Stall Speed

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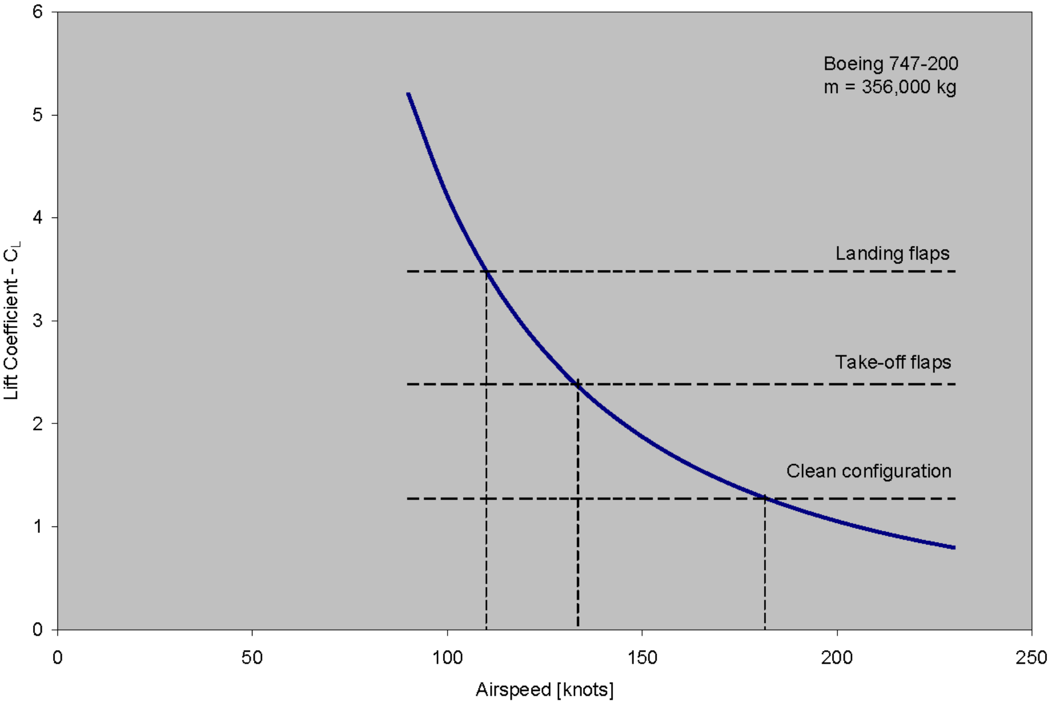

Figure 1. Lift coefficient versus airspeed, and stall speeds for B747-200 ($n = 1$).

Remember the relationship between airplane lift, lift coefficient, and airspeed

$$L = C_L \frac{\rho}{2} V^2 S \tag{1}$$

In general, lift is proportional with the airplane weight

$$L = nW = C_L \frac{\rho}{2} V^2 S \tag{2}$$

where n is the load factor. Therefore the lift coefficient becomes

$$C_L = \frac{2nW}{\rho V^2 S} \tag{3}$$

Eq. (3) implies that the lift coefficient is inversely proportional with square of airspeed for a given aircraft weight, thus higher lift coefficients are required at low speeds, and lower lift coefficients are required at higher speeds. Fig. 1 shows this relation for Boeing 747-200 aircraft at 356,000 kg maximum take-off mass. Note that a lift coefficient of 4.0 is required if the aircraft speed is reduced around 100 knots. However, this is impossible, because lift coefficient is a limited quantity.

As it was previously mentioned, the lift coefficient is a function of the angle of attack. The lift coefficient increases linearly until a certain angle of attack, then variation becomes non-linear and the lift coefficient reaches to a maximum, and decreases if the angle of attack is increased furthermore. This situation is shown in Fig. 2. The phenomenon causing a decrease in the lift coefficient after reaching to a maximum is called stall. The angle of attack where the lift coefficient reaches to a maximum is called the stall angle of attack. Fig. 2 also shows the airspeeds corresponding to the various lift coefficients for a Boeing 747 size aircraft. Figure implies that slightly below 183 KCAS, the aircraft will require flying with maximum lift coefficient, thus it will stall. The airspeed where the aircraft reaches to the maximum lift coefficient is called the stall speed, because stalling of the wing starts at this point. Since flying below the stall speed will cause a significant lift reduction, stall speed is the minimum flight speed of an aircraft. The maximum lift coefficients of current wing designs are limited around 1.5, so that there is always a minimum flight speed for all aircraft. In summary, the stall speed

$$V_S = \sqrt{\frac{2nW}{\rho C_{L_{\max}} S}} \qquad (4)$$

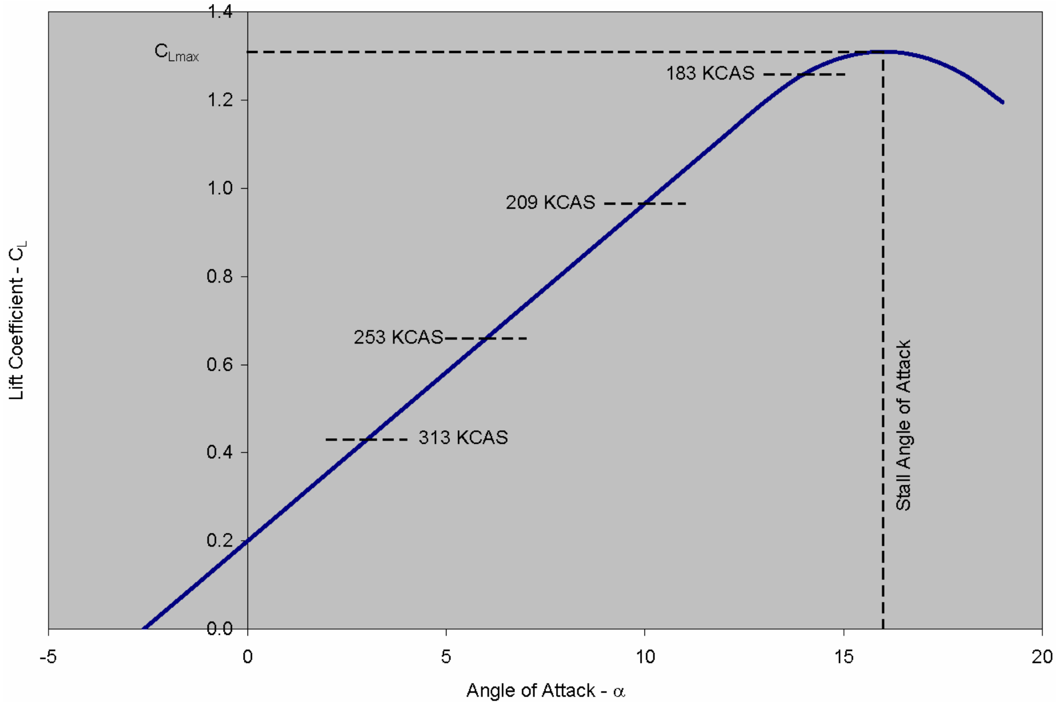

Figure 2. Lift coefficient versus angle of attack, and stall.

Factors Affecting the Stall Speed

Eq. (4) well defines the factors affecting the stall speed, in summary; aircraft weight, air density, maximum lift coefficient, and the load factor.

Aircraft weight

Stall speed is proportional with the aircraft weight. Stall speed increases, as the weight increases; and decreases as the weight decreases.

Air density

Aircraft stall speeds are usually given in terms of calibrated air speed or indicated air speed as an aircraft limitation. However, as it is seen from Eq. (4), it is actually a true airspeed which is inversely proportional with the density. Therefore, although it is constant in terms of CAS, it increases with the altitude because of the density variation. Fig. 3 shows how stall speed of Boeing 747 varies with altitude.

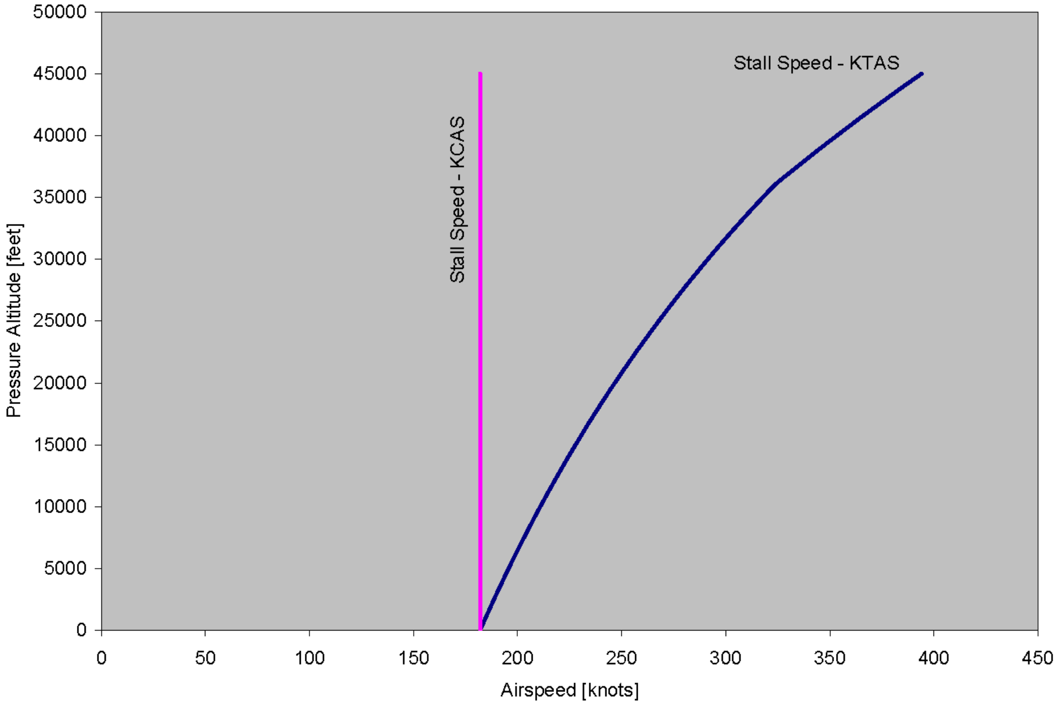

Figure 3. Altitude versus stall speed for Boeing 747 in terms of CAS and TAS.

Maximum lift coefficient

Maximum lift coefficient of an airplane can be varied by high lift devices such as flaps and slats. Effects of flaps on the lift and drag characteristics is shown in Fig.

4. Depending on the angle of attack and flap deflection angle, it is possible to obtain lift coefficients as high as 3.0.

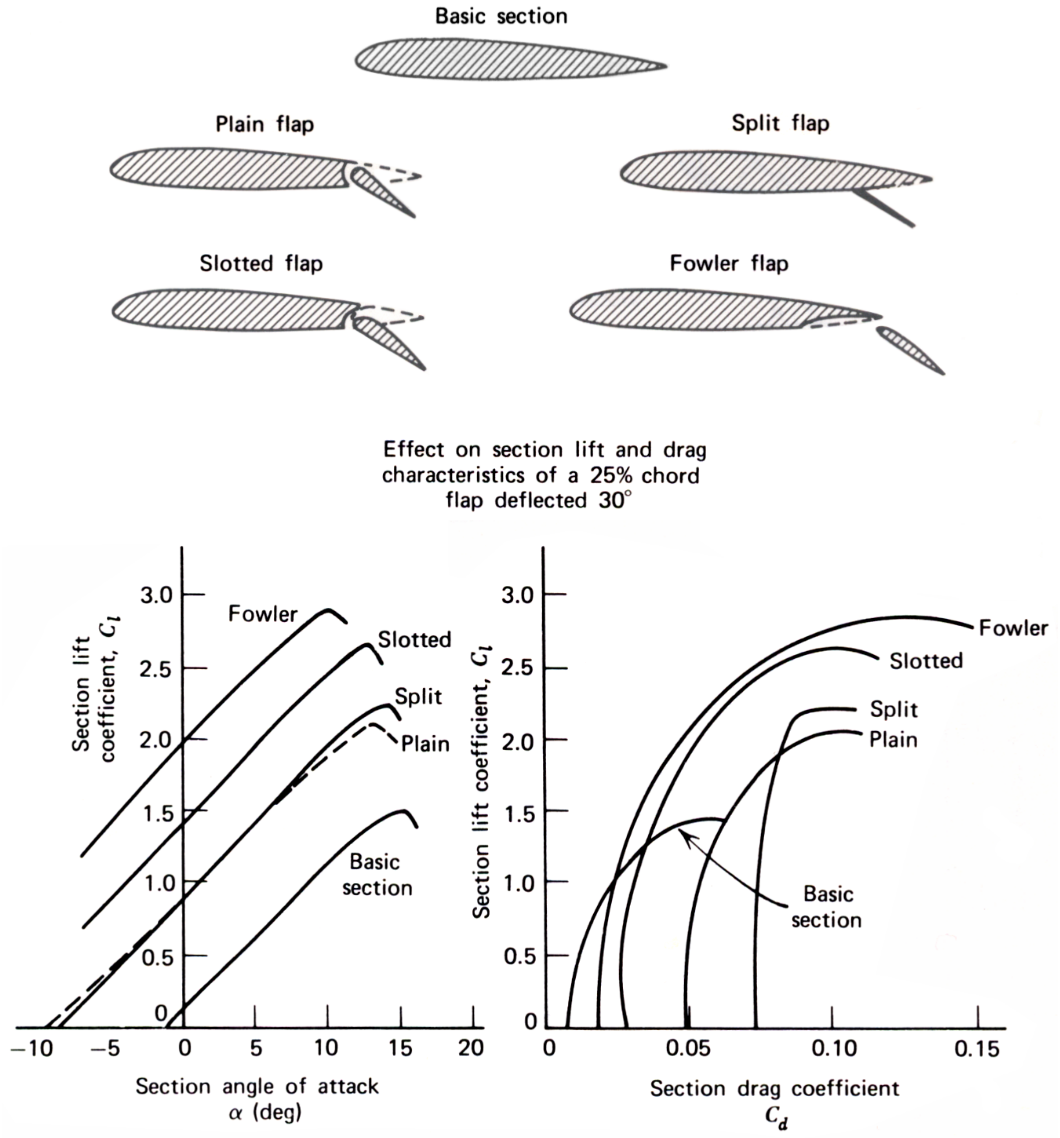

Figure 4. Effects of trailing edge flaps on lift and drag characteristics of wing sections [1].

Higher maximum lift coefficients will obviously result in slower stall speeds as seen from Fig. 1. Lowest maximum lift coefficient is obtained when flaps are retracted, i.e. airplane in clean configuration, thus highest stall speed occurs in clean configuration. When flaps are deflected, maximum lift coefficient increases and stall speed decreases. However, flap deflection angles are also limited, because airplane drag increases as the flap angles increase. Since higher flap angles are used during landing, stall speeds in the landing configuration are slower.

Load factor

Stall speed is proportional with the load factor. It increases as the load factor increases. If V_{S_S} is the stall speed of an aircraft in steady level flight, then stall speed during maneuvers will be

$$V_{S_N} = \sqrt{n} V_{S_S} \tag{5}$$

or during a turn maneuver

$$V_{S_N} = \frac{V_{S_S}}{\sqrt{\cos\phi}} \tag{6}$$

Fig. 5 shows sensitivity of the stall speed to the bank angles during turn maneuvers. It is seen that a 30° bank causes 7.5% increase in the stall speed. Therefore, flight envelope of an aircraft is narrowed down during maneuvers. At higher altitudes, bank angle of aircraft is limited due to stall speed limitations, and at the absolute ceiling a turn maneuver becomes impossible. Fig. 6 shows how Boeing 747 stall speeds are affected by bank angle.

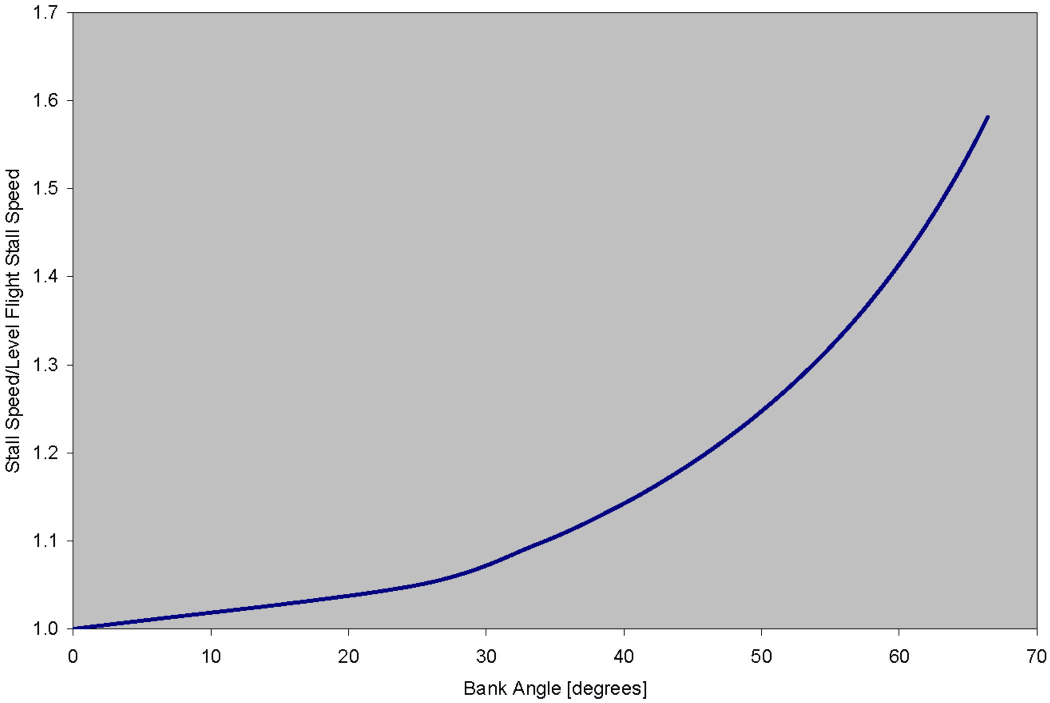

Figure 5. Ratio of the stall speed to the level flight stall speed versus bank angle.

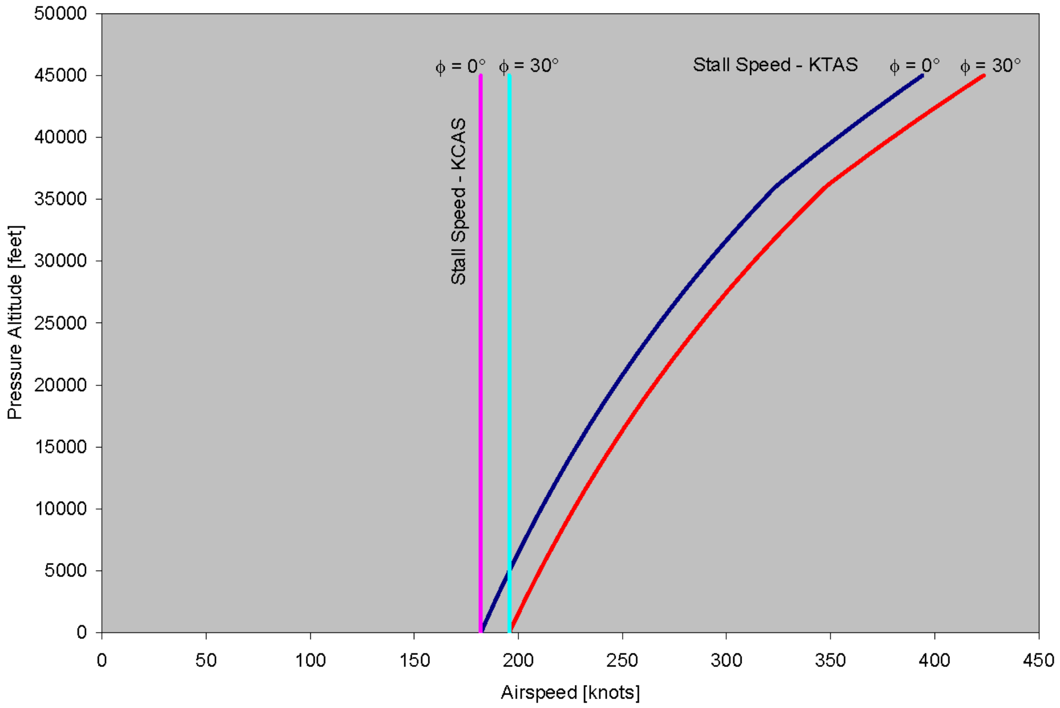

Figure 6. Effect of the pressure altitude and bank angle on stall speed of clean configuration Boeing 747.

References

[1] Saunders, G.H., Dynamics of Helicopter Flight, John Wiley & Sons, Inc., New York, 1975, pp. 45.