16.3.2 Pitch Static Stability

For a configuration to be stable at a positive angle of attack, there are two requirements:

- The derivative of pitching moment ($C_{m_{cg}}$) with respect to lift coefficient (C_L) [Raymer Eq. (16.11)] must be negative.
- When $C_L = 0$, the airplane must exhibit a nose-up pitching moment ($C_{m0} > 0$).

The first requirement is described in Raymer Section 16.3.2. The second requirement is not defined in Raymer, but it is equally important.

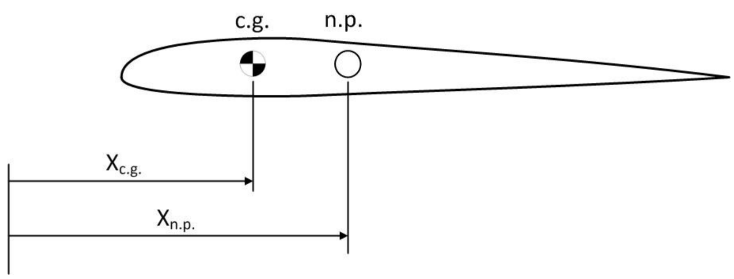

Fig. 16.3.2.1 Location of Center of Gravity and Neutral Point on MAC

Raymer Eq. (16.11) is the most important equation in this section. In a slightly different form, it can be expressed as:

$$\overline{X}_{cg} - \overline{X}_{np} = \frac{dC_m}{dC_L} \quad (6.3.2.1)$$

Remember that X values are non-dimensionalized so that

$$\overline{X}_{cg} - \overline{X}_{np} = \frac{X_{cg} - X_{np}}{MAC} \quad (6.3.2.2)$$

Fig. 16.3.2.1 shows the definition of the location of the center of gravity and neutral point.

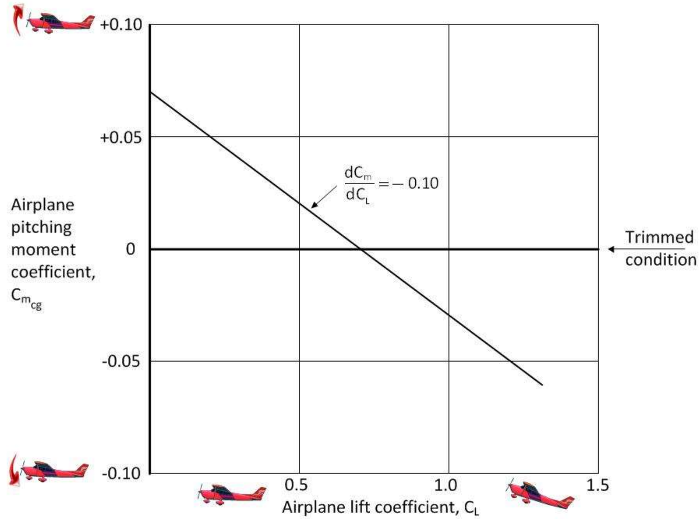

Figure 16.3.2.2 Stable Configuration Trimmed at Positive C_L

Figure 16.3.2.2 illustrates a stable configuration that is trimmed at a positive lift coefficient. The c.g. is located at 10% of the MAC forward of the n.p.

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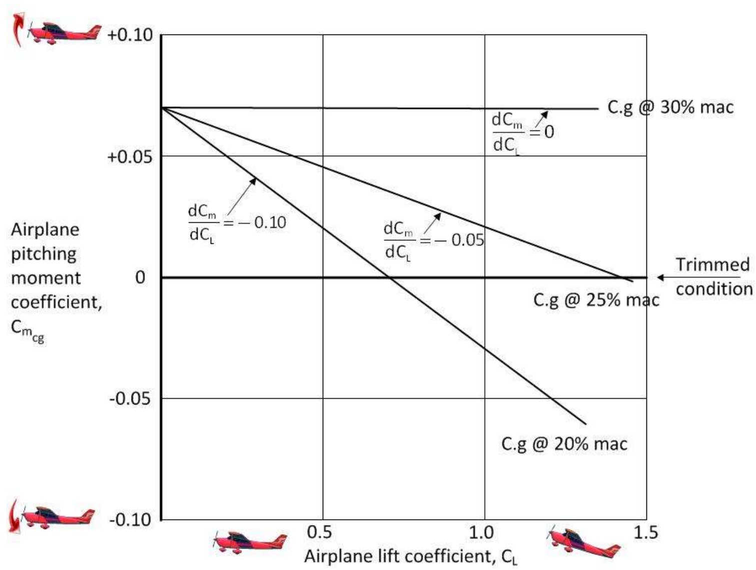

Fig. 16.3.2.3 Effect of Change in C.g. Location on Longitudinal Stability

The position of the neutral point (X_{np}) is fixed for a given configuration, but the center of gravity moves with aircraft loading and fuel consumption. If the c.g. moves aft, the aircraft becomes progressively less stable, as shown in Fig. 16.3.2.3. If $C_{m_{cg}}$ is not decreased (i.e. elevator angle is not increased), the aircraft will trim at progressively higher C_L.

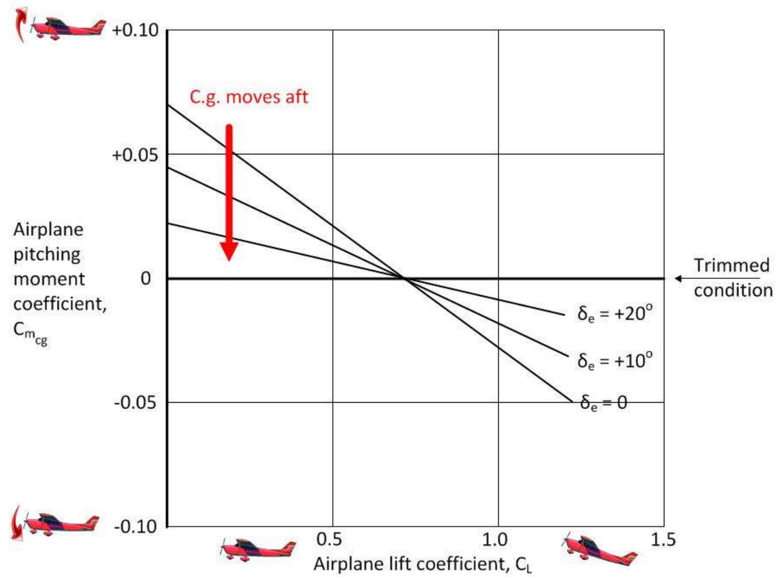

Fig. 16.3.2.4 Change of Pitching Moment with Elevator Deflection

In order to trim the aircraft at the same C_L, the nose-up pitching moment must be progressively reduced by increasing (trailing edge down) the elevator angle, as shown in Fig. 16.3.2.4. Compare this figure with Raymer Fig. 16.18, where the elevator angle is changed with a fixed c.g. location (i.e. constant gradient to the dC_m/dC_L line), resulting in trimming at different values of C_L.

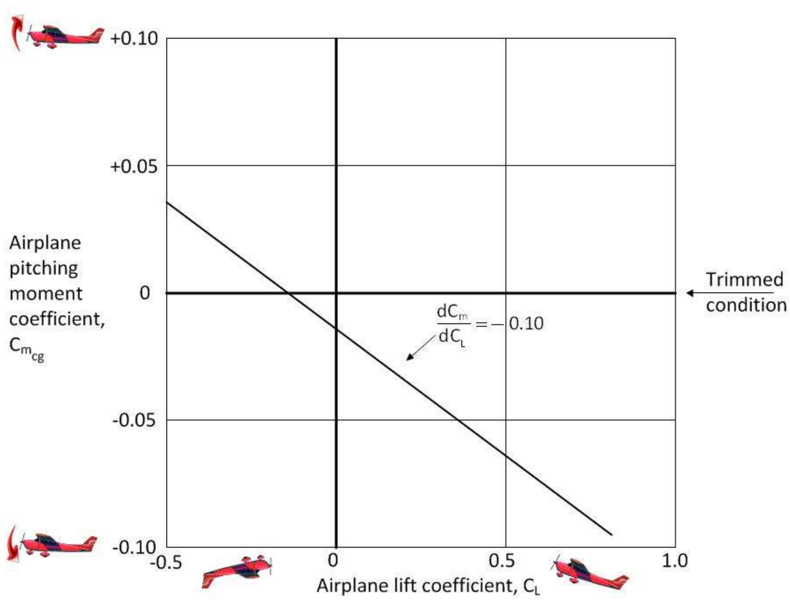

Fig. 16.3.2.5 Stable Configuration Trimmed at Negative C_L

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Fig. 16.3.2.5 shows a configuration that is also stable, but trims at a negative lift coefficient. A configuration that is only stable when flying inverted would not be very comfortable for the passengers and crew. This indicates that $C_{m_{cg}}$ (the pitching moment about the center of gravity) must be positive when C_L is zero. This is the second criterion stated at the beginning of this section. In order to achieve this, the horizontal stabilizer (if a conventional aft stabilizer is used) must provide a nose-up pitching moment (i.e. a download) at the condition at which $C_L = 0$, unless the wing or fuselage provides the necessary pitching moment, but that is not usually the case. This does not imply that the horizontal stabilizer must provide a download at the cruise condition, although it quite often turns out to be the case for a stable airplane. If the airplane has a canard it must provide an upload at the condition at which $C_L = 0$. These conditions can be met if the aft aerodynamic surface is at a lower angle of incidence on the airplane than the forward aerodynamic surface. This arrangement is known as décalage, or longitudinal dihedral.

The requirement is the same for a tailless aircraft. Nose-up pitching moment can be achieved for a swept wing by applying a significant amount of washout (or nose-down twist) to the outer wing section. For an unswept trailing edge (for an unswept or delta wing), the trailing edge must be reflexed, which means that the camber line must be curved upwards at the trailing edge. For an unswept wing this results in an inefficient wing section, so this is done very rarely. For a delta wing, with a larger MAC, the reflex does not have to be very great for adequate stability, and stable delta wings can be achieved quite easily.

For the balsawood glider described in the Annotation to Section 4.5.2 Tail Arrangements, the wing had thin cambered sections. The horizontal stabilizer was uncambered and had adequate décalage for longitudinal stability. The décalage was the same whether the aircraft was flown as a conventional configuration or as a canard.

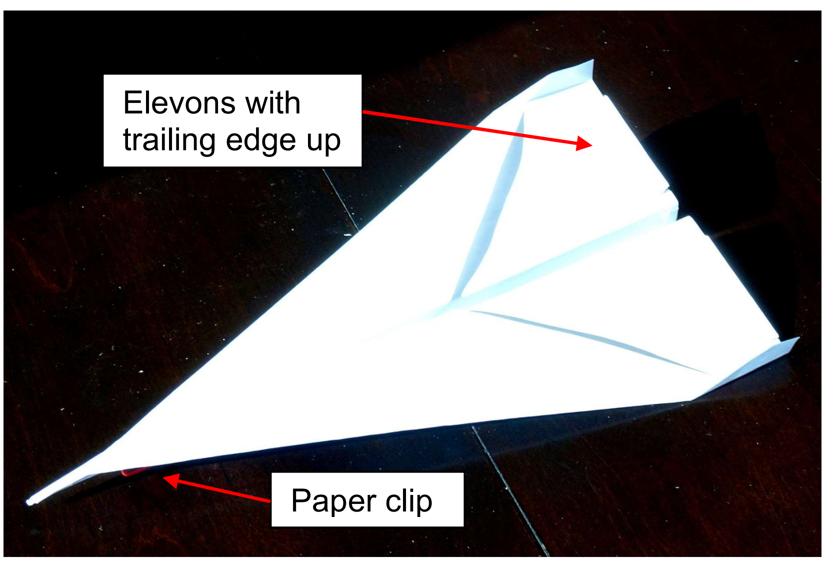

Fig. 16.2.3.6 Paper glider demonstrator

The two requirements for longitudinal stability can be demonstrated in the classroom using a paper glider as shown in Fig 16.2.3.6. The wing is uncambered, and the requirement for positive pitching moment at zero lift (C_{m_0}) can be met using elevons set with trailing edge up, as shown in the figure. Although the positive static margin cannot be demonstrated quantitatively, the effect of changes in the static margin using a paper clip (just visible in red in the figure near the nose) can be demonstrated. Moving the paper clip aft decreases the static margin, and thus the gradient of the dC_m/dC_L line, which now intersects the $C_m = 0$ axis at a higher value of C_L, so that the glider stabilizes at a lower speed. To return to the prior value of C_L, the negative angle of the elevons must be reduced to reduce C_{m_0}, as illustrated in Fig. 16.3.2.4. Note that elevator or elevon angles are positive for trailing edge down, so that increasing positive elevator angle has the same effect on C_{m_0} as decreasing negative elevon angle.

Often pitching moments for airfoils are shown referenced to the section quarter-chord, as shown in Raymer Appendix D. This is in part because the airfoil aerodynamic center (especially for uncambered airfoils) lies very close to the quarter-chord. For aircraft, the quarter-chord of the MAC is often used (as in Schaufele Figure 6.3). These data show the characteristics of the airplane as if the c.g. were at the wing quarter-chord. For many aircraft this is close to the reference c.g. location for performance calculations.

To illustrate the mechanics of the effect of décalage, imagine a tandem-wing airplane with forward wing and aft wing of equal area. Each wing has airfoils with symmetric sections. The effect of downwash of the foreplane on the aftplane (as described in Raymer Sections 4.5.2 and 16.3.6) will be ignored, even though it is significant. These assumptions simplify the illustration, but do not negate it.

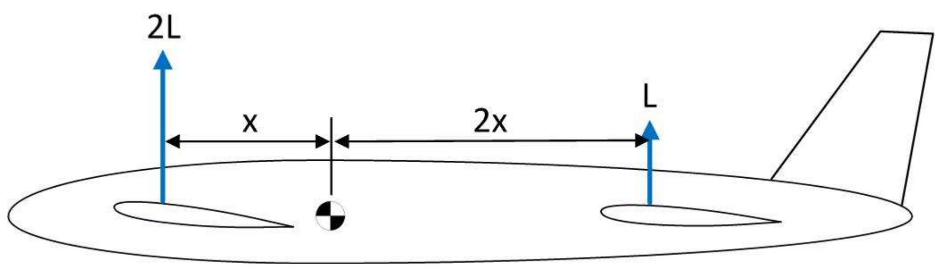

Fig. 16.2.3.7 Tandem Wing in Stable Configuration

As Raymer states in Section 4.5.2, for a stable configuration the forward wing must carry more load than the aft wing, and in the example shown in Fig. 16.2.3.7 it carries twice the load.

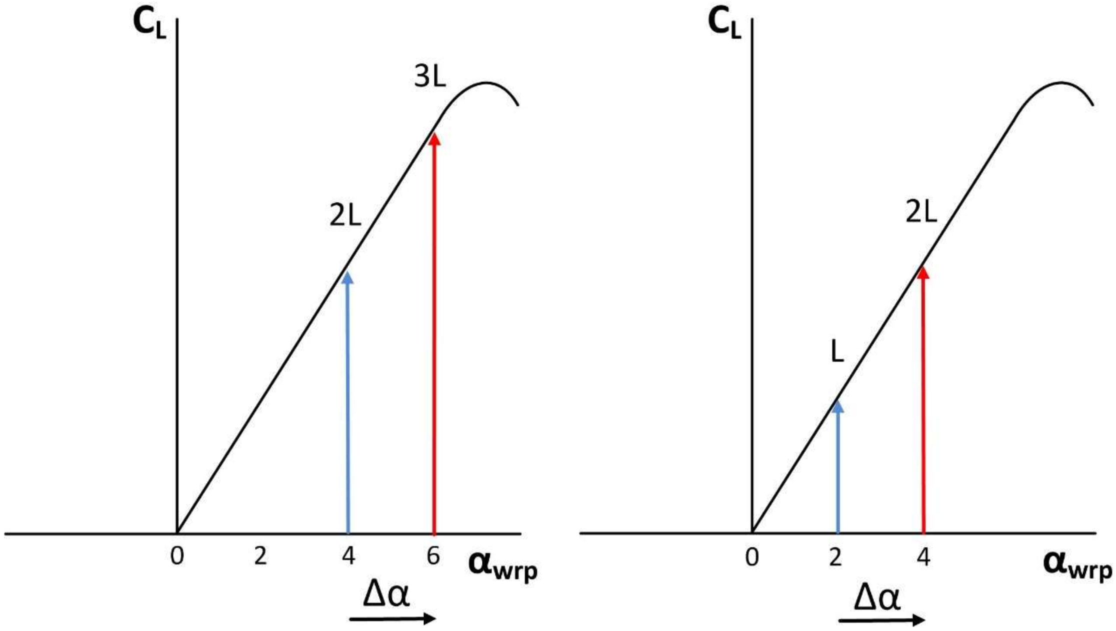

Fig.16.2.3.8 C_L vs. α plots for forward wing and aft wing

If the airplane angle of attack increases by an amount Δα then the lift on the forward wing will increase by 50% from 2L to 3L, but the lift on the aft wing will increase by 100% from L to 2L, as shown in Fig. 16.2.3.8.

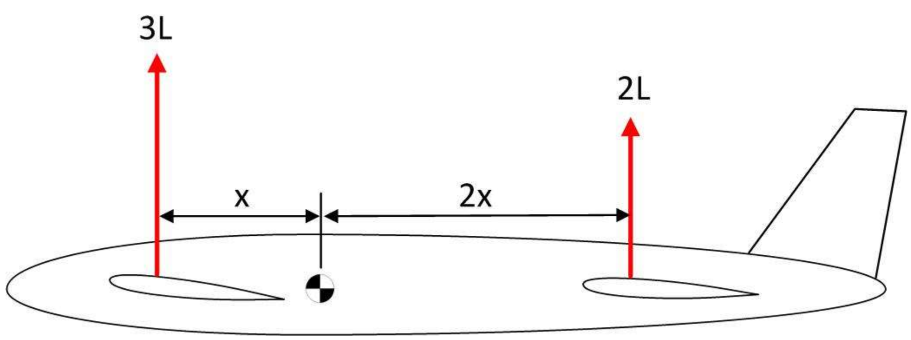

Fig. 16.2.3.9 Tandem Wing with Angle of Attack increased by Δα

As illustrated in Fig. 16.2.3.9, the increase in angle of attack of Δα produces a nose-down pitching moment, as required for a stable airplane. Although described here for a tandem wing, the same principle applies for any wing configuration, whether conventional or canard.

On the ADAC website, under Support > Sample Spreadsheets, a spreadsheet "Cm vs alpha" is provided for testing different wing and tail configurations.