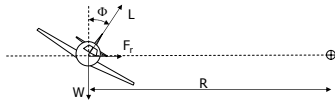


Turning Flight

- Now consider situations where the acceleration is normal to the flight path. The most important of these is banked turn as illustrated below.



- A side force, F_r , is generated by banking the aircraft and tilting the lift vector.
- This side force acts as to produce centripetal acceleration that pulls the aircraft around in an arc of radius R

Turning Flight (continued)

- Note that since the lift vector is tilted by the bank angle, Φ , to maintain level flight, the lift force must exceed the weight according to:

$$L \cos \Phi = W$$



- If we define a load factor, n , as the ratio of lift to weight, then by vector math:

$$n = \frac{L}{W} \quad F_r = \sqrt{L^2 - W^2} = W \sqrt{n^2 - 1}$$

- Thus, the centripetal force is related to the load factor.

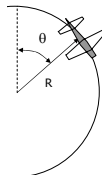
Turning Flight (continued)

- From physics, we know that the centripetal force is calculated by:

$$F_r = m \frac{V_\infty^2}{R}$$

- Thus, the turn radius, R , is a function of the aircraft velocity and load factor:

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

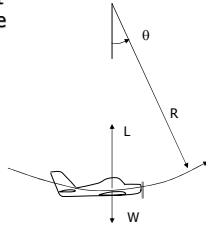


- Similarly for the turning rate:

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

Pullup Maneuver

- In a pullup maneuver the aircraft suddenly experiences an increase in lift above that necessary to support the weight.
- This is normally achieved by rotating the craft up to a higher angle-of-attack through use of the elevator control surface.
- As a result of the imbalance of forces in the vertical direction, the flight path begins to curve upwards as shown in the sketch.



Pullup Maneuver (continued)

- The centripetal force for this maneuver is now in the vertical plane:

$$F_r = L - W = W(n - 1)$$

- The radius of curvature of the flight path and the pitch-up rate are similarly given by:

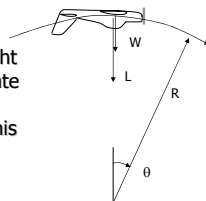
$$R = m \frac{V_\infty^2}{F_r} = \frac{V_\infty^2}{g(n-1)}$$

$$\omega = \frac{V_\infty}{R} = \frac{g(n-1)}{V_\infty}$$

- Note that these relations are equally valid for a pushover maneuver - a "pullup" with $n < 1.0$.

Pulldown Maneuver

- The pulldown maneuver is the inverted form of the pullup maneuver.
- In this case, both lift and weight are contributing to the pitch rate - as a result, simply rolling an airplane inverted will initiate this maneuver.
- By convention, we will still consider lift and thus load factor positive as sketched.



Pulldown Maneuver (continued)

- Since the lift and weight are now in the same direction, the downward acting centripetal forces is:

$$F_r = L + W = W(n+1)$$

- And the flight path radius of curvature and pitch down rate are given by:

$$R = m \frac{V_\infty^2}{F_r} = \frac{V_\infty^2}{g(n+1)}$$

$$\omega = \frac{V_\infty}{R} = \frac{g(n+1)}{V_\infty}$$

- Note that as long as $n > -1$, R and ω are positive - for $n=-1$ the plane is in level flight; for $n < -1$ the plane begins climbing in a "pushup" maneuver.

Maneuver Summary

- A highly maneuverable aircraft is one for which the maneuver radius, R , is small and the turn/pitch rate, ω , is large.
- To achieve this, all the equations derived so far indicate that a low velocity and high load factor are desirable!
- High load factors, of course, require strong structures - but the maximum load factor also depends upon the $C_{L,max}$ of the aircraft and it's flight velocity.
- To see how load factor and velocity are inter-related, we use a so-called V-n diagram.
