11

ESTIMATED LOW SPEED LIFT CURVES AND MAXIMUM LIFT COEFFICIENTS

In order to perform more detailed aerodynamic performance analysis on the baseline preliminary design, some basic aerodynamic characteristics of the configuration must be estimated. One of the most important set of aerodynamic characteristics are the lift curves and maximum lift coefficients for the cruise, takeoff, and landing configurations. As noted in Chapter 1, the airplane lift curve has a special relationship to airplane operation in steady, unaccelerated flight, namely that the airplane's speed is primarily a function of lift coefficient, and the lowest steady flight speed, called the stalling speed, V_{stall} , corresponds to operation at the maximum lift coefficient, C_{Lmax}. We shall see in this chapter that the cruise lift curve is the key to determining the aircraft pitch angle in cruise, and we will see in Chapter 13 that a key design airspeed depends on the C_{Lmax} for the cruise configuration. Furthermore, the C_{Lmax} in the takeoff configuration is directly involved in the determination of the FAR required takeoff field length, and the C_{Lmax} in the landing configuration is directly involved in the determination of the required FAR landing field length.

The following paragraphs describe the background and procedure used to estimate the low speed lift curves and the maximum lift coefficients for the cruise, takeoff, and landing configurations.

CRUISE CONFIGURATION LIFT CURVE

The linear variation of lift coefficient, C_L, with airplane angle of attack α, usually written as $dC_L/d\alpha$, is related primarily to the wing planform geometry parameters, namely aspect

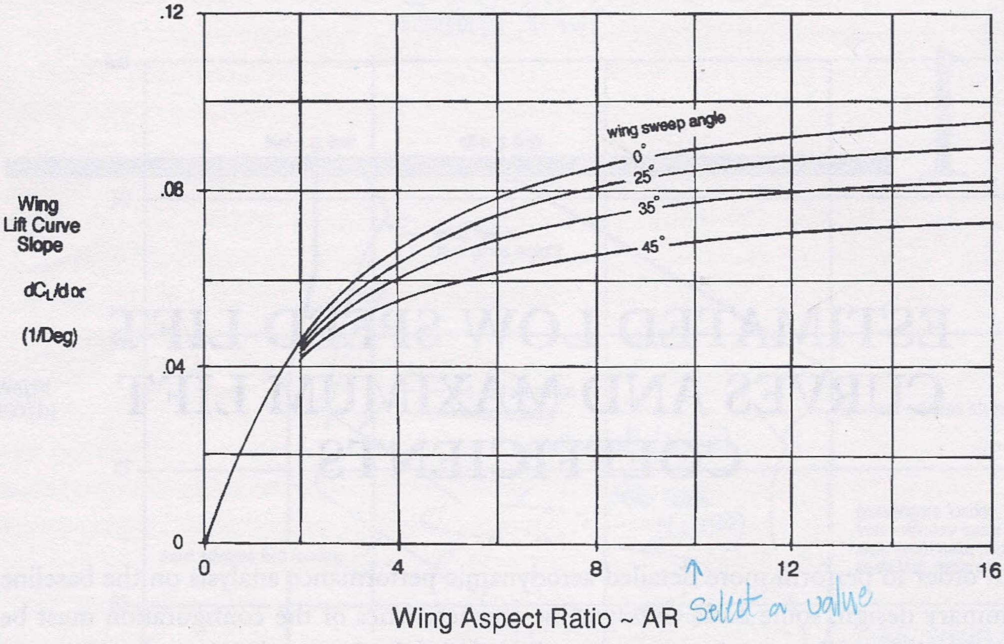

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Fig.11-1 Lift Curve Slope Variation with Aspect Ratio and Sweepback

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ratio, AR, and sweep angle, Λ, as shown in Fig. 11-1. Since a small amount of lift is carried on other parts of the airplane, such as the fuselage, nacelles, and horizontal tail, the value of the airplane lift curve slope is slightly higher* than the wing lift curve slope. The zero lift angle, that is, the airplane angle of attack where the airplane lift coefficient is zero, called a_{OL}, depends on a number of parameters, such as the zero lift angle of the wing airfoils, the variation in the airfoil zero lift angle across the wing span or aerodynamic twist, the influence of the fuselage shape and the angle at which the entire wing is attached to the fuselage. An analysis of all of these parameters is made in the preliminary design phase of the program, with the objective of having the angle of attack of the fuselage reference plane, or floor line in the passenger cabin, between 0° and +2° at the cruise condition.

The maximum lift coefficient in the cruise configuration is dependent on two primary parameters, the spanwise variation of local wing section lift coefficients, as the wing approaches the angle of attack for stall, and the wing airfoil section maximum lift coefficients, which are unique values for each airfoil section. For performance reasons, airfoil sections with high values of maximum lift coefficient are usually selected to achieve the highest value of airplane maximum lift coefficient. However, as shown in Fig. 11-2, the airfoil section maximum lift coefficient values are usually varied across the span, so that the wing spanwise lift distribution will reach values of the airfoil maximum lift coefficients

* $C_L = \frac{L}{q S_{ref}}$ + additional fuselage lift is obtained with no change in S_{ref}

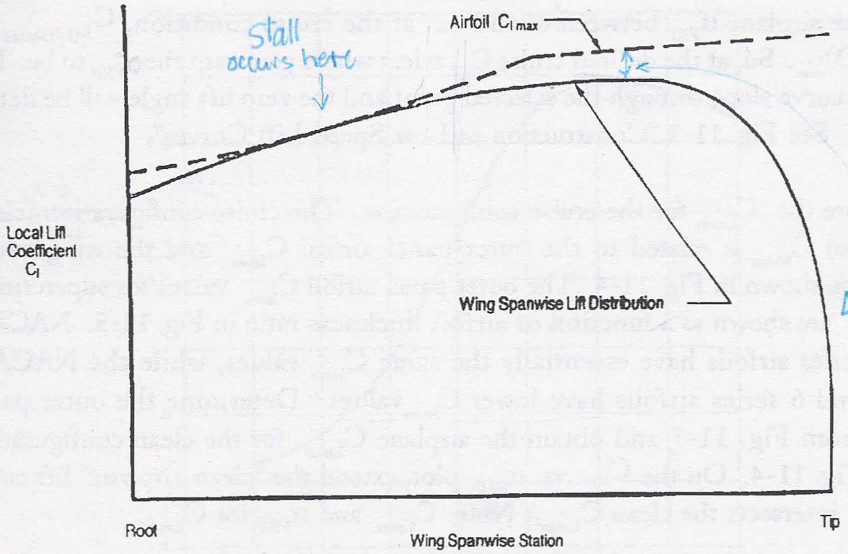


Fig.11-2 Span Loading/Airfoil $C_{L_{max}}$ Relationship for Proper Stall

over the inboard portion of the wing, producing local stalling inboard while maintaining some lift coefficient margin to stall over the outer portion of the wing. This margin in lift coefficient to stall is used to protect against initial local stalling over the outer portion of the wing, which leads to severe roll off and loss of aileron control at the stall. For this reason, the airplane maximum lift coefficient can never be as high as the airfoil maximum lift coefficients. The detailed procedure for constructing the cruise lift curve is as follows.

1 • Determine wing lift curve slope for your AR and sweep angle at low speed from Fig. 11-1.

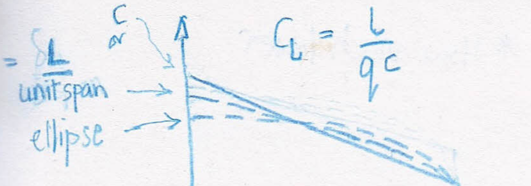
2 • Increase this value by 8% to account for the lift contribution of the rest of the airplane, i.e., fuselage. nacelles, horizontal tail

$$C_{L\alpha_{airplane}} = 1.08\, C_{L\alpha_{wing}}$$

Fig 11.1

3 • On a plot of C_{LA} vs. α_{FRP}, draw in this slope through $C_{LA} = 0$ and $\alpha_{FRP} = 0$, as shown in Fig. 11-3. (see chain-dashed line)

4 • The next step is to set the zero lift angle for the airplane. This is a complicated process that involves data beyond the scope of this book, but the objective is to



have the airplane α_{FRP} between 0° and +2° at the cruise condition, $C_{L(L/D)max}$ at $(ML/D)_{max}$. So, at the desired cruise C_L, select where you want the α_{FRP} to be. Put the lift curve slope through the selected point and the zero lift angle will be determined. See Fig. 11-3 "Construction of Low Speed Lift Curves".

(5) Estimate the C_{Lmax} for the cruise configuration. The cruise configuration (clean airplane) C_{Lmax} is related to the outer ? panel airfoil C_{lmax} and the wing sweep angle, as shown in Fig. 11-4. The outer panel airfoil C_{lmax} values for supercritical airfoils are shown as a function of airfoil thickness ratio in Fig. 11-5. NACA 5 digit series airfoils have essentially the same C_{lmax} values, while the NACA 4 digit and 6 series airfoils have lower C_{lmax} values.* Determine the outer panel C_{lmax} from Fig. 11-5 and obtain the airplane C_{Lmax} for the clean configuration from Fig. 11-4. On the C_{L_A} vs. α_{FRP} plot, extend the "clean airplane" lift curve until it intersects the clean C_{Lmax}. Note C_{Lmax} and α_{FRP} for C_{Lmax}.

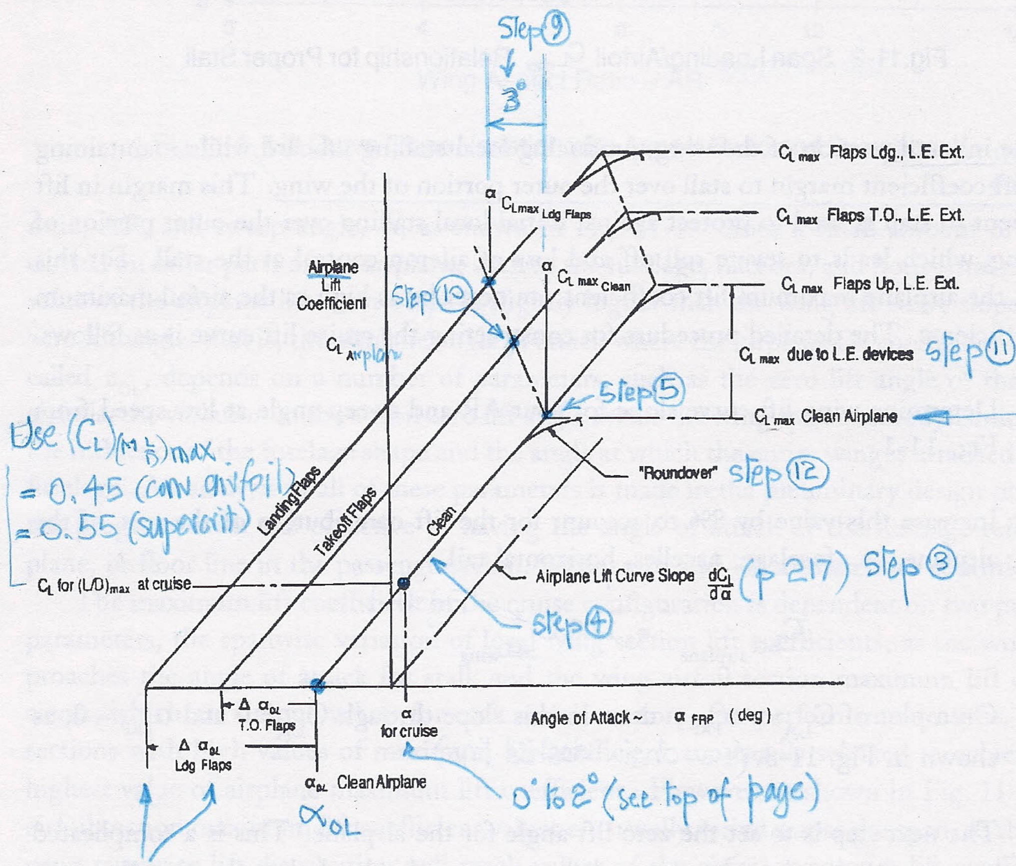


Fig. 11-3 Construction of Low Speed Lift Curves

* How much lower

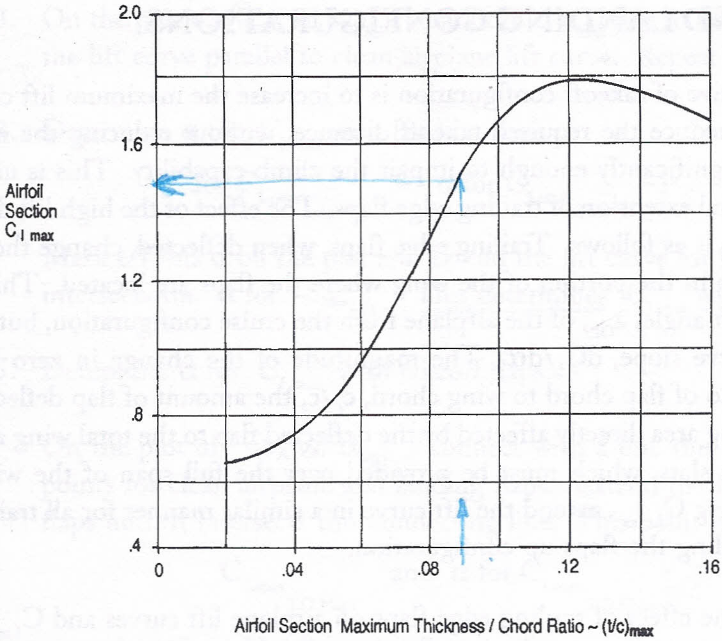


Fig. 11-4 Airfoil Section C_{lmax} Trend with Thickness Ratio

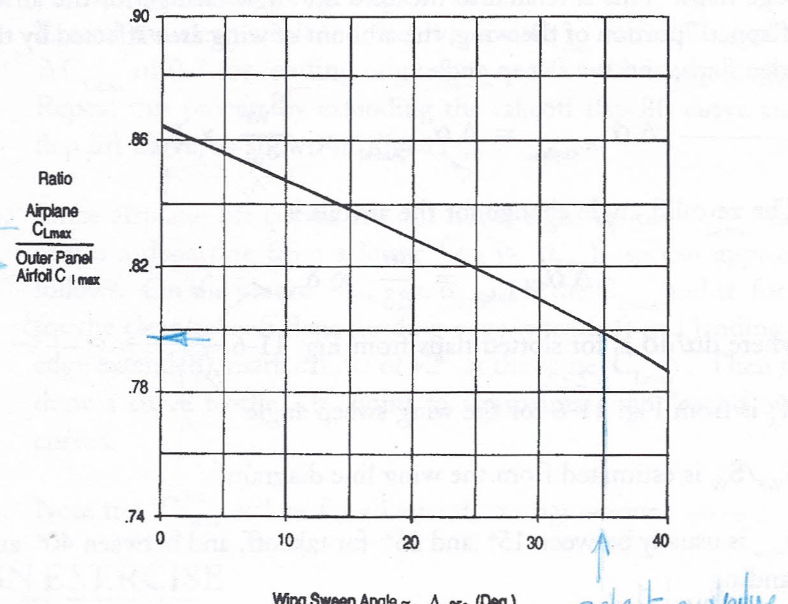


Fig. 11-5 Airplane C_{Lmax}/Airfoil C_{lmax} Ratio

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TAKEOFF AND LANDING CONFIGURATIONS

The primary objective of takeoff configuration is to increase the maximum lift coefficient of the airplane to reduce the required takeoff distance, without reducing the maximum lift-to-drag ratio significantly enough to impair the climb capability. This is usually accomplished by partial extension of trailing edge flaps. The effect of the high lift devices on the cruise lift curve is as follows. Trailing edge flaps, when deflected, change the zero lift angle of the airfoils in the portion of the wing where the flaps are located. This in turn changes the zero lift angle, a_{OL}, of the airplane from the cruise configuration, but does not change the lift curve slope, $dC_L/d\alpha$. The magnitude of the change in zero lift angle depends on the ratio of flap chord to wing chord, c_f/c, the amount of flap deflection, δ_{flap} and the ratio of wing area directly affected by the deflected flap to the total wing area, S_{WF}/S_W. Leading edge slats, which must be provided over the full span of the wing to be effective in increasing $C_{L_{max}}$, extend the lift curve in a similar manner for all trailing edge flap settings, including the flaps up configuration.

- Estimate the effect of trailing edge flaps on airplane lift curves and $C_{L_{max}}$.

Step 6 1. First, determine the change in zero lift angle of the airplane due to trailing edge flaps. This is related to the zero lift angle change for the airfoils in the "flapped" portion of the wing, the amount of wing area affected by the trailing edge flaps, and the sweep angle

$$\Delta\alpha_{OL_{Airplane}} = \Delta\alpha_{OL_{Airfoil}} \times \frac{S_{WF}}{S_W} \times K_\Lambda \tag{11-1}$$

The zero lift angle change for the airfoils is

$$\Delta\alpha_{OL_{Airfoil}} = \frac{d\alpha}{d\delta} \times \delta_{Flap} \tag{11-2}$$

where $d\alpha/d\delta$ is for slotted flaps from Fig. 11-6 → p222

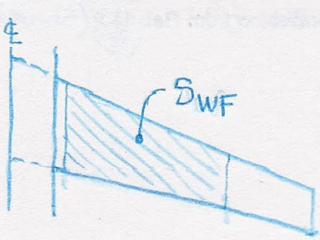
p222

K_Λ is from Fig. 11-6 for the wing sweep angle

S_{WF}/S_W is estimated from the wing line diagram

δ_{Flap} is usually between 15° and 25° for takeoff, and between 40° and 50° for landing

7 2. Calculate $\Delta\alpha_{OL_{Airplane}}$ for both takeoff and landing flaps.



8 3. On the plot of C_{L_A} vs. α_{FRP}, mark off $\Delta \alpha_{OL}$ due to takeoff flaps and draw the lift curve parallel to clean airplane lift curve. Repeat for landing flaps.

9 4. Determine α for C_{Lmax} with landing flaps

$$\alpha \text{ for } C_{Lmax_{\text{Ldg Flaps}}} = \alpha \text{ for } C_{Lmax_{\text{Clean}}} - 3^\circ$$

Mark off this α on the plot and extend the lift curve for landing flap until it intersects the α for $C_{L_{Max_{Ldg}}}$. This determines C_{Lmax} with landing flaps. (no l.e. devices)

C_{Lmax} landing (no l.e. devices) →

10 5. Determine α for C_{Lmax} with takeoff flaps.

On the plot of C_{L_A} vs. α_{FRP}, connect with a line the C_{Lmax}, α for C_{Lmax} points for clean airplane and landing flaps. Extend the lift curve for takeoff flaps until it intersects this connecting line. This point is

C_{Lmax} TO →

$$C_{Lmax_{\text{T.O.Flaps}}} \quad \text{and} \quad \alpha \text{ for } C_{Lmax_{\text{T.O.Flaps}}}$$ (no l.e. devices)

- Estimate the effect of leading edge flaps or slats

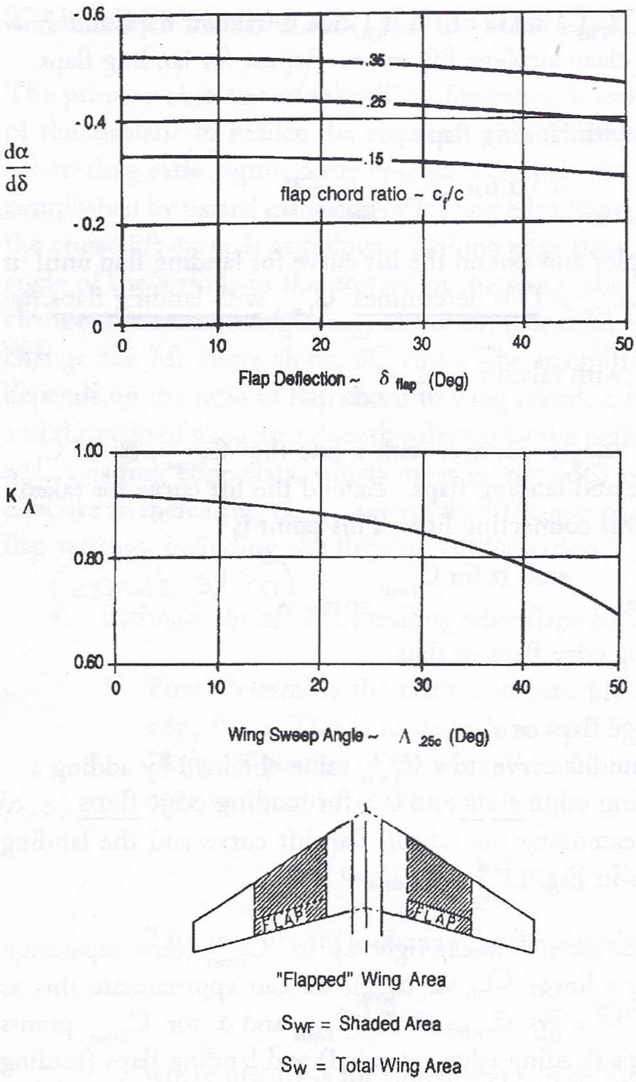
11 1. For full span leading edge flaps or slats,
Extend the clean airplane lift curve, to a C_{Lmax} value obtained by adding a ΔC_{Lmax} of 0.7 for leading edge slats and 0.5 for leading edge flaps (ie. Krueger)
Repeat this process by extending the takeoff flap lift curve and the landing flap lift curve, as shown in Fig. 11-3.

12 2. Since airplane lift curves are not linear right up to C_{Lmax} (flow separation causes a departure from a linear C_{L_A} vs. α_{FRP}), we can approximate this as follows. On the plot of C_{L_A} vs. α_{FRP}, at the C_{Lmax} and α for C_{Lmax} points for the clean takeoff flaps (leading edge extended) and landing flaps (leading edge extended), mark off $\Delta\alpha$ of $+2^\circ$ at the same C_{Lmax}. Then from .9 C_{Lmax}, draw a curve to the $+2^\circ$ point to approximate the "round over" of the lift curves.

3. Note the C_{Lmax} values for all aircraft configurations.

DESIGN EXERCISE

Construct the low speed lift curves for your design project. Plot them on appropriate graph paper so that you may read C_{Lmax} values from them with reasonable accuracy.



Typical Values (from p106)

	c_f/c	δ_f
Single slotted	25%-30%	35°
Double slotted	30%-35%	45-50°
Triple slotted	-40%	55°

Fig. 11-6
Charts for Determining the Effect of Trailing Edge Flaps on Airplane Lift Curves

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