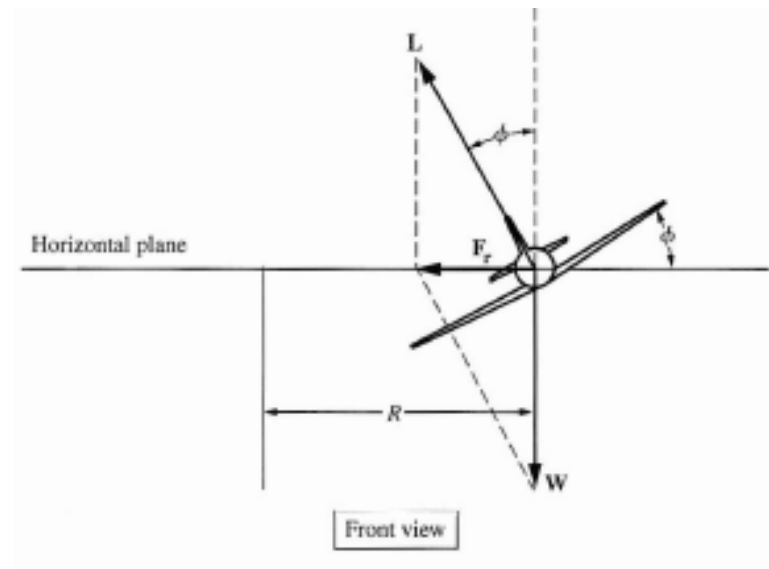
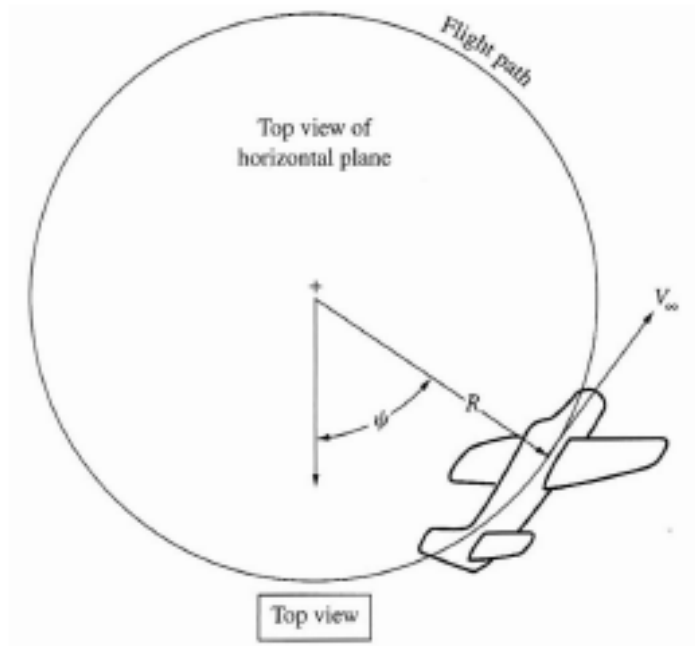


Level Turn



a level turn is one in which the curved flight path is in a horizontal plane parallel to the plane of the ground; that is, in a level turn the altitude remains constant.

$$L \cos \phi = W$$

$$m \frac{V_\infty^2}{R} = L \sin \phi$$

the centrifugal force is balanced by the radial force $L \sin(\phi)$.

The two performance characteristics of greatest importance in turning flight are

1. The turn radius R .
2. The turn rate ω . The turn rate is simply the local **angular** velocity of the airplane along the curved flight path.

These characteristics are particularly germane to combat aircraft. For superior dog fighting capability, the airplane should have the smallest possible turn radius R and the fastest possible turn rate.

Hence, the lift vector L controls the turn when a pilot goes to turn the airplane, she or he rolls the airplane in order to point the lift vector in the general direction of the turn. Keep in mind that L and ϕ are not independent:

$$\cos \phi = \frac{W}{L} = \frac{1}{L/W}$$

L/W is an important parameter in turning performance; it is defined as the **load factor n** , where

$$n \equiv \frac{L}{W}$$

$$\phi = \text{Arccos} \frac{1}{n}$$

The roll angle depends on the load factor only; if you know the load factor, then you know the roll angle, and viceversa.

$$m \frac{V_{\infty}^2}{R} = L \sin \phi$$

$$L \cos \phi = W$$

$$R = \frac{m V_{\infty}^2}{L \sin \phi} = \frac{W}{L} \frac{V_{\infty}^2}{g \sin \phi} = \frac{V_{\infty}^2}{gn \sin \phi}$$

$$\cos \phi = \frac{1}{n}$$

$$\cos^2 \phi + \sin^2 \phi = 1$$

$$\sin \phi = \sqrt{1 - \frac{1}{n^2}} = \frac{1}{n} \sqrt{n^2 - 1}$$

$$R = \frac{V_{\infty}^2}{g \sqrt{n^2 - 1}}$$

The turn radius depends only on V and n . To obtain the smallest possible R , we need

1. The highest possible load factor (i.e. the highest possible L/W).
2. The lowest possible velocity.

To obtain an expression for the turn rate

$$\omega = \frac{d\psi}{dt} = \frac{V_{\infty}}{R}$$

$$\omega = \frac{g \sqrt{n^2 - 1}}{V_{\infty}}$$

the largest possible turn rate, we want

1. The highest possible load factor.
2. The lowest possible velocity.

as the airplane's bank angle is increased, the magnitude of the lift must increase. As L increases, *the drag due to lift increases*.

to maintain a sustained level turn at a given velocity and a given bank angle, the **thrust must be increased from its straight and level flight value to compensate for the increase in drag**. If this increase in thrust pushes the required thrust beyond the maximum thrust available from the power plant, then the level turn cannot be sustained at the given velocity and bank angle. In this case, to maintain a turn at the given V , the bank angle will have to be decreased in order to decrease the drag sufficiently that the thrust required does not exceed the thrust available.

$$D = \frac{1}{2} \rho_{\infty} V_{\infty}^2 S (C_{D,0} + K C_L^2)$$

$$T = D$$

$$L = nW = \frac{1}{2} \rho_{\infty} V_{\infty}^2 S C_L$$

$$C_L = \frac{2nW}{\rho_{\infty} V_{\infty}^2 S}$$

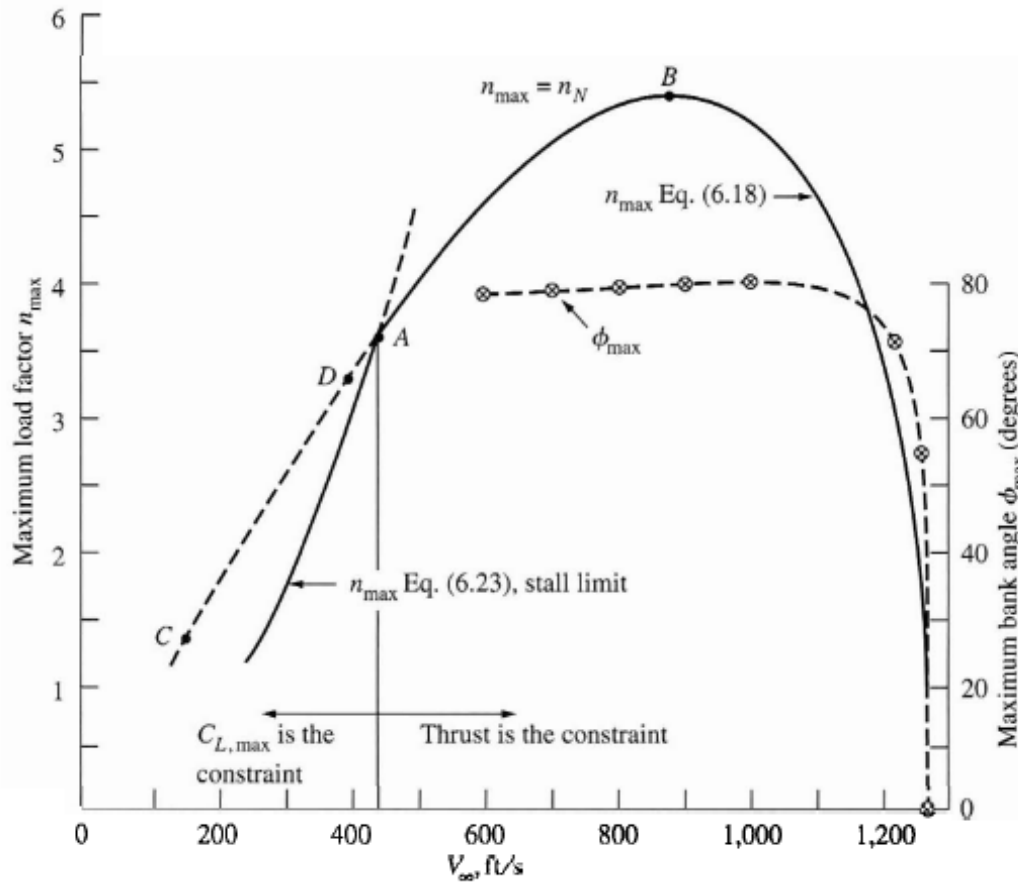
$$T = \frac{1}{2} \rho_{\infty} V_{\infty}^2 S \left[C_{D,0} + K \left(\frac{2nW}{\rho_{\infty} V_{\infty}^2 S} \right)^2 \right]$$

$$n = \left[\frac{\frac{1}{2} \rho_{\infty} V_{\infty}^2}{K(W/S)} \left(\frac{T}{W} - \frac{1}{2} \rho_{\infty} V_{\infty}^2 \frac{C_{D,0}}{W/S} \right) \right]^{1/2}$$

$$n_{\max} = \left\{ \frac{\frac{1}{2} \rho_{\infty} V_{\infty}^2}{K(W/S)} \left[\left(\frac{T}{W} \right)_{\max} - \frac{1}{2} \rho_{\infty} V_{\infty}^2 \frac{C_{D,0}}{W/S} \right] \right\}^{1/2}$$

$$1 \leq n \leq n_{\max}$$

there is a constraint on n imposed by the maximum available thrust
Moreover, n depends on the design parameters W/S , T/W , $C_{D,0}$, and K as well as the altitude.



The variation of n_{max} versus velocity for a given airplane. The airplane considered here is the Gulfstream-like airplane. The altitude is sea level; the results will be difficult for different altitudes. At the maximum velocity of the airplane, there is no excess power, hence no level turn is possible and $n = 1$. As V , decreases, n_{max} increases, reaches a local maximum value at point B, and then decreases.

For velocities higher than that at point B, the zero-lift drag (which increases with V) dominates; and for velocities lower than that at point B, the drag due to lift (which decreases with V) dominates. This is why the n , curve first increases, then reaches a local maximum, and finally decreases with velocity. At point B the airplane is flying at its maximum *LID*.

$$n \equiv \frac{L}{W} = \frac{L}{D} \frac{D}{W} = \frac{L}{D} \frac{T}{W}$$

As V (and hence the dynamic pressure) decreases the magnitude of L is maintained (or increased) by increasing C_L , that is, by increasing the angle of attack of the airplane. Obviously, C_L cannot increase indefinitely is limited by its maximum value at stall $(C_L)_{\max}$. The velocity at which $(C_L)_{\max}$ reached is denoted by point **A**. At lower velocities, less than at point A the maximum load factor is constrained by $(C_L)_{\max}$, not by available thrust.

$$n \equiv \frac{L}{W} = \frac{1}{2} \rho_{\infty} V_{\infty}^2 C_L \frac{S}{W}$$

$$n_{\max} = \frac{1}{2} \rho_{\infty} V_{\infty}^2 \frac{(C_L)_{\max}}{W/S}$$

$$\cos \phi_{\max} = \frac{1}{n_{\max}}$$