5.4 Selection of Thrust to Weight and Wing Loading

Chapter 5 contains enough information to make a pretty good first estimate of the required values of *T/W* and *W/S*. Construction of a sizing matrix plot is described in more detail in Chapter 19 (see for example Figures 19.3 and 19.4), and much of the rest of Raymer's book is a refinement of the material in this chapter and in Chapter 6.

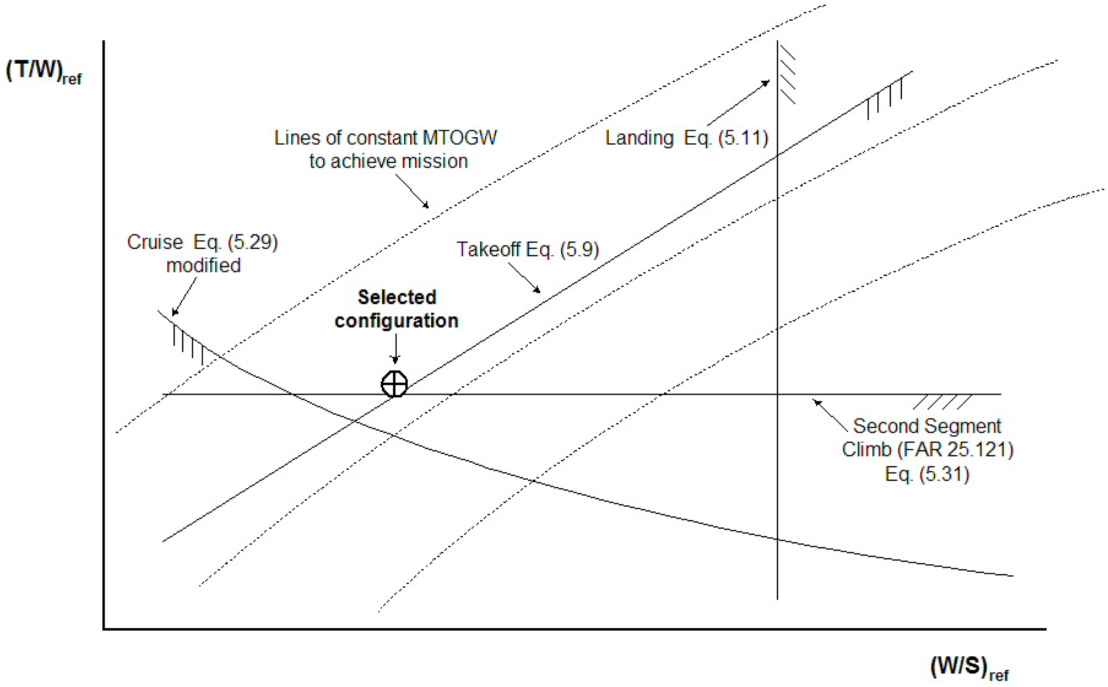

Figure 5.4.1 Sizing Matrix Plot for Commercial Aircraft

The sizing matrix plot is the single most important tool for the manual optimization and sensitivity analysis of a configuration, and it is widely used in the aerospace industry. It is also useful for students in understanding the effect of the various performance constraints on the design of an aircraft.

Figure 5.4.1 shows a sizing matrix plot for a commercial aircraft. The axes are reference values of Thrust/Weight (*T/W*) and Wing Loading (*W/S*). What constitutes "reference" may vary slightly from company to company and even within a company for certain projects, but the usual reference values are:

- Thrust (T) – Standard day, sea level, static (i.e., the airplane is stationary) installed thrust at maximum takeoff rating with all engines operating
- Weight (W) – Maximum design takeoff gross weight at brake release
- Wing Area (S) – Reference trapezoidal wing area.

The solid lines in the figure represent performance constraints. These may be either requirements that are set by the specification, in which case they may not be absolutely hard and fast, or set by FARs, or other fixed requirements.

The dashed lines represent contours of equal takeoff gross weight required to perform the specified mission. These contours are generated completely independently of the constraint lines, and their method of generation is described in Raymer Section 19.4.

Many performance constraints are for flight conditions for which the engine thrust and airplane weight are very different from the reference values, so the values of T/W and W/S must be factored by the ratio of the thrust or weight at that flight condition to the reference thrust or weight.

To meet takeoff requirements, you can either select small engines and a big wing (bottom left quadrant of the graph) so that the airplane accelerates slowly and lifts off at a very low speed, or big engines and small wing (top right quadrant of the graph) so that the airplane accelerates fast and lifts off at a high speed, so the takeoff field length line goes from bottom left to top right.

Landing field length is a function only of approach speed, and thus only of wing loading (thrust reversers are not included in landing field length calculations, even though they may be used in practice). The landing field length line is therefore vertical

Cruise and climb constraints are U-shaped curves that have a minimum value of *T/W* at a value of *W/S* that is normally outside the area of interest on the figure. The annotation for Section 5.3 describes a modification of Eq. (5.29) that will enable you to plot constraint lines for cruise (as shown here) or climb at a specified dynamic pressure, *q*. The FAR climb constraints are a special case in which the climb speed varies with wing loading, resulting in a constraint that is a function of T/W only; these are described in the annotations to Section 17.3.

The equations in Fig 5.4.1 must be rearranged to the form T/W = f (W/S) so that they can be plotted using Excel or Matlab.

Raymer defines the wing loading for maximum range in Eq. 5.14. This is not a constraint because other wing loadings will also work, but at a higher takeoff gross weight to meet a given range. For most subsonic commercial aircraft this wing loading is higher than that imposed by other constraints, such as the takeoff or landing constraint.

In many cases the contours of constant TOGW to perform the mission are roughly parallel to the takeoff field length constraint. In this case there is some flexibility as to whether to choose smaller engines and bigger wing, or bigger engines and smaller wing. It’s always better to choose a smaller engines and bigger wing, if such a choice is available, and the selected configuration is identified in Fig. 5.4.1. If the engine manufacturer offers an engine with a higher rated thrust at some time in the future, then the designer can increase the takeoff gross weight of the airplane and still meet all the performance constraints. If the wing is sized for the landing constraint, then the designer is stuck, and the only way to increase the takeoff gross weight is to either increase the wing area or redesign the high-lift system.

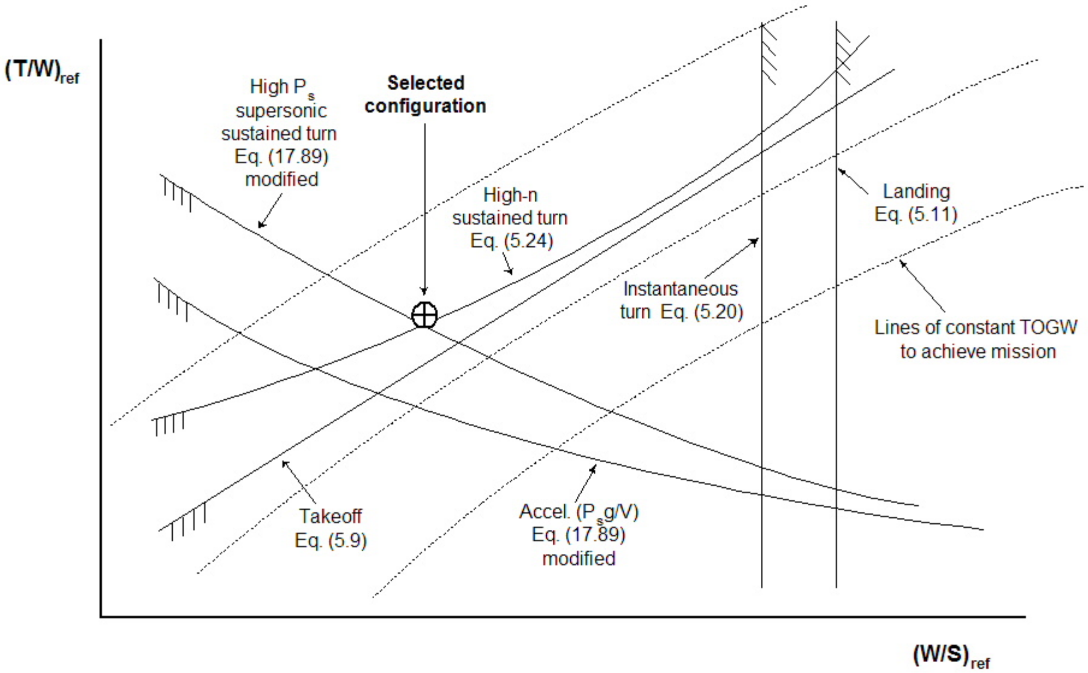

Figure 5.4.2 Sizing Matrix Plot for Combat Aircraft

For a combat aircraft there are usually many performance requirements associated with aerial maneuvering, as illustrated in Figure 5.4.2. Some of these requirements, such as for a defined specific excess power (P_s) at certain maneuver conditions, are not addressed until Raymer Chapter 17, so it is more difficult to estimate the required values of *T/W* and *W/S* at this point in the design process. Nearly all the aerial maneuver requirements are defined by one equation, as described in the annotation to Section 17.6.

Note that constraints involving P_s, which imply climb or acceleration capability, usually have a minimum *T/W* at a high value of *W/S*, whereas a high-*n* turn has a minimum *T/W* at a low value of *W/S*. A large wing is not required for climb or acceleration, but a large wing is required for high-*n* turn. A more detailed explanation of these requirements is given in the annotation to Section 17.6.