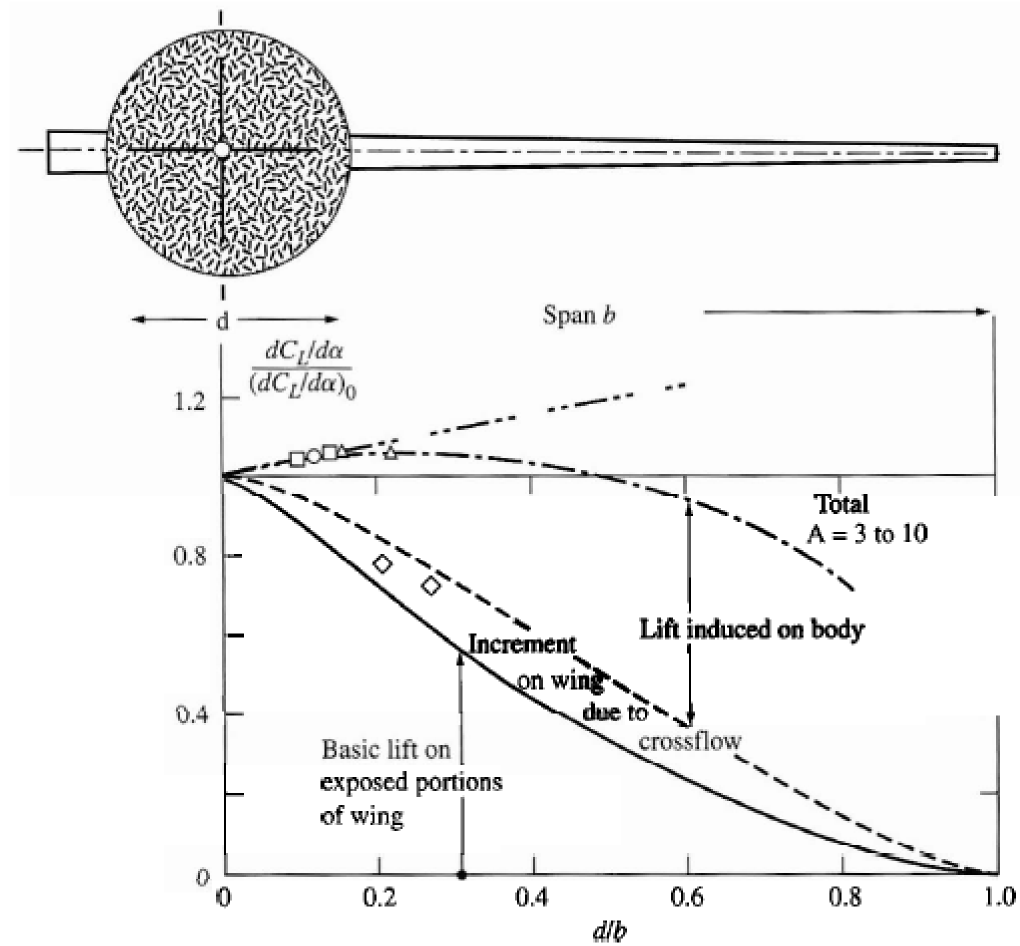
Wing-Body Combinations

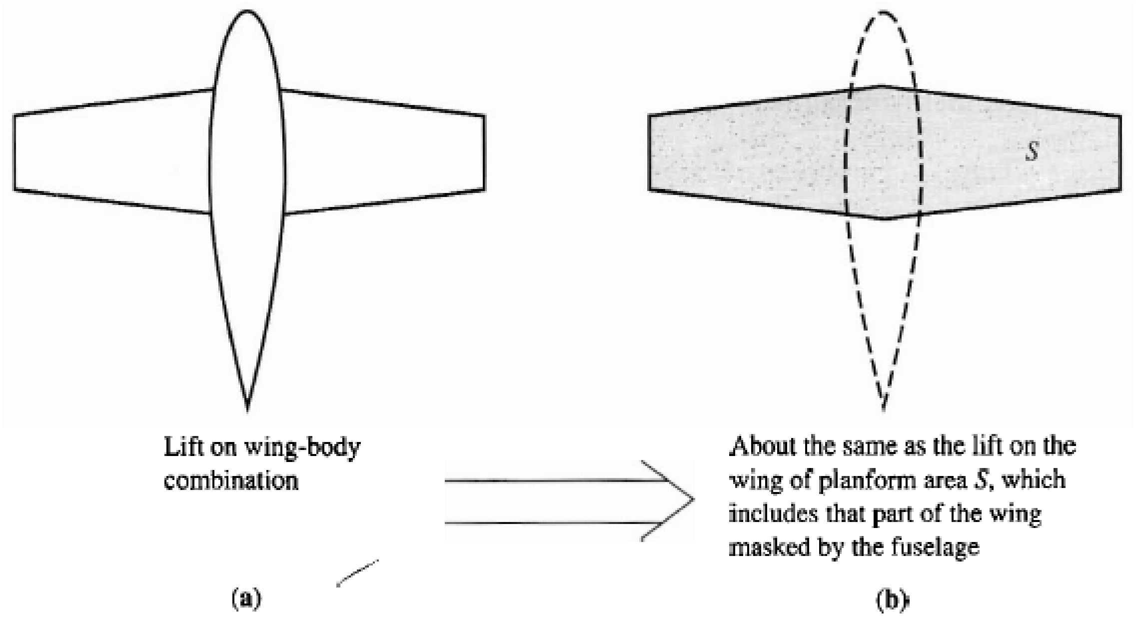
- even a pencil at an angle of attack will generate lift, albeit small.
- Hence, lift is produced by the fuselage of an airplane as well as the wing.
- The mating of a wing with a fuselage is called a *wing-body combination.*
- The lift of a wing-body combination is *not* obtained by simply adding the lift of the wing alone to the lift of the body alone. Rather, as soon as the wing and body are mated, the flow field over the body modifies the flow field over the wing, and vice versa-this is called the *wing-body interaction.*

The lift slope of the wing-body combination, divided by the lift slope of the wing alone is shown as a function of d/b (d is the fuselage diameter). The magnitudes of the three contributions to the lift are identified in Fig. as (1) the basic lift due to exposed portions of the wing, (2) the increase in lift on the wing due to crossflow from the fuselage acting favorably on the pressure distribution on the wing, and (3) the lift on the fuselage.



For a range of d/b from 0 (wing only) to 6 (which would be an inordinately fat fuselage with a short, stubby wing), the *total* lift for the wing-body combination is essentially constant (within about 5%). Hence, the lift of the wing-body combination can be treated as simply the lift on the complete wing by itself, including that portion of the wing that is masked by the fuselage.

For subsonic speeds, this is a reasonable approximation for preliminary airplane performance and design considerations. Hence, in all our future references to the platform area of a wing of an airplane, it will be construed



DRAG

minimizing drag has been one of the strongest drivers in the historical development of applied aerodynamics. In airplane performance and design, drag is perhaps the most important aerodynamic quantity.

There are only two sources of aerodynamic force on a body moving through a fluid: the pressure distribution and the shear stress distribution acting over the body surface. Therefore, there are only two general types of drag:
1) Pressure drag-due to a net imbalance of surface pressure acting in the drag direction
2) Friction drag-due to the net effect of shear stress acting in the drag direction

For a purely laminar flow, $c_f = \frac{1.328}{\sqrt{\text{Re}}}$

One of the used formulas for turbulent flows is $(c_f)^{-1/2} = 4.13 \log(\text{Re}\, c_f)$

The location at which transition actually occurs on the surface is a function of a number of variables; suffice it to say that the transition Reynolds number is

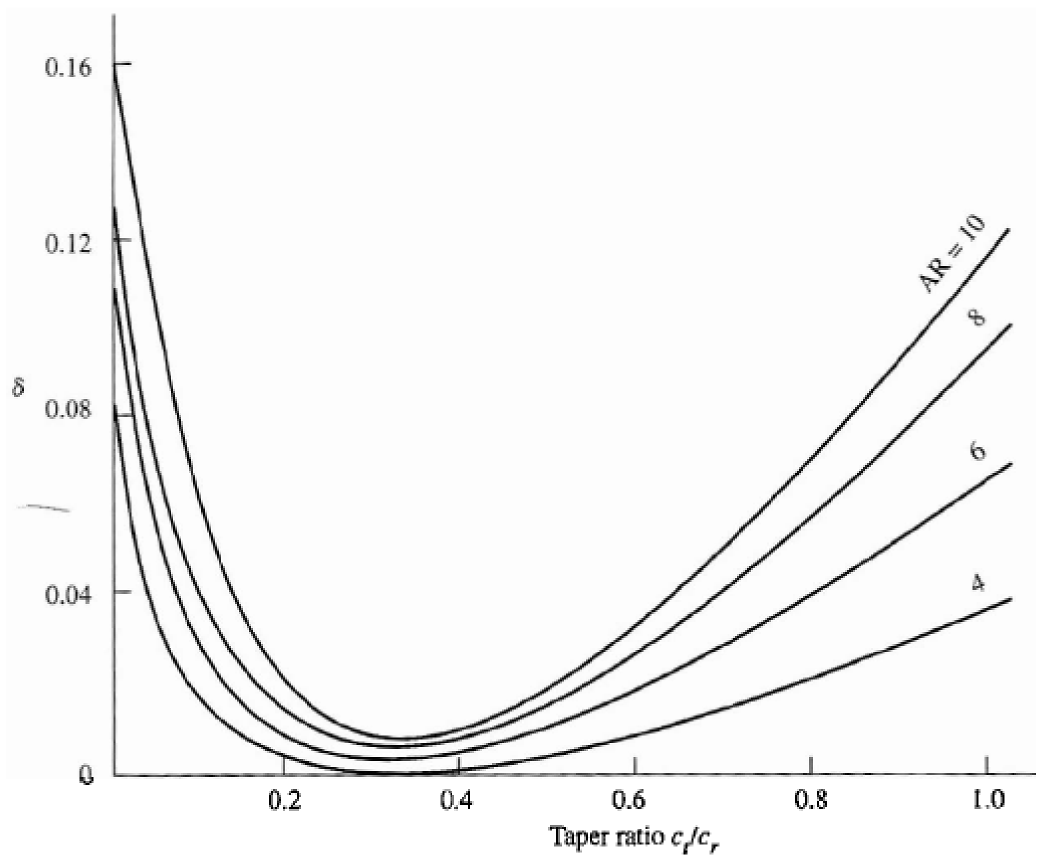
$$\text{Re}_{\text{trans}} = \frac{\rho_\infty V_\infty x_{\text{tr}}}{\mu_\infty} \approx 350{,}000 \text{ to } 1{,}000{,}000$$

No simple formulas exist to estimate the pressure drag.

The induced flow effects due to the wing-tip vortices result in an extra component of drag on a three-dimensional lifting body. This extra drag is called induced drag. Induced drag is purely a pressure drag. It is caused by the wing tip vortices which generate an induced, perturbing flow field over the wing, which in turn perturbs the pressure distribution over the wing surface in such a way that the integrated pressure distribution yields an increase in drag-the induced drag ***Di.*** For a high-aspect-ratio straight wing,

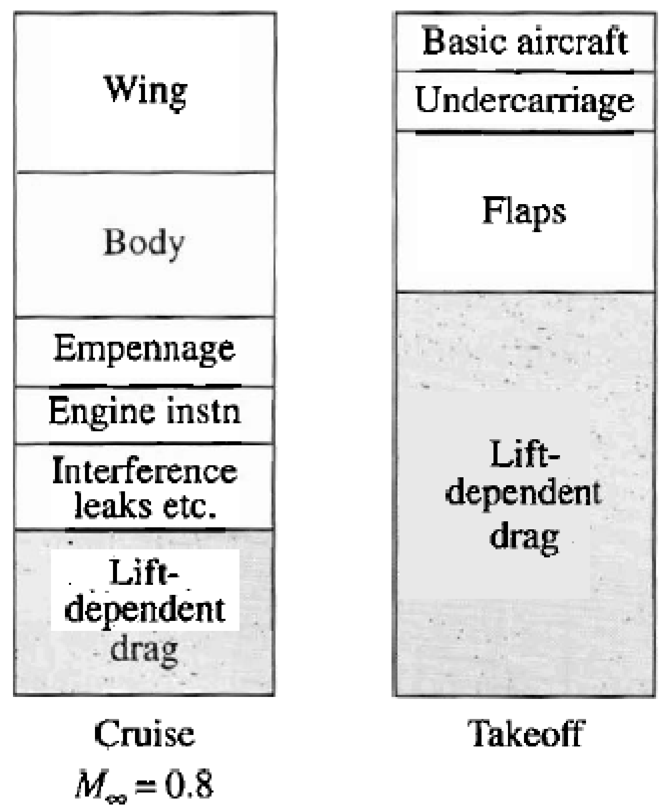
$$\frac{C_L^2}{e\text{AR}}$$

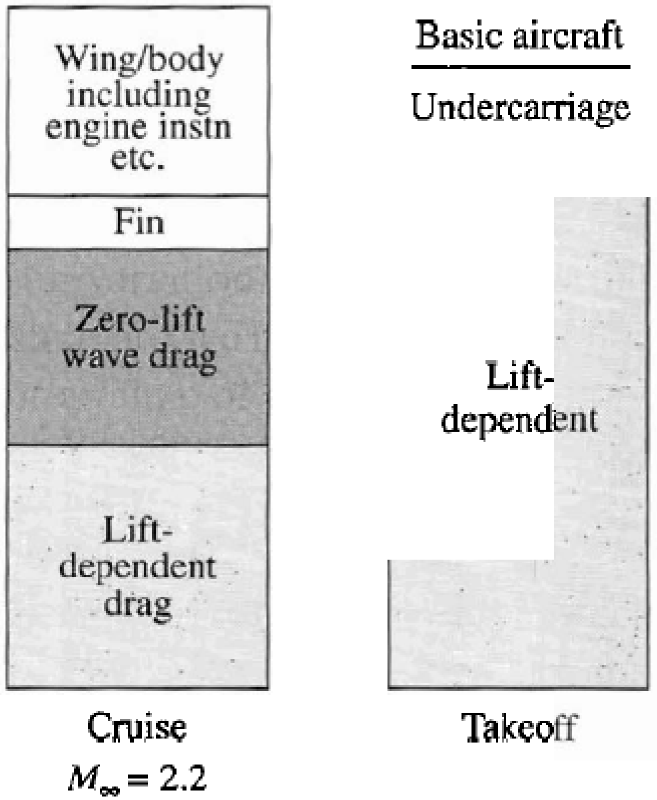
$$e = \frac{1}{1+\delta}$$



THE DRAG BREAKDOWN

For the subsonic transport wing, body, empennage, engine installations, interference, leaks, undercarriage, and flaps are the contributors to the zero-lift parasite drag: (they derive from friction drag and pressure drag due to flow separation).
The element labeled lift-dependent drag (drag due to lift) are due to the increment of parasite drag associated with the change in angle of attack from the zero-lift valve, and the induced drag.
Most of the drag at cruise is parasite drag, whereas most of the drag at takeoff is lift-dependent drag, which in this case is mostly induced drag associated with the high lift coefficient at takeoff.





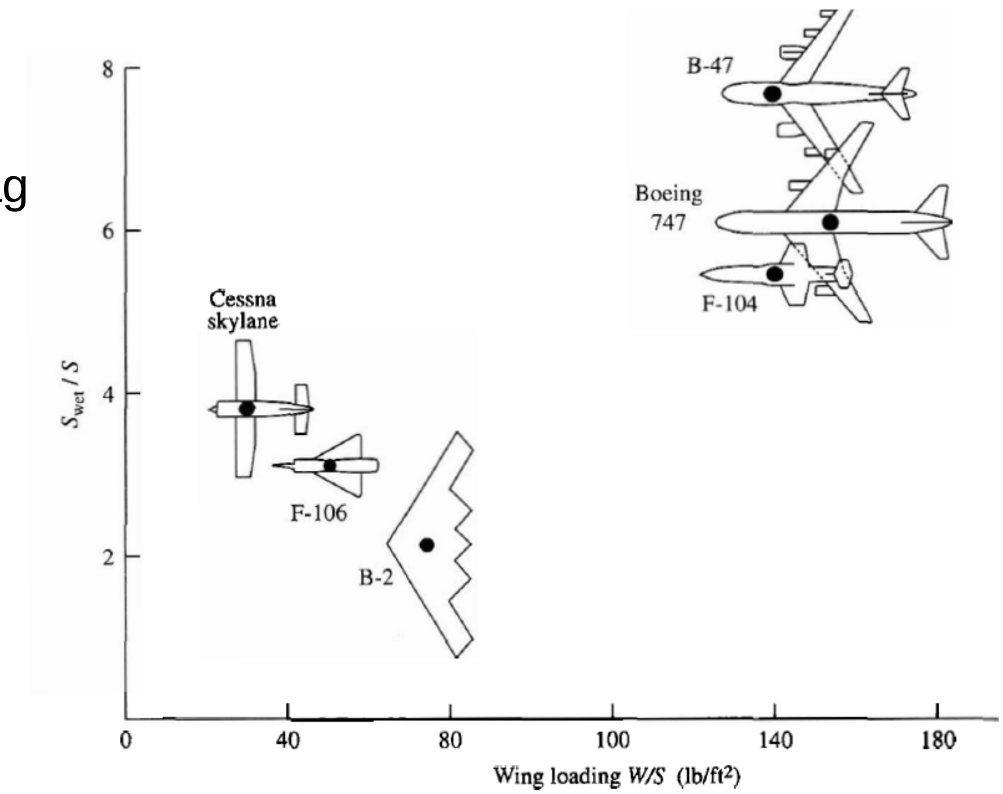
For the supersonic transport more than two-thirds of the cruise drag is wave drag-a combination of zero-lift wave drag and the lift-dependent drag (which is mainly wave drag due to lift). This dominance of wave drag is the major aerodynamic characteristic of supersonic airplanes. At takeoff, the drag of the supersonic transport is much like that of the subsonic transport, except that the supersonic transport experiences more lift-dependent drag. This is because the low-aspect-ratio delta wing increases the induced drag, and the higher angle of attack required for the delta wing at takeoff (because of the lower lift slope) increases the increment in parasite drag due to lift.

For a subsonic cruise drag, of the total parasite drag at cruise, about two-thirds is usually due to skin friction, and the rest is form drag and interference drag. Since friction drag is a function of the total wetted surface area of the airplane, an estimate of the parasite drag of the whole airplane should involve the wetted surface area. The wetted surface area ***Swet*** can be anywhere between 2 and 8 times the reference planform area of the wing ***S.*** At the conceptual design stage of an airplane, the wetted surface area can be estimated based on historical data from previous airplanes.

$$D_0 = q_\infty S_{\text{wet}} C_{\text{fe}}$$

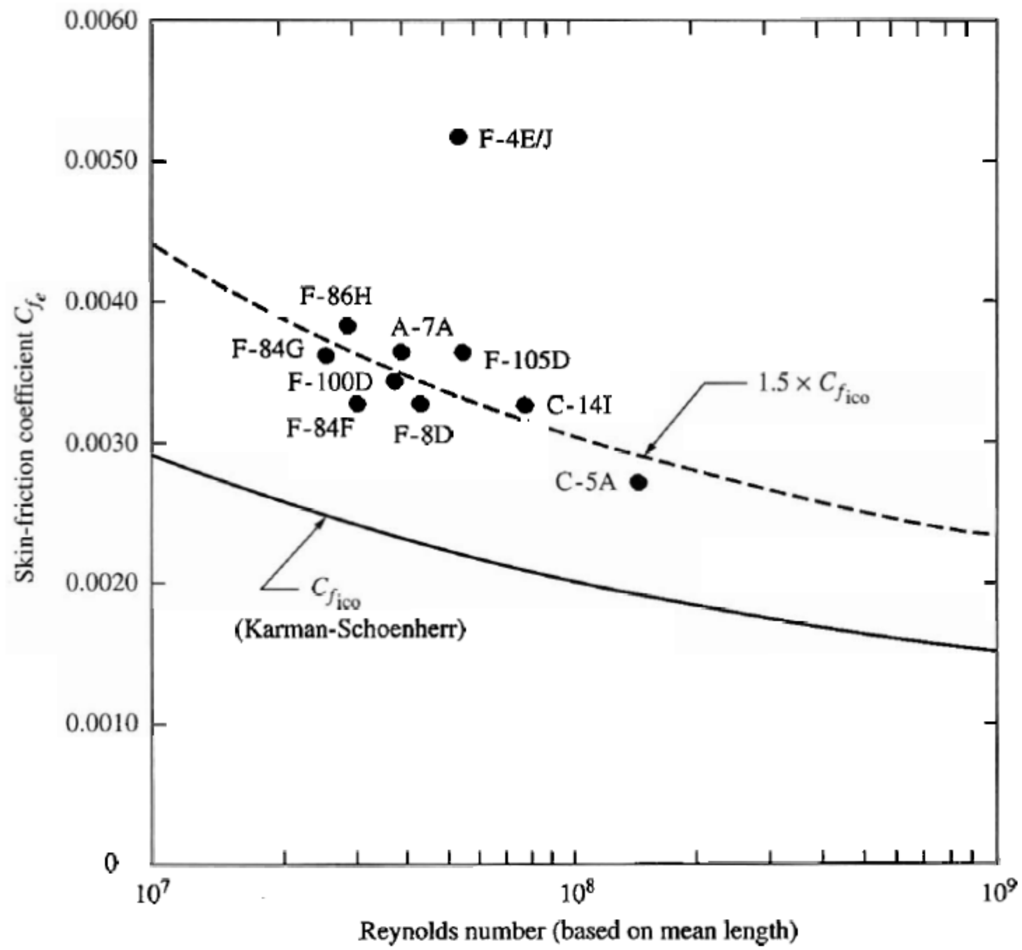
The more conventional zero-lift drag coefficient ***Cd0*** is defined in terms of the planform area ***S***

$$C_{D,0} = \frac{D_0}{q_\infty S}$$



$$C_{D,0} = \frac{q_\infty S_{\text{wet}} C_{\text{fe}}}{q_\infty S} = \frac{S_{\text{wet}}}{S} C_{\text{fe}}$$

Cfe can be estimated
With the plot



The Drag Polar: What is it and How is it Used?

all the aerodynamics of the airplane is contained in the drag polar. For every aerodynamic body, there is a relation between ***CD*** and ***CL*** that can be expressed as an equation or plotted on a graph. Both the equation and the graph are called the *drag* ***polar.*** Virtually all the aerodynamic information about an airplane necessary for performance analysis is wrapped up in the drag polar.

(Total drag) = (parasite drag) + (wave drag) + (induced drag)

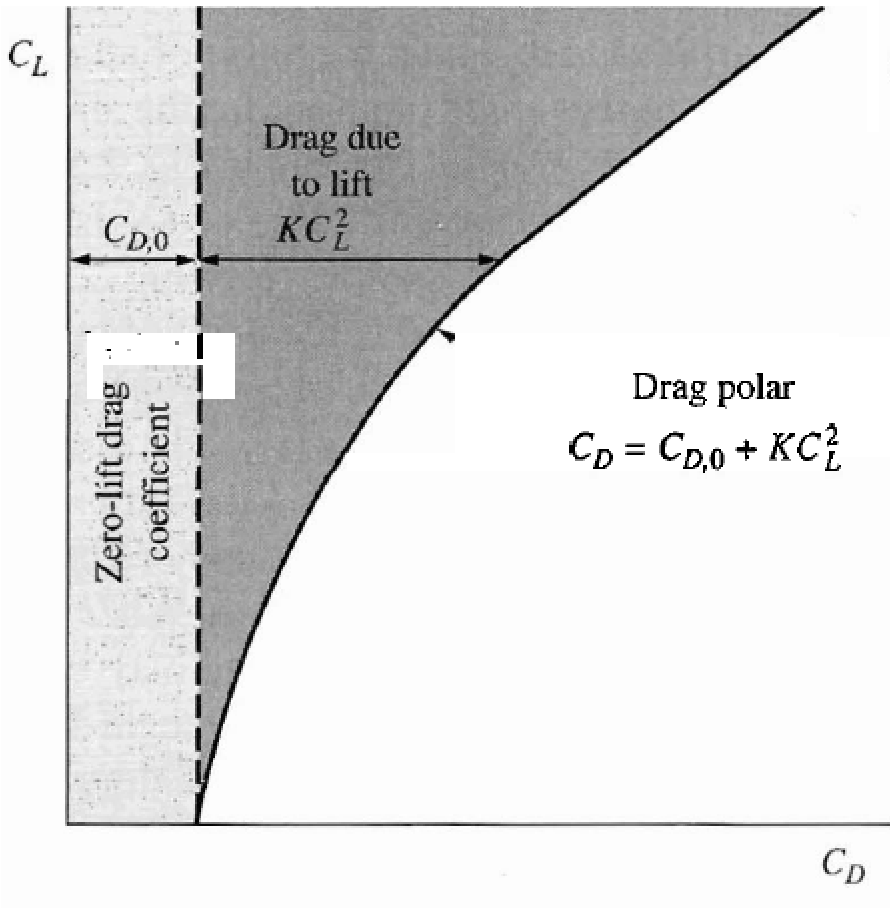
$$C_D = C_{D,e} + C_{D,w} + \frac{C_L^2}{\pi e \mathrm{AR}}$$

Parasite Drag

$$C_{D,e} = C_{D,e,0} + \Delta C_{D,e} = C_{D,e,0} + k_1 C_L^2$$

Wave drag coefficient

$$c_{d,w} = \frac{4\alpha^2}{\sqrt{M_\infty^2 - 1}} = \frac{4}{\sqrt{M_\infty^2 - 1}} \left(\frac{c_l \sqrt{M_\infty^2 - 1}}{4} \right)^2 = \frac{c_l^2 \sqrt{M_\infty^2 - 1}}{4}$$



$$C_D = C_{D,e,0} + C_{D,w,0} + k_1 C_L^2 + k_2 C_L^2 + \frac{C_L^2}{\pi e \mathrm{AR}}$$

$$C_D = C_{D,e,0} + C_{D,w,0} + (k_1 + k_2 + k_3) C_L^2$$

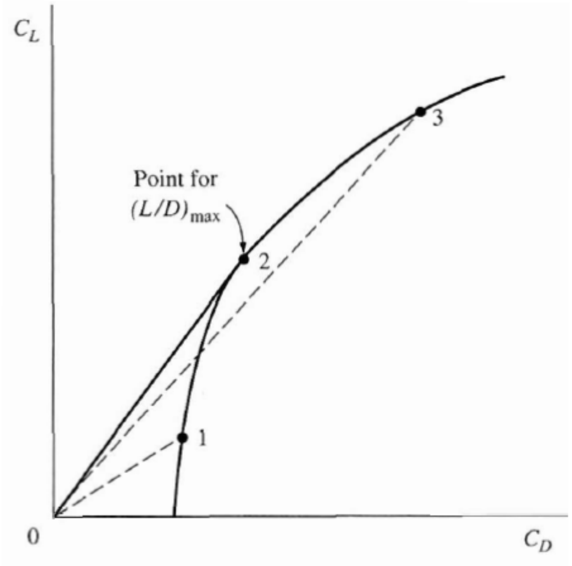
$$C_{D,e,0} + C_{D,w,0} \equiv C_{D,0}$$

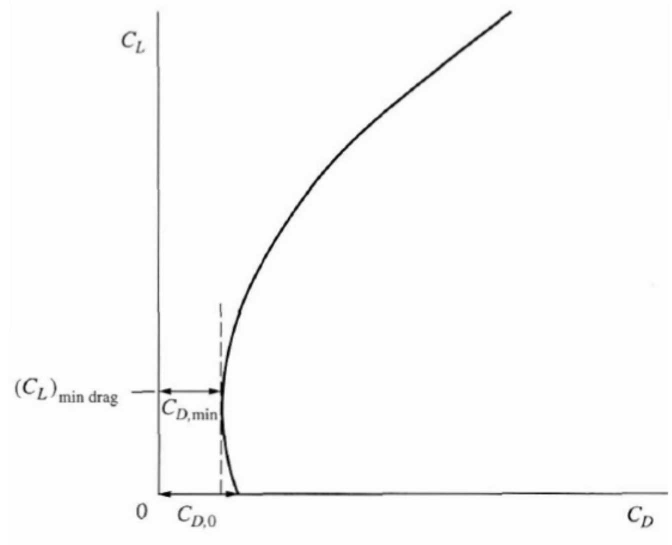
$$k_1 + k_2 + k_3 \equiv K$$

$$\boxed{C_D = C_{D,0} + K C_L^2}$$

drag polar for the airplane.

This equation is valid for both subsonic and supersonic flight. At supersonic speeds, *Cd,0* contains the wave drag at zero lift, along with the friction and form drags, and the effect of wave drag due to lift is contained in the value used for *K.*





Consider a straight line drawn from the origin to point 1 on the drag polar. The length and angle of this line correspond to the resultant force coefficient and its orientation relative to the freestream direction. Also, point 1 on the drag polar corresponds to a certain angle of attack of the airplane. The slope of the line 0-1 is equal to *CL/CD,* lift-to-drag ratio. Moving up on the polar curve the slope of the straight line from the origin will first increase, reach a maximum at point 2, and then decrease such as shown by line 0-3. The line 0-2 is *tangent* to the drag polar. *Conclusion: The tangent line to the drag polar drawn from the origin locates the point of maximum lift-to-drag ratio for the airplane. T*he angle of attack associated with the tangent point ***2*** corresponds to that angle of attack for the airplane when it is flying at *(LID)max.* Sometimes this tangent point is called the *design point* for the airplane, and the corresponding value of *CL* is sometimes called the *design lift coeficient* for the airplane.