of the wing reference area.

You then have thickness t, which as you can see in this figure is the maximum distance between the upper and the lower surface of the aerofoil you have the chord C, which is the distance between the leading edge and trailing edge of the aerofoil or the wing. And angle of attack is the angle that is made by the ambient wind vector with a reference line on to the aircraft.

There are some derived parameters like the taper ratio, which is a ratio of the tip chord to the root chord. There is an aspect ratio which is an indication of its slenderness is defined as the square of the span upon the wing reference area. And we have a thickness to chord ratio or the t/c ratio, which is the ratio of the maximum thickness divided by the mean aerodynamic chord of the wing.

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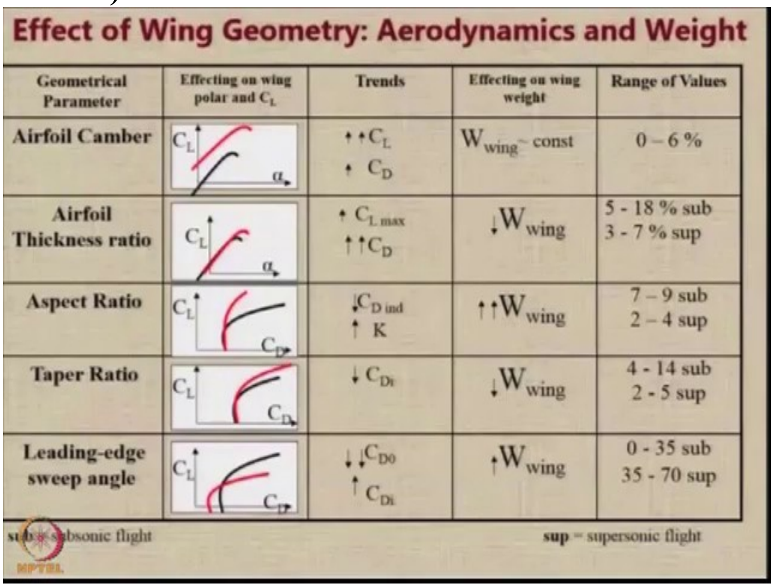
Effect of Wing Geometry: Aerodynamics and Weight

Geometrical Parameter	Effecting on wing polar and C_L	Trends	Effecting on wing weight	Range of Values
Airfoil Camber		$\uparrow\uparrow C_L$ $\uparrow C_D$	$W_{wing} \sim$ const	0 – 6 %
Airfoil Thickness ratio		$\uparrow C_{L\,max}$ $\uparrow\uparrow C_D$	$\downarrow W_{wing}$	5 - 18 % sub 3 - 7 % sup
Aspect Ratio		$\downarrow C_{D\,ind}$ $\uparrow K$	$\uparrow\uparrow W_{wing}$	7 – 9 sub 2 – 4 sup
Taper Ratio		$\downarrow C_{Di}$	$\downarrow W_{wing}$	4 - 14 sub 2 - 5 sup
Leading-edge sweep angle		$\downarrow\downarrow C_{D0}$ $\uparrow C_{Di}$	$\uparrow W_{wing}$	0 - 35 sub 35 - 70 sup

sub = subsonic flight　　sup = supersonic flight

Now, the wing geometrical parameters like the camber of the aerofoil, the thickness ratio of the airfoil aspect ratio, taper ratio and the leading edge sweep angle, they all affect the aerodynamic characteristics and the weight quite substantially. And it is summarized in this particular chart. But let us have a look at each of these elements one by one to have a better understanding. The first parameter that affects is the camber. Camber of the airfoil essentially is an indication of its curvature.

So, the black line is for the base aircraft baseline geometry and the red line is for the effect of change or increase in a particular parameter. So, we notice here that as you increase the camber then the lift coefficient increases. In fact, you have a line which is almost parallel to the original line. So, the lift coefficient increases, but the drag coefficient also increases as far as the weight is concerned effect of camber on the aircraft weight is not that substantial.

And the typical values of camber that you see are between 0 % which is a symmetric aerofoil to around 6% of the chord. The airfoil thickness ratio is another parameter which affects the C_{L_α} curve, mainly it actually increases the angle at which it stalls. So, it increases the $C_{L_{max}}$, but it also increases the drag coefficient. However, when you have a higher thickness to chord ratio, you generally can come up with a lower wing weight.

This is not very intuitive because many people think that a thicker wing should actually weight more because they think it larger in size. However, please remember that one of the main component of the aircraft that is heavy is the main and the rear spar or the spar which are present and the spars themselves consists of a flange and a web. Now, in a wing with higher thickness to chord ratio, these spar flanges are farther away because the web is larger in size.

And because they are larger in there, because they are far away they have a it gives us. It gives a higher moment of inertia and higher moment of inertia gives you a smaller value of the bending moment, which is the principal load that a spar has to carry. So, up to a point, increasing t/c can actually lead to a reduction in the aircraft weight.

Wing weight the range of values for subsonic aircraft is between around 5 to 18%. And for supersonic aircraft, the thickness to chord ratio is kept low because of the high drag between 3 to 7%. The next important parameter is the aspect ratio, the aspect ratio is a very important aerodynamic parameter as I mention, it is an indication of the slenderness of the wing. It improves the induced drag coefficient K and actually it reduces the induced drag because of that.

And another problem with the increasing aspect ratio is the more you increase the aspect ratio the more slender the wing becomes and a slender wing is going to be more prone to aeroelastic problems because of flexibility. And also, to make it sufficiently rigid, we need to provide huge support and that leads to an increase in the wing weight. In fact, increasing aspect ratio of the wing leads to a very large increase in the wing weight.

And the wing is approximately 12% of the aircraft weight in most cases between 10 to 12%. So, it substantially affects the weight of the aircraft. So, the recommend value aspect ratio is between 7 to 9 or maybe 10 for subsonic aircraft, except those which are designed for very long endurance and for supersonic aircraft, the value recommended is between 2 and 4. Taper ratio is another parameter that is very important in reducing both the weight of the wing as well as the induced drag of the aircraft.

However, giving large taper is going to create a problem with the lift distribution. So, the taper ratio generally is between 4 to 14 for subsonic aircraft and 2 to 5 for supersonic aircraft. And lastly, we look at the leading edge sweep angle. Sweep angle definitely reduces C_{D_0} but increases the induced drag coefficient and it makes the wing heavy. So, subsonic aircraft normally we do not see them to be strapped more than 35 degrees.

But for supersonic aircraft you normally see the sweep from 35 to 70 degrees or even more sometimes, it may be noted that the only advantage of riding wing sweep is to reduce the drag at high speeds and for all other considerations, the wing sweep is actually detrimental. So, wing sweep should not be provided unless it is essential from pure aerodynamic reasons.

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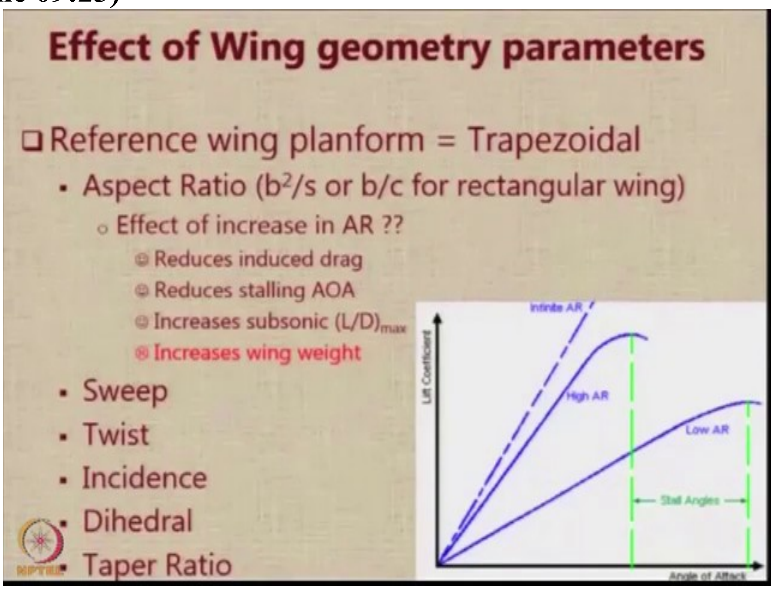

The reference wing planform is always considered as trapezoidal and we have already seen the effect of aspect ratio. If you increase aspect ratio we see that the induced drag reduces. But another good thing is that the angle at which the aircraft will stall is also going to reduce. So, the subsonic L/D of the aircraft increases because of the reduced induced drag. But as I already mention, there is a substantial increase in the wing weight sweep twist incidents dihedral are other parameters which are very important as far as the geometrical choice of an aircraft is concerned.

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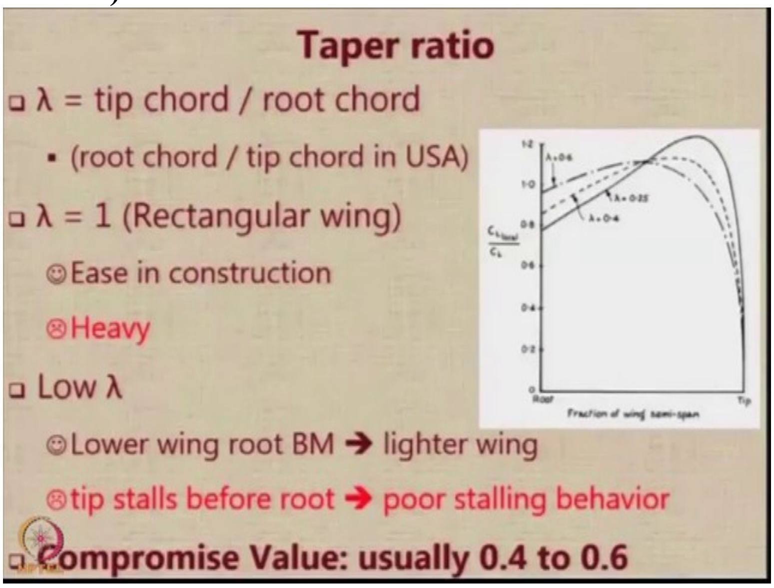

So, I did not mention to you that taper ratio of the aircraft the benefit of that is that it gives you easy construction, but it makes the wing heavy if you do not give taper then you have a rectangular wing and it gives you a heavier wing. When you have a lower taper ratio, then you have a lighter wing because the wing root bending moment is reduced. However, the concentration of the lift moves towards the tip.

So, therefore, as the value of taper ratio reduces that tip start getting loaded and that means the tips will start stalling first and that is not desirable as far as controllability is concerned. For a good controllability in the post stall scenario, we do not want the tips to stall first we want the route to stall first, because when the route stalls first it gives some kind of vibration and physical feel to the tail.

And also, if the route stalls before the tip, then the aileron which are normally outboard are in unstalled wing. So, they are still providing the required moment for controllability. Whereas, if the tip stalls first, then the ailerons which are at the tips will also be in the stalled condition and it will be ineffective. So, it will be difficult to recover from a disturbance especially in roll. So, the compromise value of paper ratio is normally between; 0.4 to 0.6 in most aircraft. Thanks for your attention we will now move to the next section.