17.2 Steady Level Flight

Eq. (17.11) expresses T/W as a function of W/S, q, and the airplane drag characteristics C_{D_o} and K.

$$\frac{T}{W} = \frac{1}{\left(\frac{L}{D}\right)} = q\,\frac{C_{D_o}}{\left(\frac{W}{S}\right)} + \left(\frac{W}{S}\right)\frac{K}{q} \qquad (17.2.1)$$

Knowledge of the relationship between T/W and W/S at different flight conditions is important when selecting these values for aircraft sizing and trade studies (see for example Figure 19.4). Remember that these values of T/W and W/S must be corrected to the reference values, as described in the annotations to Section 5.4, when used in constraint analysis.

In the first term T/W is inversely proportional to W/S, and in the second term T/W is directly proportional to W/S. If we plot this equation with T/W as a function of W/S, then the result will look something like Figure 17.2.1.

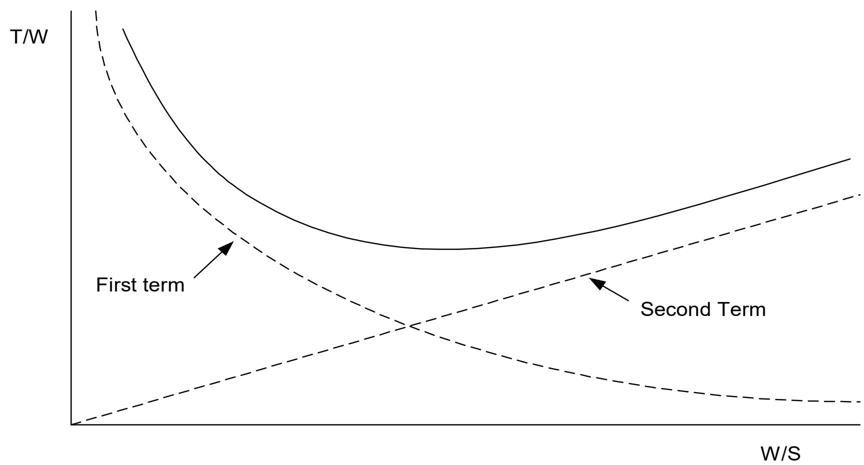

Figure 17.2.1 Cruise Thrust/Weight Ratio as a Function of Wing Loading

Notice that there is a value of W/S for which T/W is a minimum at the cruise condition. Unfortunately other design constraints, such as those for takeoff and landing, often force the wing to be larger than the optimum (or the wing loading to be lower than the optimum) for the cruise condition.

Another way of looking at Eq. (17.11) is to plot T/W as a function of q as shown in Figure 17.2.2. In this case the first term is proportional to q and the second term is inversely proportional to q. The sum of the two terms also has a minimum value of T/W, indicating that a value of q exists (and by extension a value of cruise speed V) for which T/W is a minimum. This speed is quantified in Eq. (17.13) as:

$$V_{min\ thrust\ or\ drag} = \sqrt{\left(2\,\frac{W}{\rho S}\sqrt{\frac{K}{C_{D_o}}}\right)} \qquad (17.2.2)$$

If we substitute this value of $V_{min\ thrust\ or\ drag}$ into the definition of C_L, i.e.

$$C_L = \frac{W}{\frac{1}{2}\rho V^2 S}$$
(17.2.3)

then we find that

$$C_{L_{min\ thrust\ or\ drag}} = \sqrt{\frac{C_{D_0}}{K}} \qquad (17.2.4)$$

By the definition of drag due to lift factor K, we can deduce that at this particular condition:

$$C_{D_i} = K\,C_L^2 = K\,\frac{C_{D_0}}{K} = C_{D_0} \qquad (17.2.5)$$

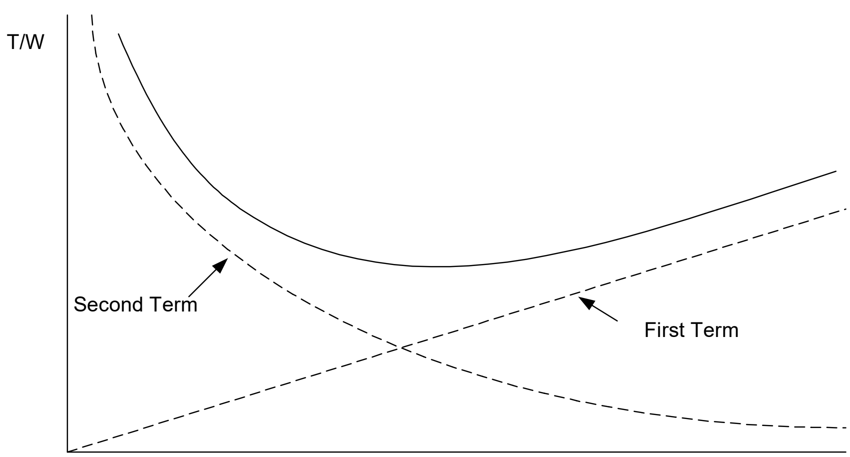

Figure 17.2.2 Cruise Thrust/Weight Ratio as a Function of Dynamic Pressure

I.e. zero-lift drag is equal to drag due to lift at the speed for minimum thrust or drag. As stated by Raymer later in this section, this speed is also the speed for maximum endurance for a jet and also maximum angle of climb for a jet.

It is also useful to know the value of L/D at this condition, and this can be derived from Eq. (17.14).

$$\left(\frac{L}{D}\right)_{max} = \left(\frac{C_L}{C_D}\right)_{max} = \frac{1}{C_D}\sqrt{\frac{C_{D_0}}{K}} = \frac{1}{2\,C_{D_0}}\sqrt{\frac{C_{D_0}}{K}} = \frac{1}{2\sqrt{C_{D_0}K}} \tag{17.2.6}$$

Note we have assumed that the relationship between drag due to lift and lift coefficient is parabolic and symmetrical about the C_D axis. This implies that the airfoil is uncambered, so Eq. (17.2.6) also only applies to uncambered wings. The error is small for wings with small camber, and the equation is valid for conceptual design analysis. This issue was discussed in Raymer Section 12.3 and its associated annotation.