

Load Factor and Maneuvering Limitations

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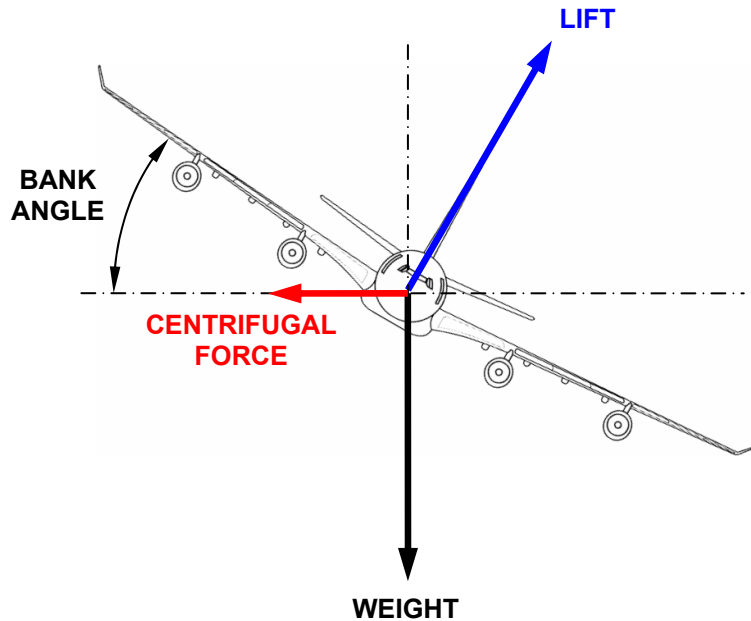


Figure 1. Forces acting on an aircraft during a level coordinated turn.

Load factor is a very important structural design parameter of an aircraft, as it indicates the amount of the load which the structure of an aircraft can bear. For this reason, maximum load factor is a maneuvering and performance limit. The limit load factor is the highest load factor to be expected over the lifetime of the aircraft. It also serves as a limit not to be exceeded by the pilots [1]. The steady, coordinated turn is the most proper phase of the flight to describe the load factor.

During a steady, coordinated turn the lift required to balance the airplane weight in order to keep the altitude constant:

$$L \cos \phi = W \quad (1)$$

where ϕ is the bank angle. Therefore, the ratio of lift to weight is

$$\frac{L}{W} = \frac{1}{\cos \phi} \quad (2)$$

Since the lift is greater than the weight in a banked turn because $\cos \phi < 1$, the ratio of lift to weight is the normal load factor

$$n = \frac{L}{W} \quad (3)$$

This also means that the aircraft structure is stressed by a load of nW . For example, a B747 of 360,000 kg mass (3,531,600 N) at $n = 2$ will be stressed by a force of 7,063,200 N. It is obvious from Eq. (3) that during a steady straight and level flight, the load factor

$$n = 1 \quad (4)$$

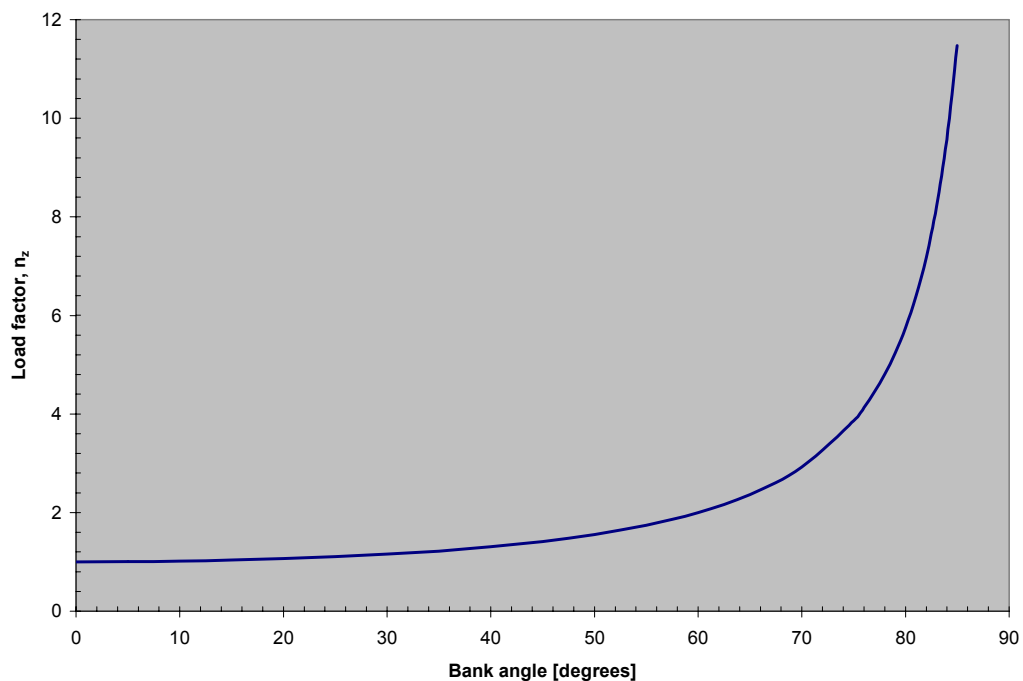


Figure 2. Load factor versus bank angle.

Figure 2 shows variation of the load factor with bank angle. The load factor is not dependent to aircraft weight and size, as implied by previously given equations. Whatever the type of aircraft is, same load factors apply for same bank angles.

The load factor limitations of aircraft are defined by airworthiness regulations such as, FAR23/JAR23 for small aircraft, and FAR25/JAR25 for large aircraft. Load factor limitations of an aircraft are shown by a graphics called maneuvering envelope or $V - n$ diagram as it shows the load factor versus airspeed in terms of EAS. An example maneuvering envelope is given in Figure 3. An aircraft cannot fly out of the load factor boundaries given by the maneuvering envelope.

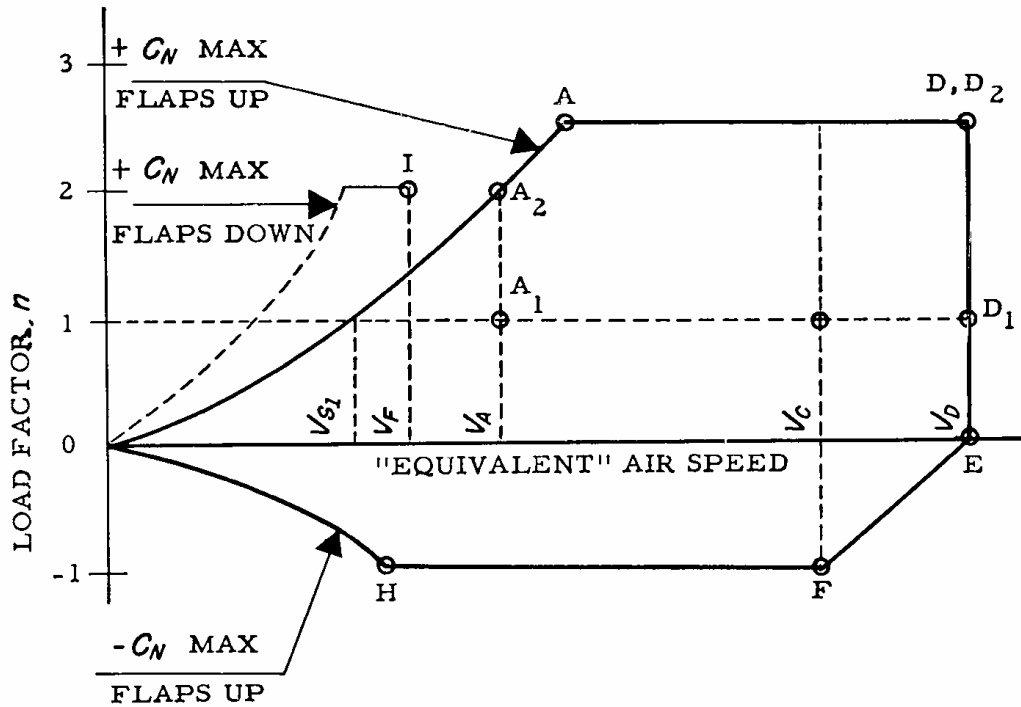


Figure 3. Maneuvering envelope for transport category aircraft.

JAR25/FAR25 specifies the limiting load factors of transport category aircraft as follows [2, 3]:

- (a) The positive limit maneuvering load factor ‘ n ’ for any speed up to V_D may not be less than $2.1 + \frac{24000}{W + 10000}$ except that ‘ n ’ may not be less than 2.5 and need not be greater than 3.8 – where ‘ W ’ is the design maximum take-off weight (lb).
- (b) The negative limit maneuvering load factor –
 - (1) May not be less than -1.0 at speeds up to V_C ; and
 - (2) Must vary linearly with speed from the value at V_C to zero at V_D .

Here V_C is the design cruise speed and V_D is the design dive speed.

Example: What may be the maximum bank angle of a B747-400 with maximum design take-off weight of 800,000 lb in clean configuration (flaps up)?

For B747-400 maximum load factor is 2.5, therefore

$$\cos \phi = \frac{1}{n} = \frac{1}{2.5} = 0.4 \text{ then } \phi = 66.5^\circ.$$

Example: What may be the maximum bank angle of a B737-800 with maximum design take-off weight of 174,200 lb in clean configuration (flaps up)?

For B737-800 maximum load factor is 2.5, therefore

$$\cos \phi = \frac{1}{n} = \frac{1}{2.5} = 0.4 \text{ then } \phi = 66.5^\circ.$$

Both examples show that maximum bank angles are same for both types of aircraft although B747 weighs four times of B737.

References

- [1] Shevell, R.S., Fundamentals of Flight, Prentice Hall, Englewood Cliffs, NJ, 1989.
- [2] Joint Aviation Authorities (JAA), Joint Aviation Requirements for Large Aeroplanes, JAR-25, Amendment 16, Hoofddorp, 2003.
- [3] Federal Aviation Agency (FAA), Airworthiness Standards: Transport Category Airplanes, Part 25, Amdt. 25-23, Washington D.C., 1970.