Schaufele Annotations
Chapter 17 FAR Climb Gradient Requirements

FAR Climb Profile

The FAR climb profile is shown in Figure 17.1. The required climb gradients are shown in Schaufele page 297. Note that the conditions require that the critical engine be inoperative. The table shows that the second segment climb requirements are the most stringent, and these often define the required T/W for the airplane.

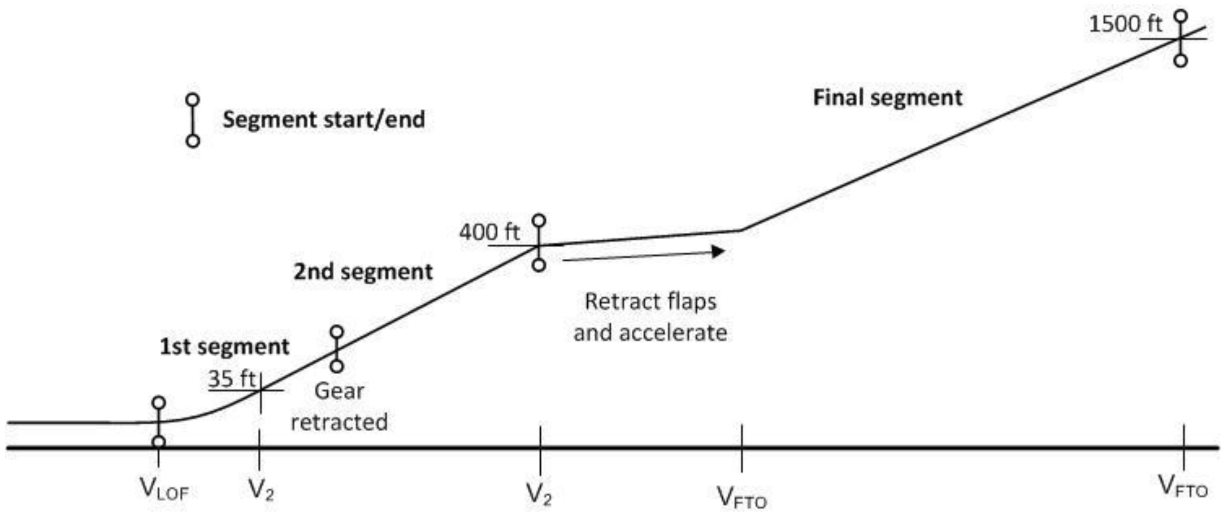

Figure 17.1 FAR Climb Profile

Second Segment Climb

The design exercise in this chapter requires that the second segment limit weight (SSLW) be calculated for your design configuration. This implies that a chart similar to that of Schaufele Fig 17-1 be generated (with different values of flap setting rather than altitude). The steps are as follows

1. For a given flap setting, find the value of $C_{L_{max}}$ for the takeoff condition from the chart of C_L versus α that was generated in the Chapter 11 exercise.
2. The speed in the second segment, V_2 is defined as $V_2 = 1.2\ V_{S_{to}}$, so that the lift coefficient in the second segment is $C_{L_{to}} = (C_{L_{max}})_{to}/1.44$.
3. From the plot of L/D versus C_L that was generated in Chapter 12, find the value of L/D for this value of $C_{L_{to}}$ for the appropriate flap setting and with gear retracted. (Normally the value of L/D should be recalculated to account for the additional drag due to a windmilling engine and trim drag resulting from rudder deflection required to counteract the yawing moment due to

asymmetric thrust. According to Jenkinson (Ref 17.1), this is typically about 5% of parasite drag. However, in this exercise, this extra drag will be ignored).

4. The climb gradient is defined in Schaufele Figure 17-1 as

$$\gamma = \frac{T - D}{W}$$

Assuming the climb angle is small, this can be rewritten

$$\gamma = \frac{T}{W} - \frac{1}{\left(\frac{L}{D}\right)} \qquad \text{Eq. 17.1}$$

5. The climb condition is for one engine inoperative (OEI), so that the thrust is

6. $$T = T_{AEO}\frac{N - 1}{N} \qquad \text{Eq 17.2}$$

   where

   T_{AEO} = thrust at climb speed with all engines operating. The value of T_{AEO} is calculated from a knowledge of the reference thrust (i.e., static, installed) for your airplane which was calculated in Chapter 8, and Figure 8.1 in the annotations, assuming V_2 is at MTOGW.

   N = number of engines

7. A plot similar to that of Schaufele Fig. 17-1 (for different values of flap setting rather than altitude) can now be generated using the equation for γ (shown above) for the sea level condition. The cutoff value is given in the table on page 297.
8. The values of second segment weight limit can now be used to generate a sketch (but not a quantitative plot of FAR takeoff field length) similar to Schaufele Fig. 17-4.

The procedure described above is an approximation, because the value of V_2 in step 6 is a function of TOGW, and the climb thrust is a function of V_2, so that an exact solution requires an iterative procedure.

Second Segment Climb as a Design Constraint

If takeoff reference thrust is substituted for climb thrust in the equation above, it can be rearranged to the form

$$\left(\frac{T}{W}\right)_{ref} = \gamma + \frac{1}{\left(\frac{L}{D}\right)} \qquad \text{Eq. 17.3}$$

Note that the reference T/W is independent of wing loading. On a plot of T/W versus W/S, this design constraint line therefore acts as a "floor" in the design space. Because the airplane is climbing at a low airspeed, drag due to lift is a large component of total drag. An option for lowering the floor is to increase aspect ratio, which produces a significant increase in climb L/D and a consequent reduction in reference T/W. In the overall design optimization process, it is quite possible that the airplane aspect ratio is selected based on the second segment climb requirement, rather than the cruise condition.

References

17.1 Jenkinson, L.R., Simpkin, P., Rhodes, D., "Civil Jet Aircraft Design", AIAA, 1999.