CPL Theory
Aerodynamics (CADA)

CAE Oxford Aviation Academy

CADA 9 - Turning

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2. Related Documents

Related Documents	Document Identification

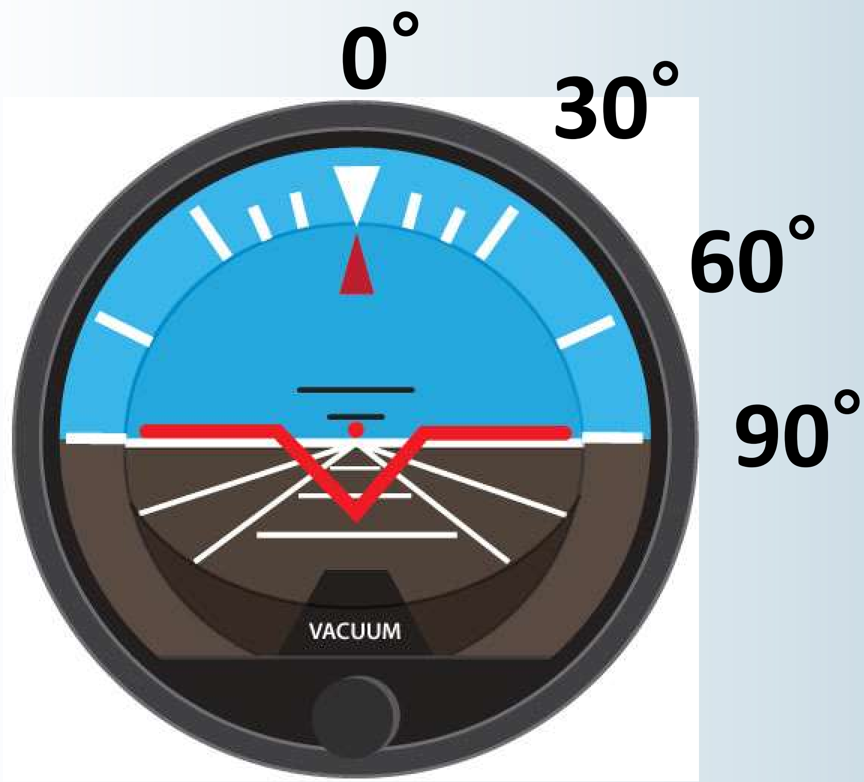
Amendments made to this document since the previous version are listed below. All amendments to this document have been made in accordance with CAE OAAM's document management procedure.

Slide	Changes

TYPES OF TURNS

Types of Turns

- Level Turns (turning whilst maintaining altitude) are classified according to the bank angle used:



- **Gentle Turn:** 0° to 15°
- **Medium Turn:** 15° to 45°
- **Steep Turn:** 45° to 60°
- Past 60° is considered an **aerobatic manoeuvre**

- There are also climbing & descending turns. You will learn about these after mastering medium level turns

Types of Turns

- There is also a Rate 1 turn which you will use extensively in IFR Flight

- A Rate 1 turn is one that takes 2 minutes to turn a full 360 degrees

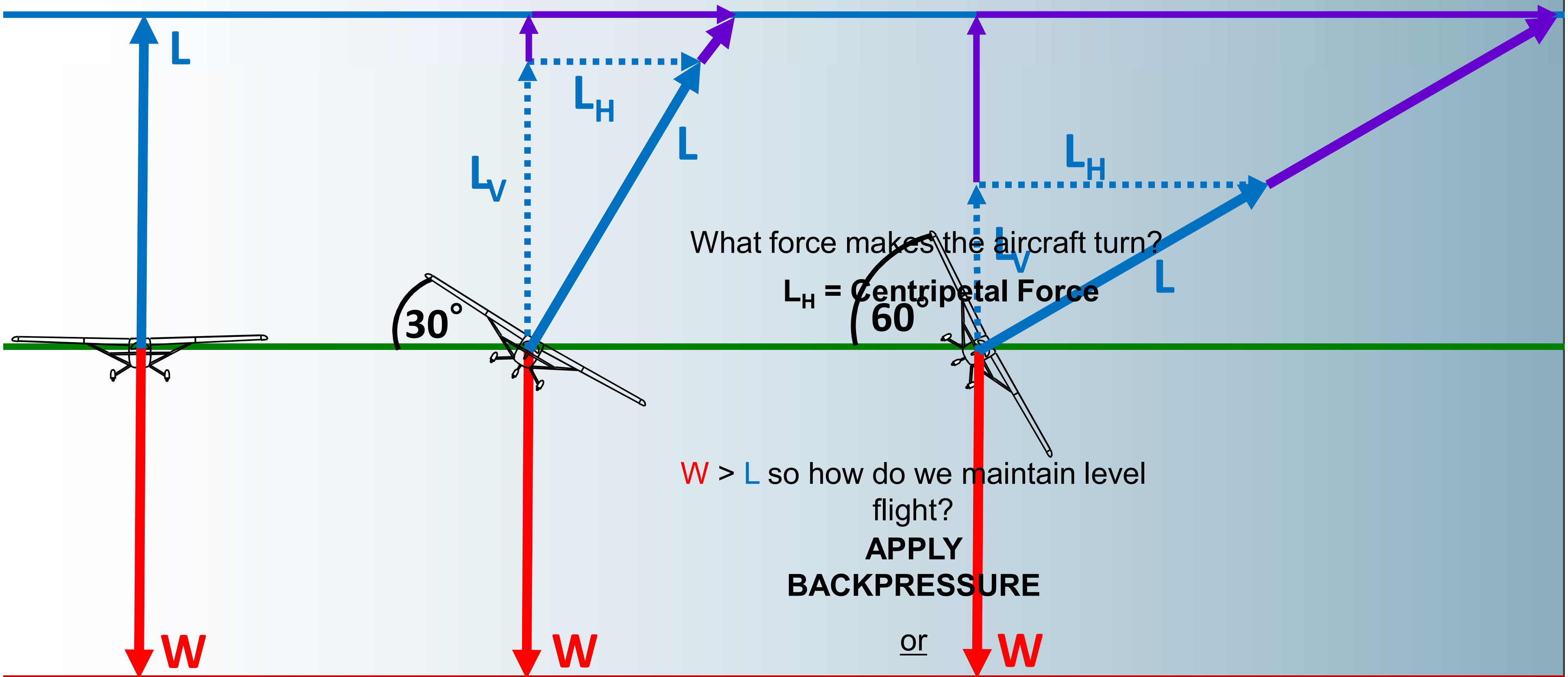
- The angle of bank required for a rate 1 turn will vary depending on atmospheric conditions

- However, it may be approximated using the following formula:

$$\text{AoB for Rate 1 Turn} = (\text{IAS} \div 10) + 7$$

BALANCE OF FORCES IN A CORRECTLY BALANCED LEVEL TURN

Balance of Forces – Level Turns



What force makes the aircraft turn?

L_H = Centripetal Force

W > L so how do we maintain level flight?

APPLY BACKPRESSURE

or

INCREASE AIRSPEED

L = W	**L > W**	**L > W (L = 2W)**
n = 1	**n = 1.15**	**n = 2**
Vs = 48	**Vs = 51**	**Vs = 68**

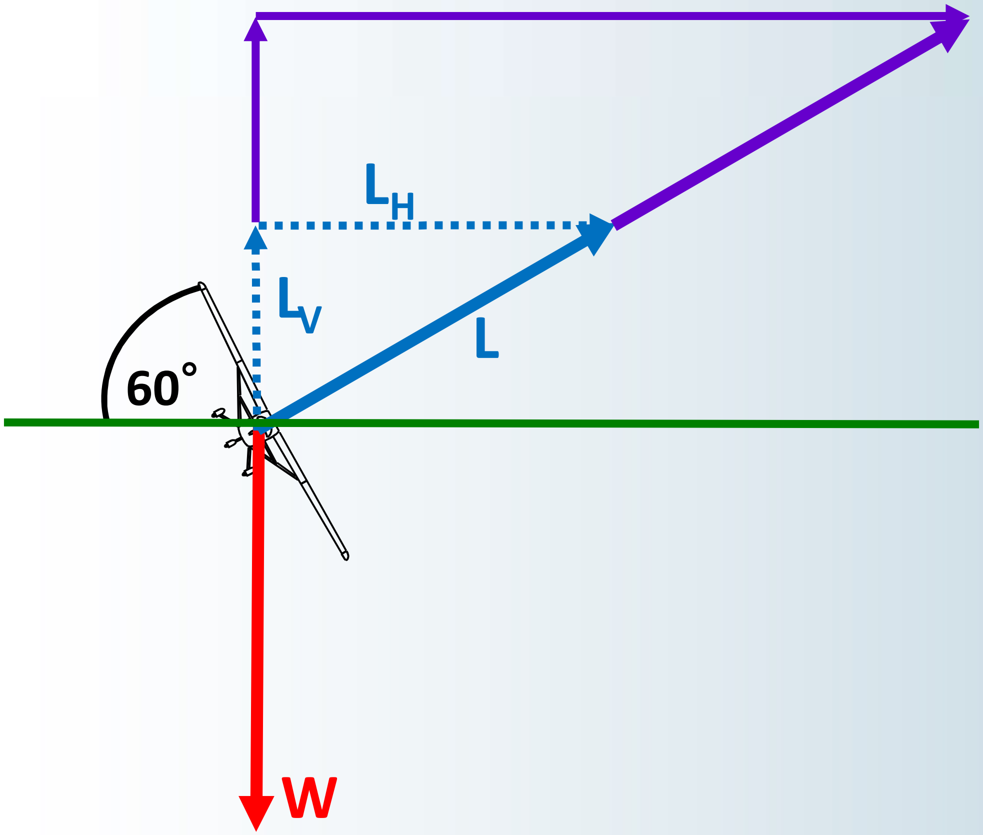
LOAD FACTOR

Load Factor

$$\text{Load Factor} = n = \frac{\text{Lift}}{\text{Weight}} = \frac{\text{Wing Loading in a Manoeuvre}}{\text{Wing Loading S\&L}}$$

- Load Factor is expressed in terms of “g” force
- S&L = 1g
- 60° AoB = 2g

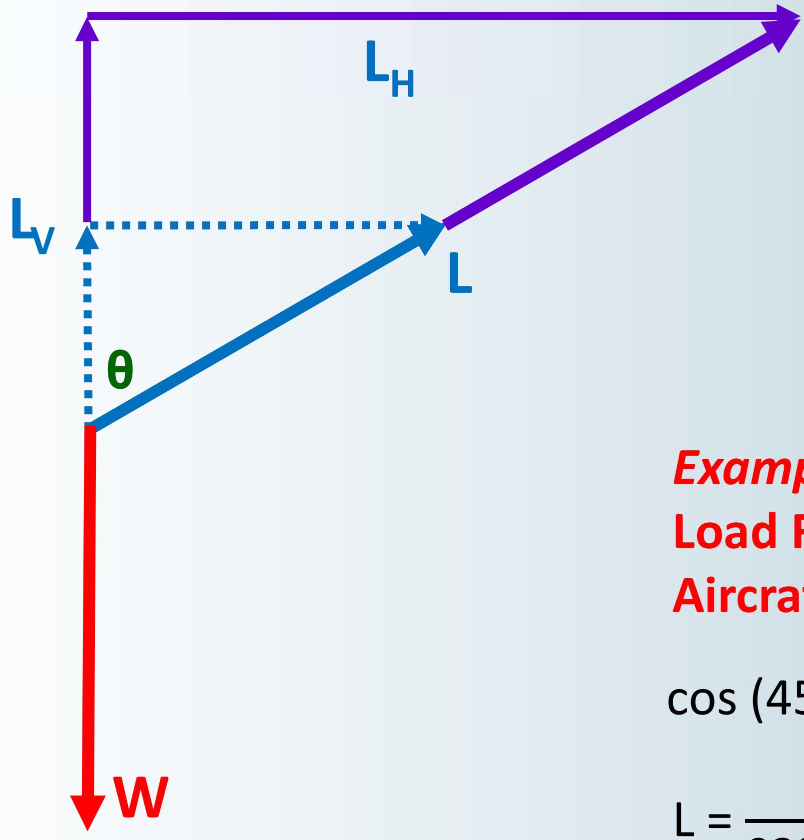
How To Calculate Load Factor



$L_V = W$

$L > W$ ($L = ?W$)

How To Calculate Load Factor



$L_V = W$

$L > W$ ($L = ?W$)

θ = AoB

$$\cos\theta = \frac{\text{Adjacent Side}}{\text{Hypotenuse Side}} = \frac{L_V}{L} = \frac{W}{L}$$

Example:

Load Factor in a 45º Turn

Aircraft weighs 5000kg

$$\cos(45^o) = \frac{W}{L} = \frac{5000\text{kg}}{L}$$

$$L = \frac{5000}{\cos^{-1}(45^o)}$$

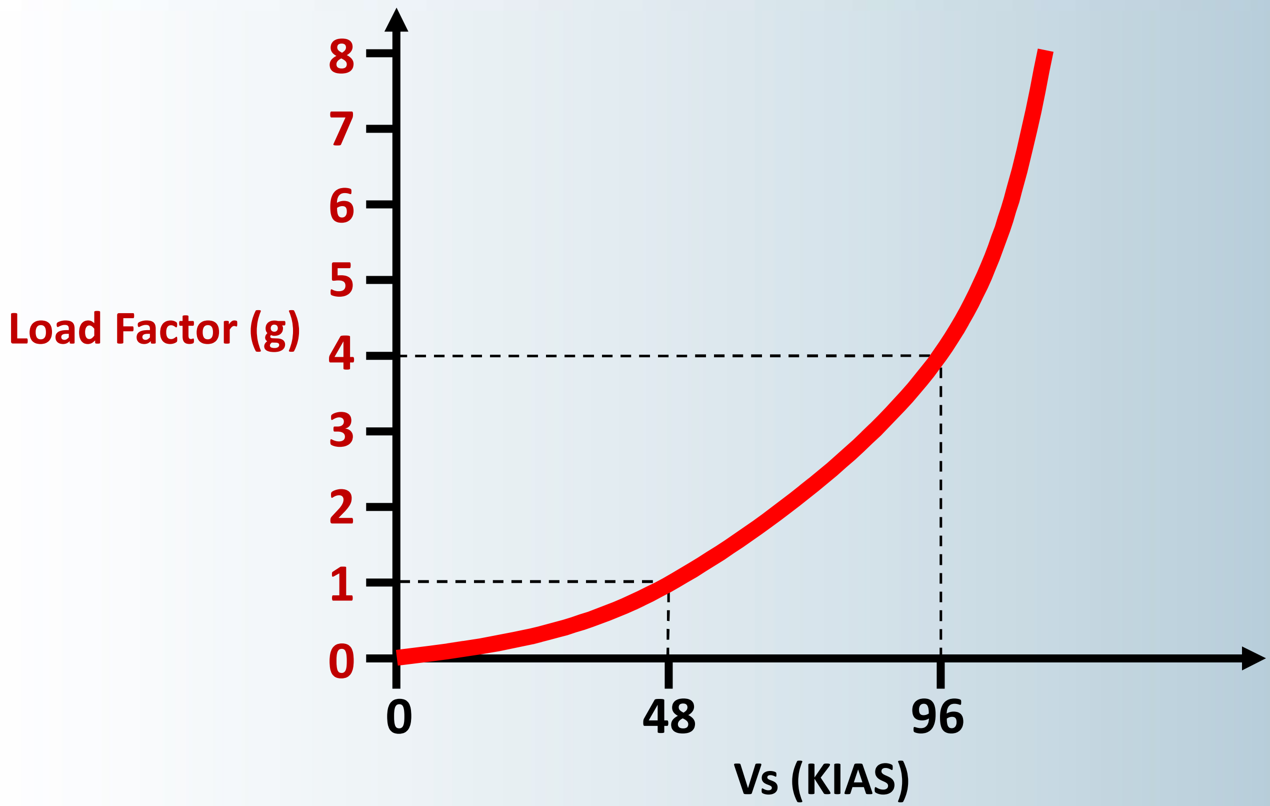
$$L = 7071\text{kg}$$

$$\text{Load Factor} = \frac{L}{W} = \frac{7071\text{kg}}{5000\text{kg}} = 1.41\text{g}$$

STALL SPEED

Load Factor

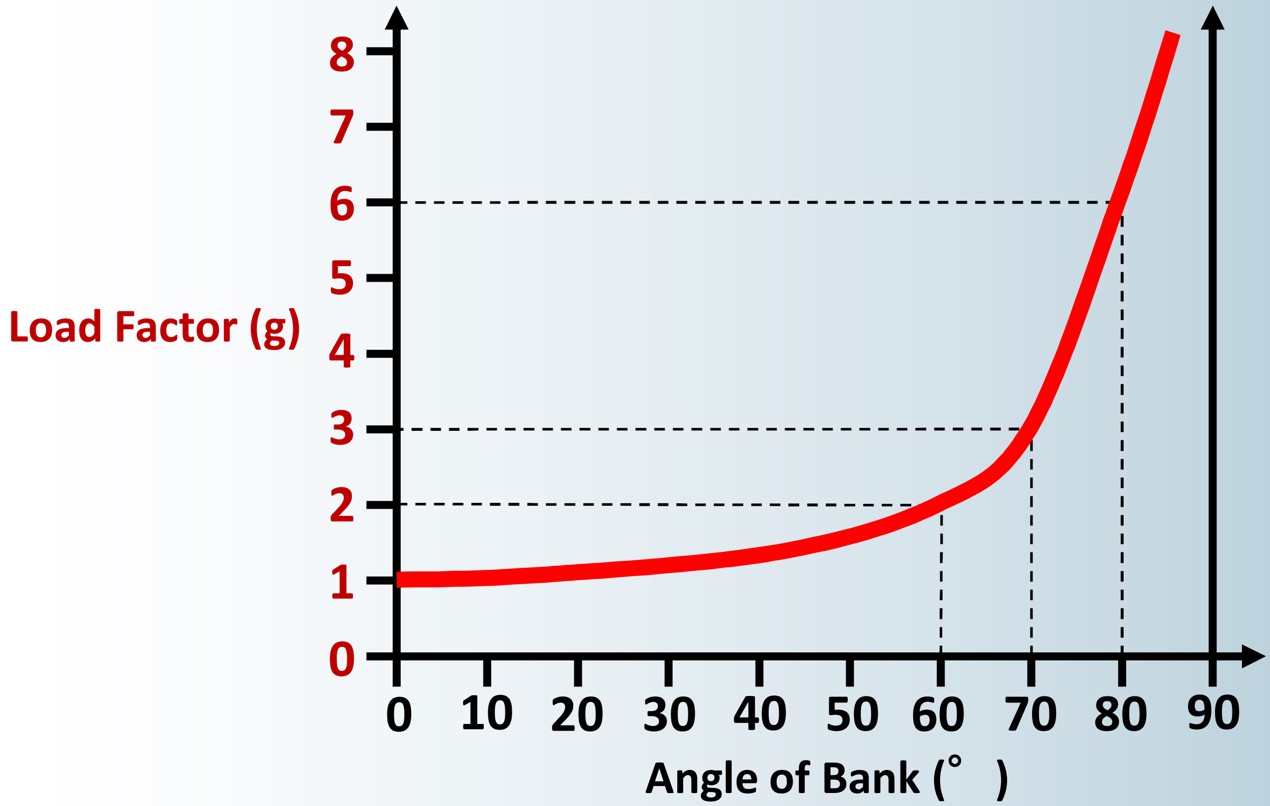
- We have also seen that an increase in load factor increases the stall speed



- Remember the formula: $New\ V_S = Old\ V_S \times \sqrt{Load\ Factor}$

Load Factor

- As we have seen, any control input where we “pull” will increase the load factor or “g” we experience



Angle of Bank	Vs Increase (%)
30	7%
45	19%
60	41%
75	100%

- This can be added to the lift equation: $L = C_L \frac{1}{2} \rho v^2 S = nW$

TURN PERFORMANCE

Turn Performance

- When examining turn performance, we must consider:

  1. Radius of Turn

  2. Rate of Turn

- An aircraft is maximising its turn performance when:

  1. The Radius of Turn is a **minimum**

  2. The Rate of Turn is a **maximum**

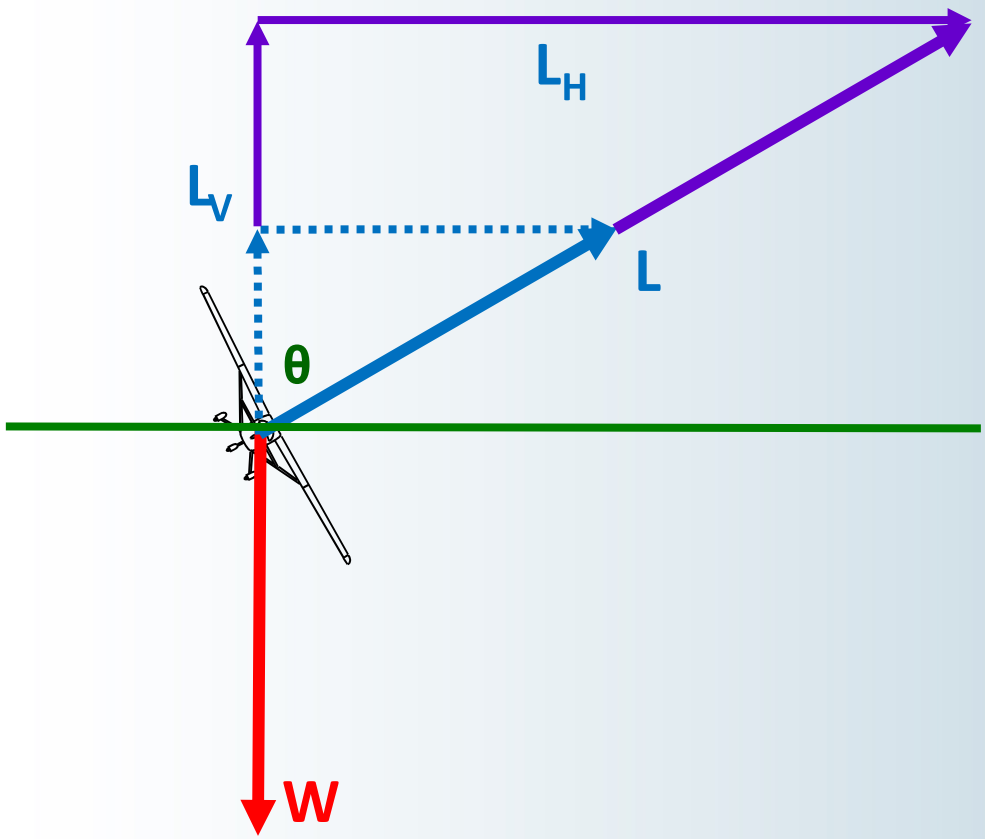
Turn Performance

What variables affect turning performance?

- Weight? X
- AoB? ✔
- TAS? ✔

Turn Performance - Weight

- Centripetal Force = $L_H = \frac{W v^2}{g r}$



$$\tan\theta = \frac{\text{Opposite Side}}{\text{Adjacent Side}} = \frac{L_H}{L_V} = \frac{\frac{\cancel{W} v^2}{g r}}{\cancel{W}}$$

$$= \frac{\mathbf{v^2}}{\mathbf{g\ r}}$$

WEIGHT <u>DOES NOT</u> affect centripetal acceleration

Therefore, **WEIGHT <u>DOES NOT</u>** affect rate or radius of turn

Turn Performance - TAS

- Constant Angle of Bank with changing TAS
  - An Aircraft in a 30° turn will travel a different path depending on its airspeed
  - At low TAS the turn will be tighter (the radius of the turn is smaller) than at high speed. The rate of turn will also be greater at low TAS
  - Weight will <u>NOT</u> affect turning performance unless you have to fly a greater TAS (not really relevant for light aircraft)
  - If you fly a turn at a given IAS at high altitude, the TAS (actual airspeed) will be greater at the higher altitude therefore the radius of the turn will be greater

Turn Performance - AoB

- Constant TAS with changing AoB

  - At a constant airspeed, the greater the bank angle, the tighter the turn (i.e. the smaller the radius)

    As a result the rate of turn will be greater in degrees per second.

Turn Performance

- Effect of Altitude on Turning Performance

  - IAS = $\frac{1}{2}\rho V^2$
  - Increase ALT = Reduced density = Increased TAS = Increased radius of turn & decreased rate of turn

Turn Performance

- Effect of Power on Turning Performance
  - During a level turn, airspeed decreases slightly due to increased drag
  - If airspeed is to be maintained during the turn, an increase in power that produces an increase in thrust is required
  - Because the addition of power causes a higher airspeed, this will in turn decrease the rate of turn and increase the radius of turn

Turn Performance - Summary

- Two variables control turn performance
  - Angle of Bank
  - TAS
- Increase in Angle of Bank – decrease radius of turn, increase rate of turn
- Decrease Angle of Bank – increase radius of turn, decrease rate of turn
- Increase TAS – increase radius of turn, decrease rate of turn
- Decrease TAS – decrease radius of turn, increase rate of turn
- Doubling the speed (TAS) = 4 x turn radius

RATE OF TURN

Rate of Turn

Rate of turn may be measured in degrees per second, or the number of seconds to turn trough 360°

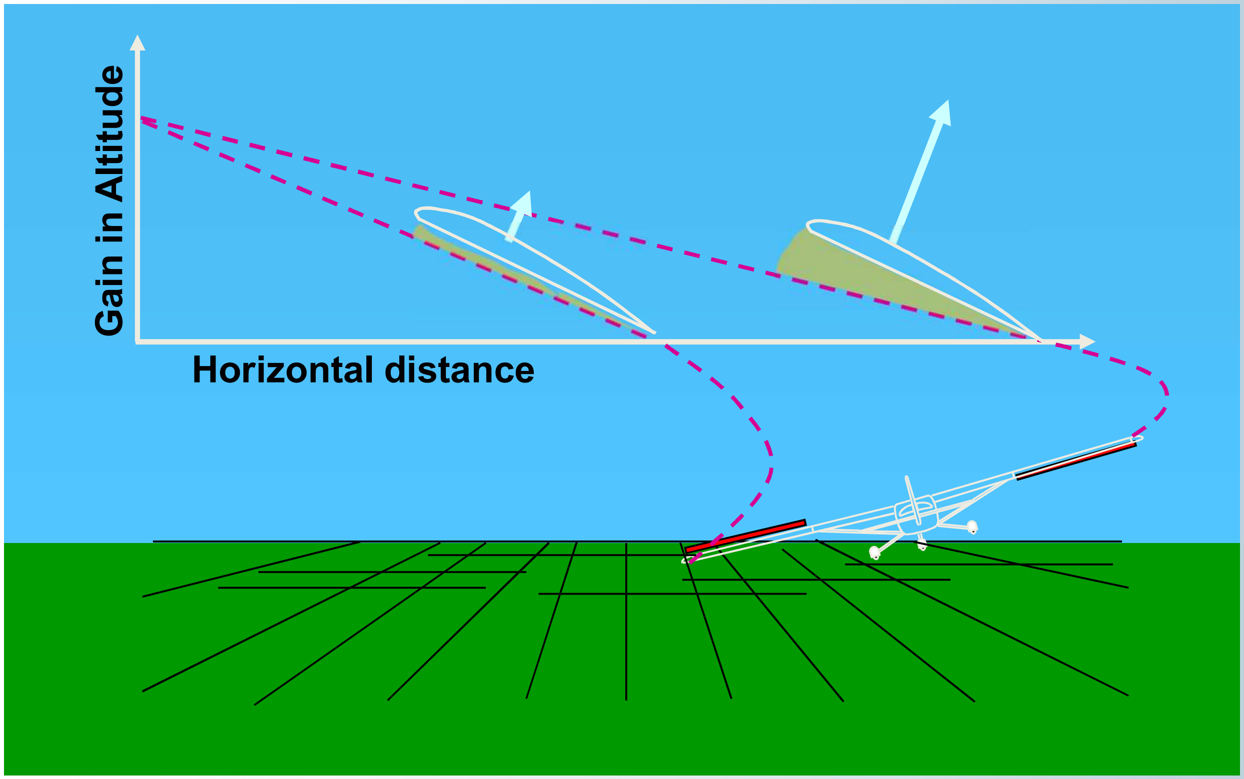
Rate	Time to Complete 360º	Degrees/Second
Rate 1	2 minutes	3º/second
Rate 2	1 minute	6º/second
Rate 3	40 seconds	9º/second
Rate 4	30 seconds	12º/second

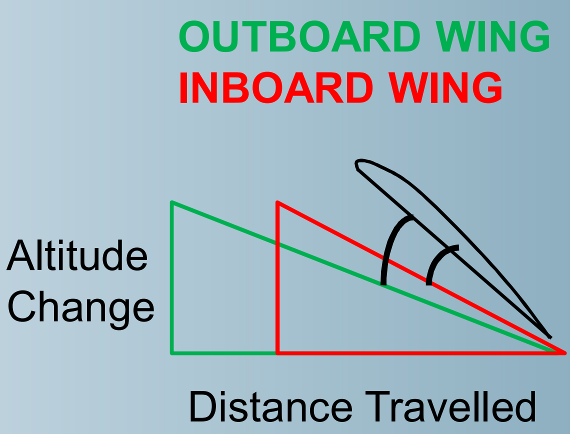
$$\textbf{AoB for a Rate 1 Turn} = \frac{\textbf{TAS}}{\textbf{10}} + \textbf{7}$$

CLIMBING AND DESCENDING TURNS

Over Banking in a Climb

Higher speed and ↑ AoA on the outer wing creates more lift than the inner. Thus, an over banking tendency occurs. Some bank may have to be held off.

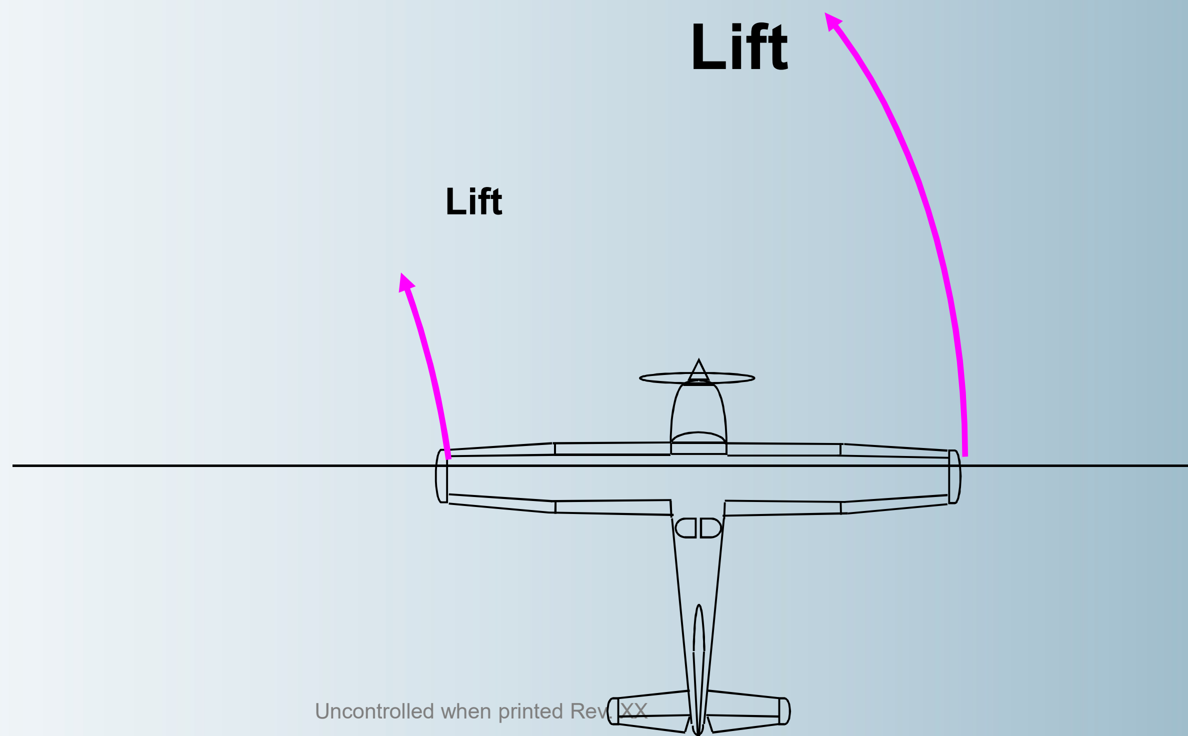




Over Banking in a Climb

In any turn, one wing must travel further (hence faster), therefore creating more lift – banking the aircraft further.

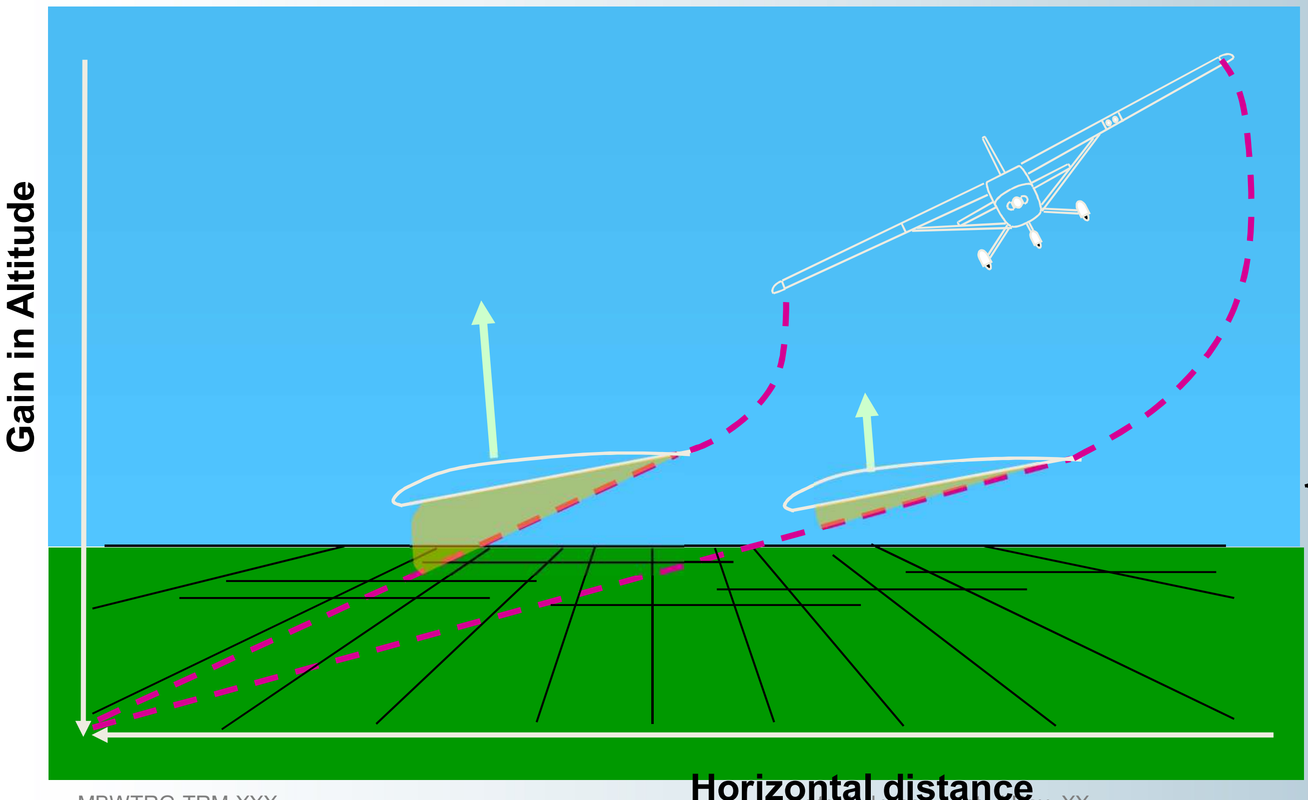
Counteract this tendency by using opposite aileron once established in the turn.



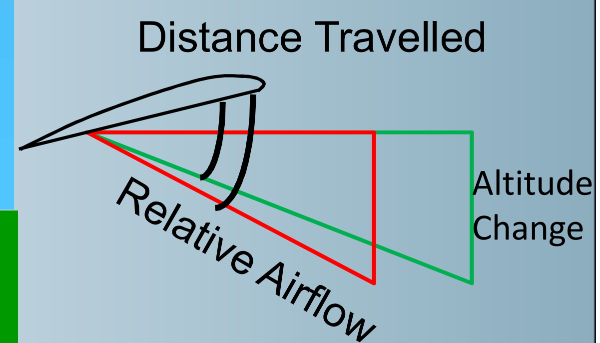
Under Banking in a Descent

The outer wing travels a greater distance while the inner wing has a greater AoA.

The increase AoA on the inner wing counteracts the over-banking tendency of the outer wing, and may lead to an under-banking tendency.



OUTBOARD WING
INBOARD WING



SLIPPING & SKIDDING

Slipping

- Experienced when turning from upwind to downwind
- Aircraft is pushed into the turn due to the wind
- Bank should be reduced as you turn

When ground speed is highest, bank must be highest

When ground speed is lowest, bank must be lowest

Skidding

- Experienced when turning from downwind to upwind
- Aircraft is pushed out of the turn due to the wind
- Bank should be increased as you turn

When ground speed is highest, bank must be highest

When ground speed is lowest, bank must be lowest

AIRSPEED

Airspeeds

- V_s – Stalling Speed
  - V_{S1} – Stalling Speed with flaps and wheels <u>up</u> – bottom of green arc
  - V_{S0} – Stalling Speed with flaps and wheels <u>down</u> – bottom of white arc
- V_a – Manoeuvring Speed *or* Maximum Control Deflection Speed
- V_{no} – Normal Operating Speed – top of the green arc
- V_{ne} – Never Exceed Speed – red line
- V_b – Turbulence Penetration Speed
- V_{le} – Maximum Landing Gear Extended Speed
- V_{fe} – Maximum Flap Extended Speed – top of the white arc

Airspeeds


TEMP °C
30 + 0 - 30
PRESS
ALT
200
180
160
140
120
100
80
60
40
AIRSPEED
KNOTS
TAS
120
100

Airspeeds - V_a

V_a

Manoeuvring Speed *<u>or</u>* Maximum Control Deflection Speed

V_a ***decreases*** with an ***decrease*** in weight

Airspeeds - V_a