

Principles of glider flight

[Lecture 2: Control and stability]

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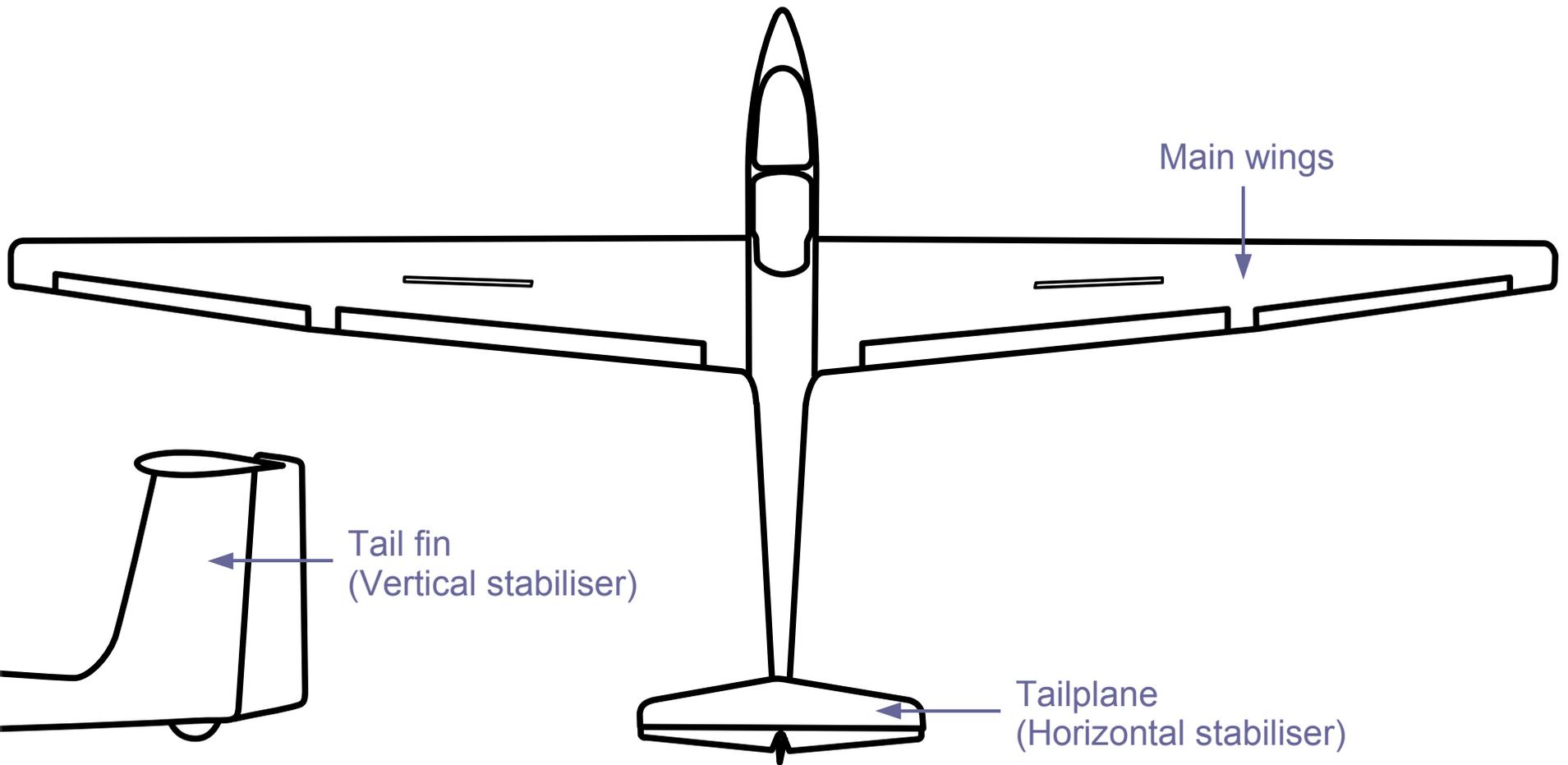
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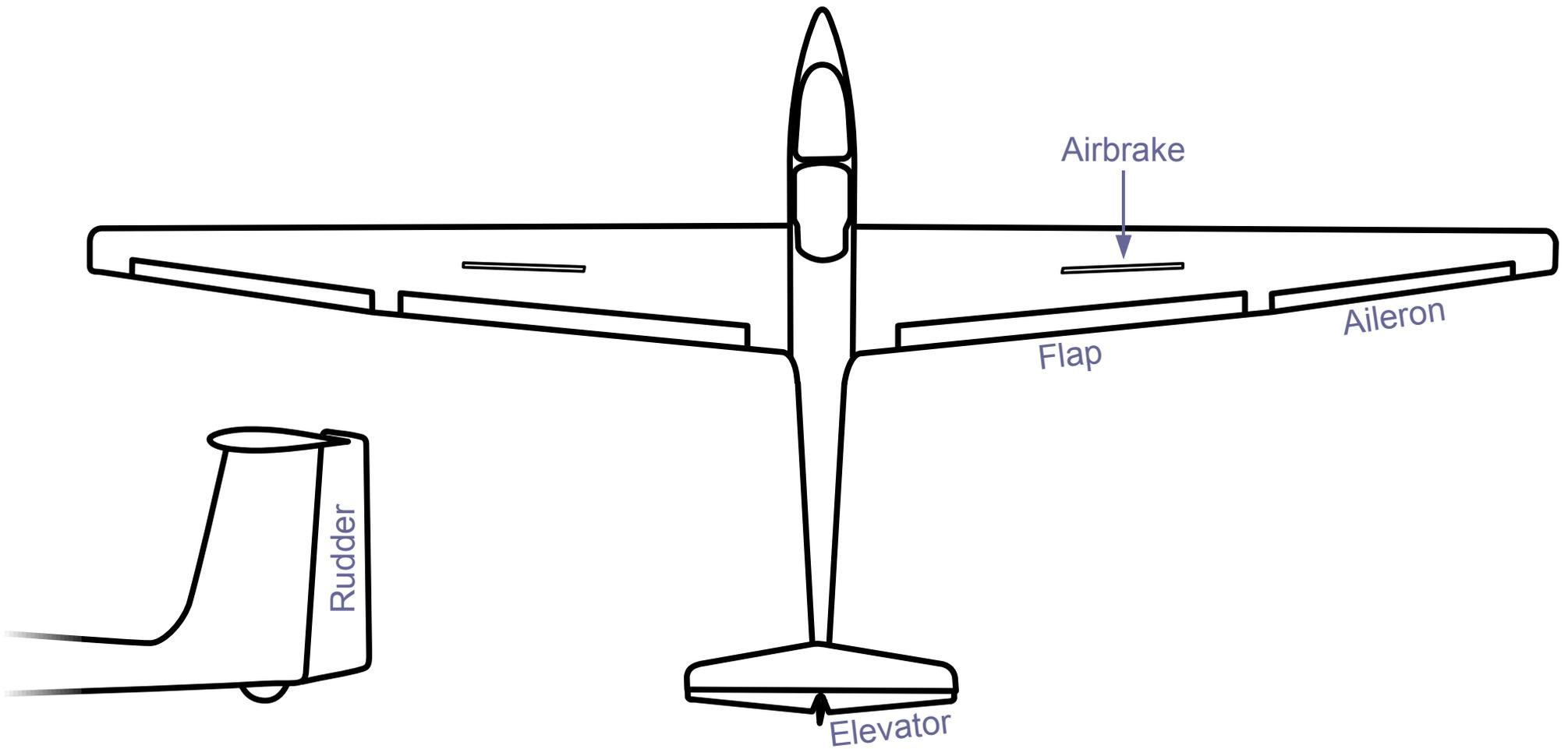
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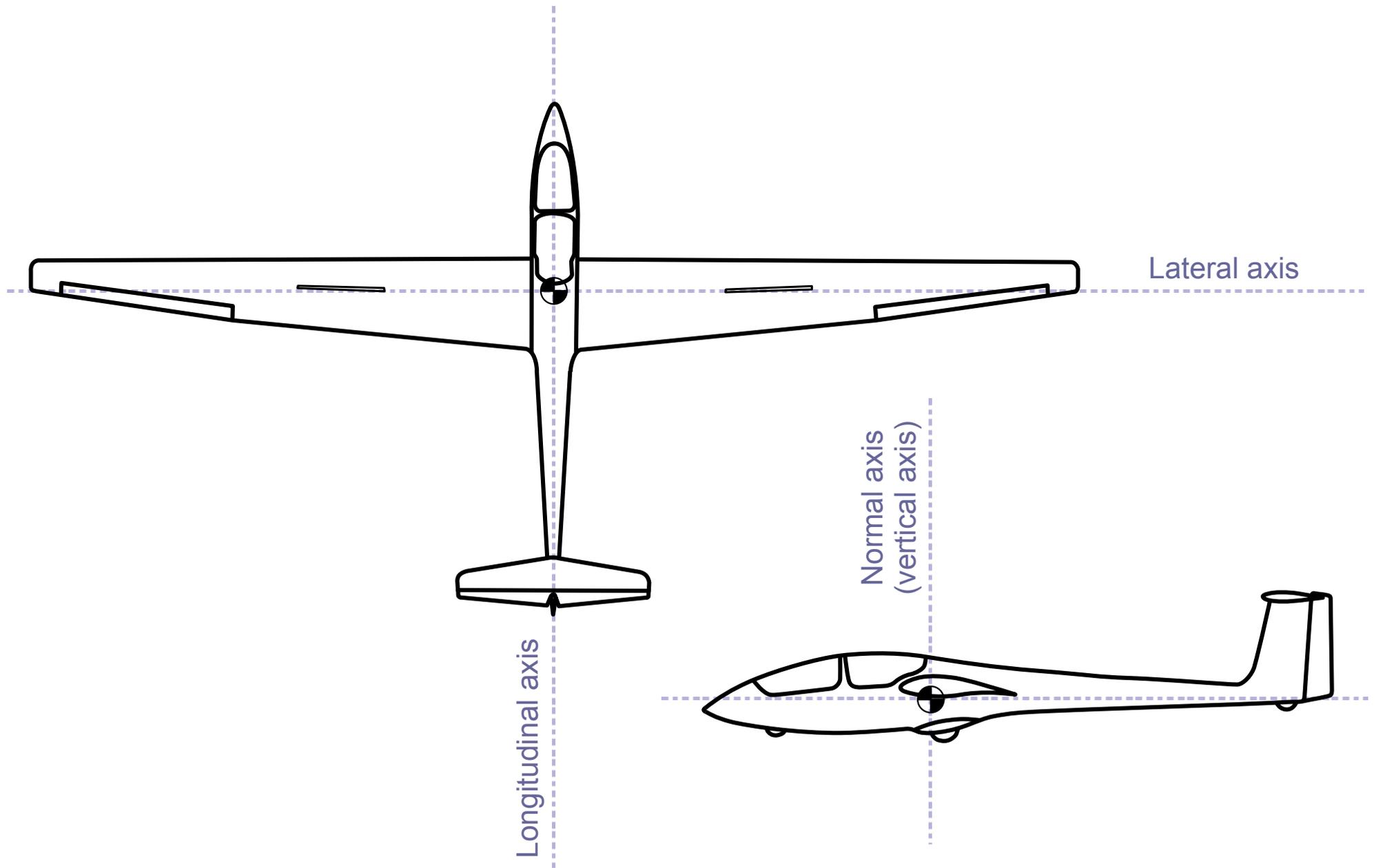
[Flight surfaces]



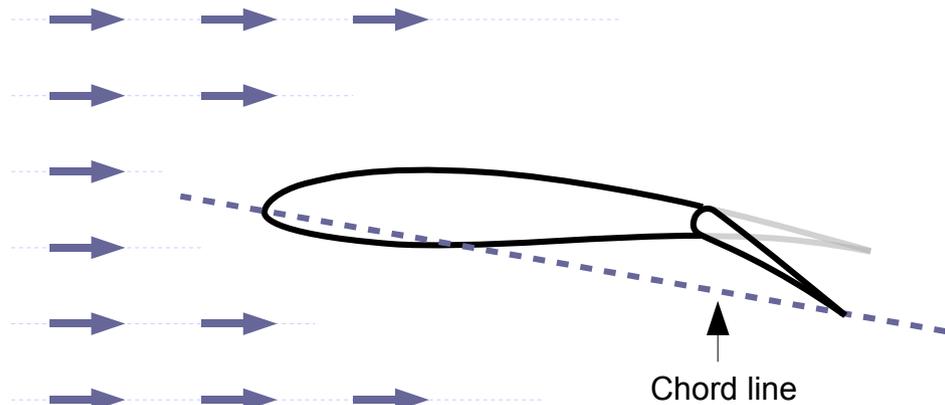
[Control surfaces]



[Axes]



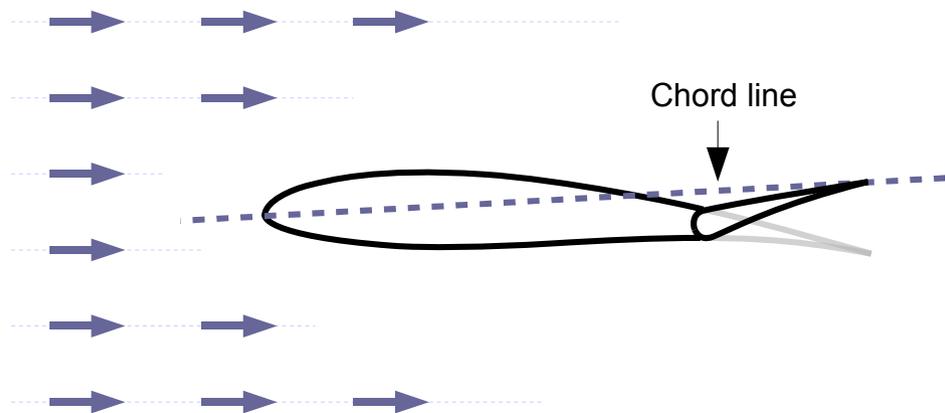
[How a control surface works]



1 Deflecting a control surface down:

- Increases aerofoil camber.
- Increases angle of attack.

Therefore **lift is increased**.



2 Deflecting a control surface up:

- Decreases aerofoil camber.
- Decreases angle of attack.

Therefore **lift is reduced**.

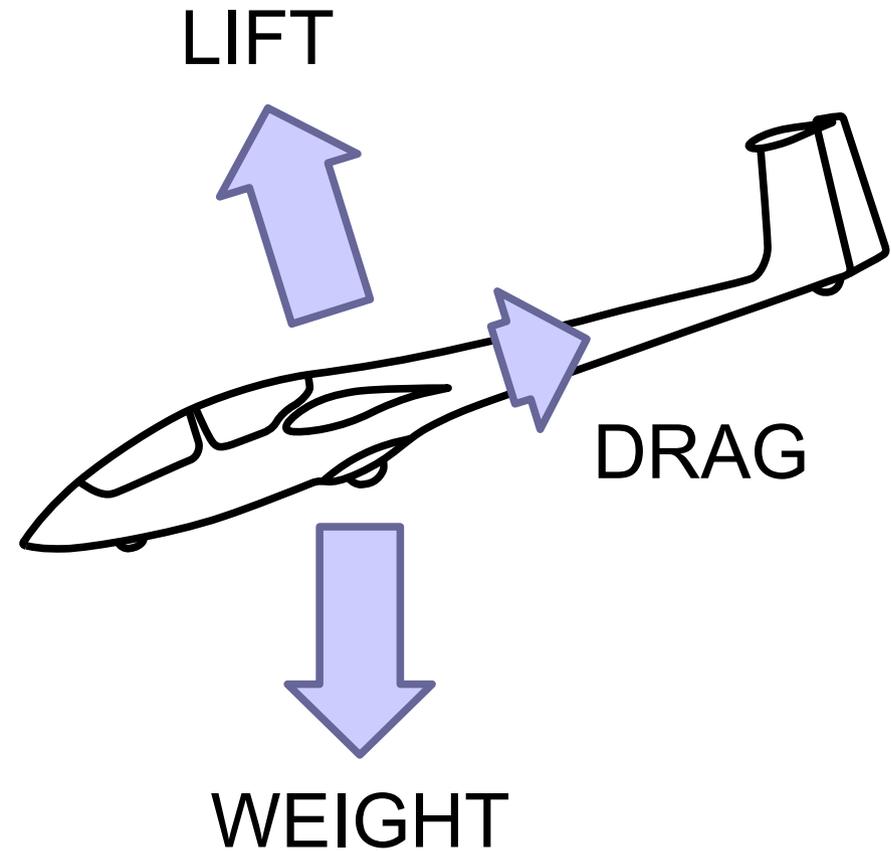
[Equilibrium]

[Linear equilibrium]

1 To maintain steady wings level flight the **lift**, **drag** and **weight** forces must exactly balance each other out.

2

Increase lift	⇒ glider climbs
Reduce lift	⇒ glider falls
Increase drag	⇒ glider decelerates
Reduce drag	⇒ glider accelerates



[Centre of gravity (CG)]

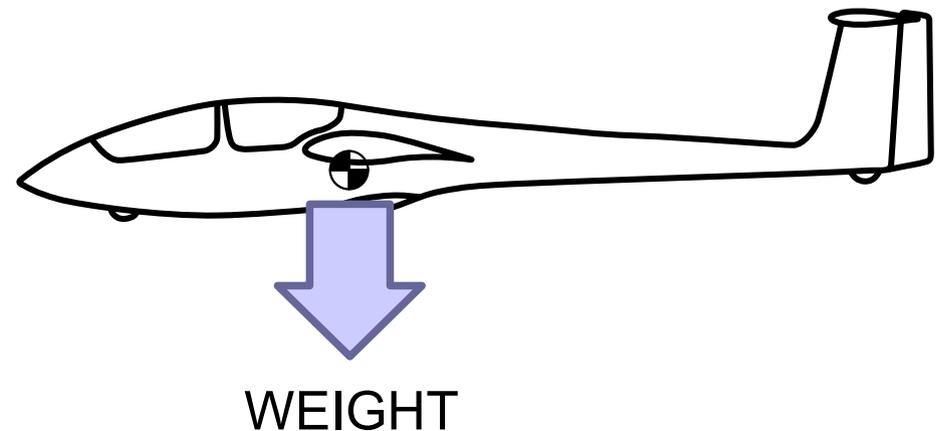
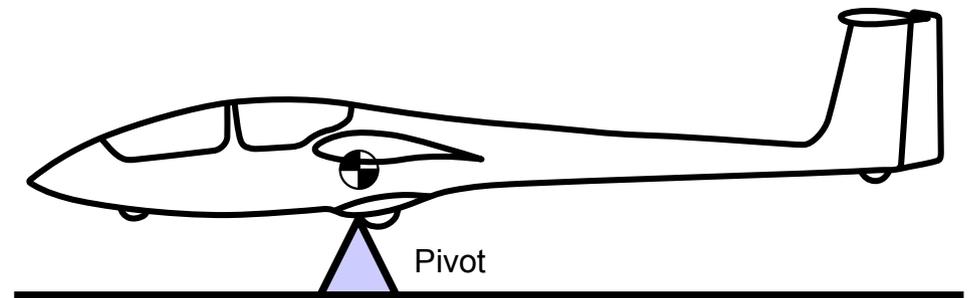
1 A glider's **Centre of Gravity (CG)** is the point at which if you placed the glider on a pivot it would balance perfectly.

2 Increasing the weight of the pilot will move the CG forwards.

Decreasing the weight of the pilot will move the CG backwards.

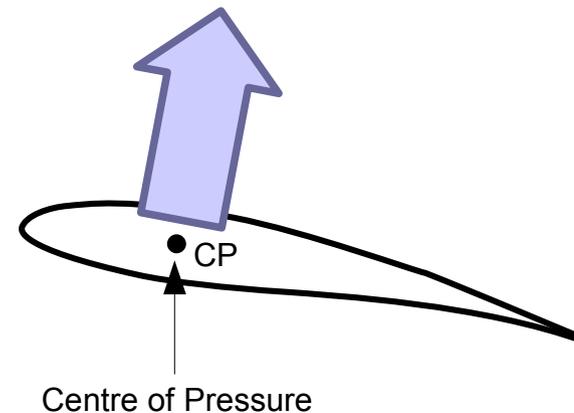
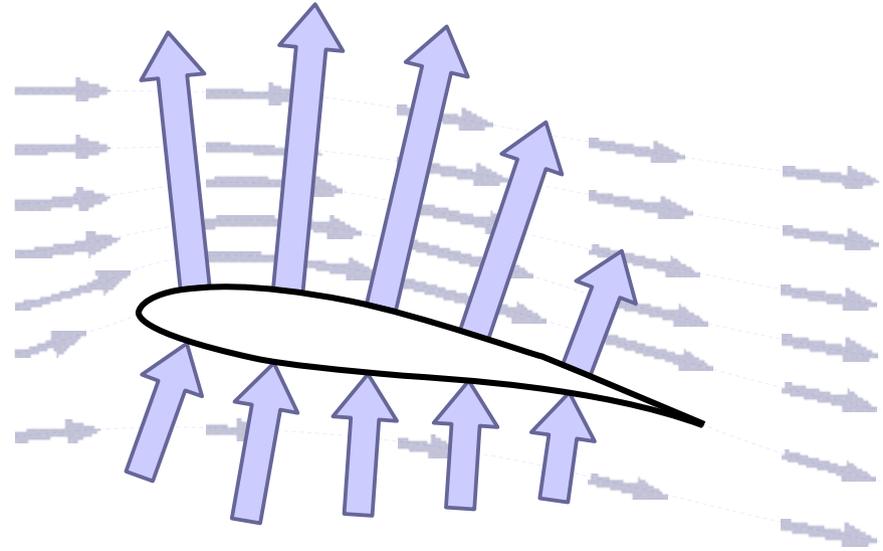
3 The CG can be considered as the point on which the force of gravity acts.

⊕ = **Centre of Gravity (CG)**



[Centre of pressure (CP)]

- 1 Lift and drag forces are produced across the entire surface of the wing.
- 2 For the sake of simplicity, all of these individual forces can be represented by a single force. The point on the wing at which this single force can be considered to act is called the **Centre of Pressure (CP)**.
- 3 The distribution of pressure across a wing changes with angle of attack. On most glider wings this causes the centre of pressure to move forward on the wing as the angle of attack is increased and back as it is decreased.

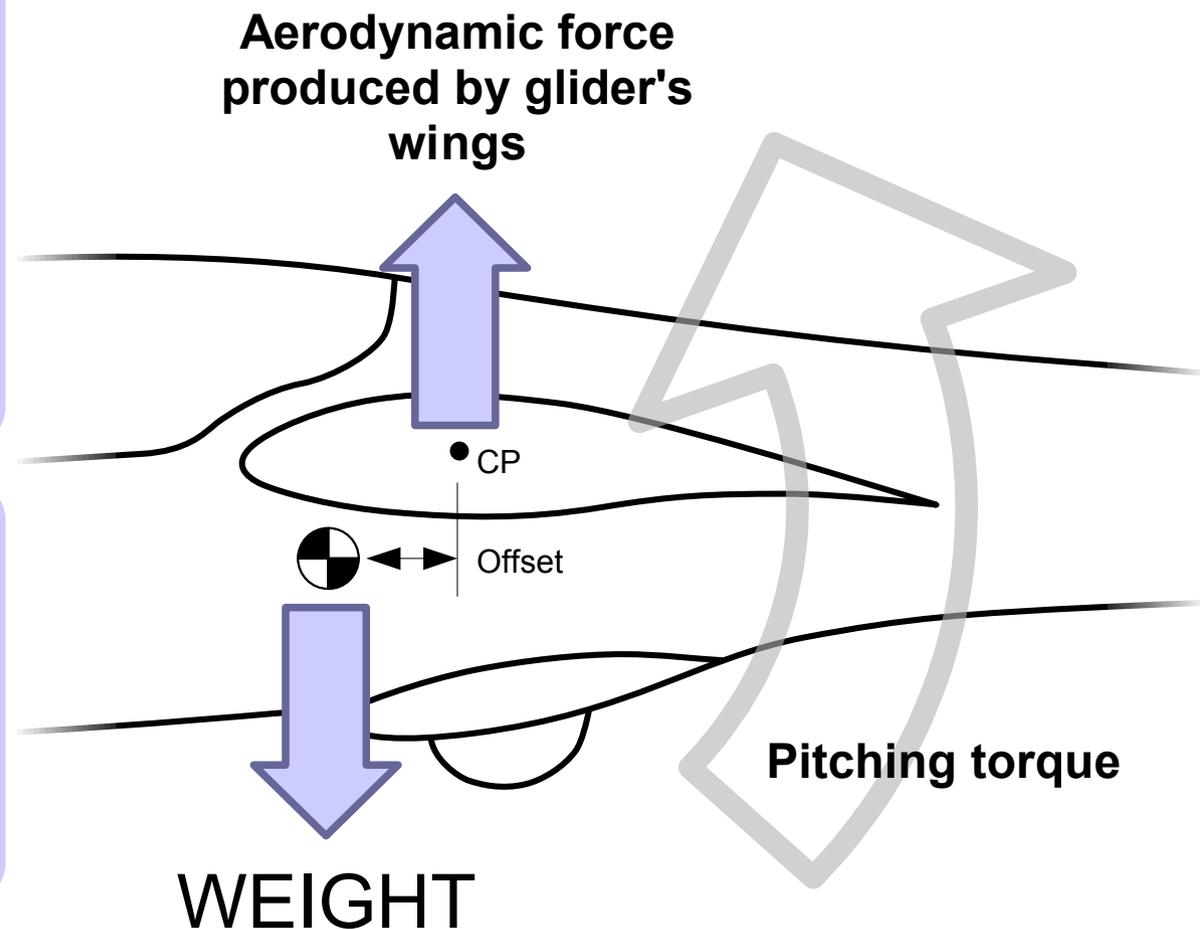


[Unwanted pitching forces]

1 The **centre of gravity** will not move significantly during a flight as its position is set by the weights of the pilots and ballast.
The **centre of pressure** will move forward and backward on the wing depending on the angle of attack.

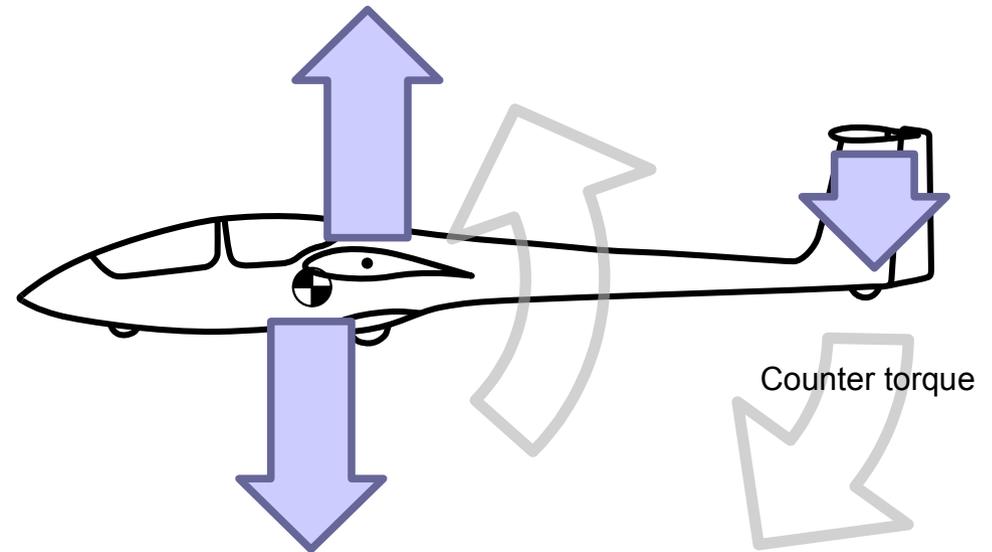
2 Therefore although the aerodynamic force produced by the wing may be of the correct size to balance the gravitational force, the point at which it acts on the aircraft may be offset from the CG.

3 This produces a rotational pitching torque on the aircraft.



[Rotational equilibrium & trimming]

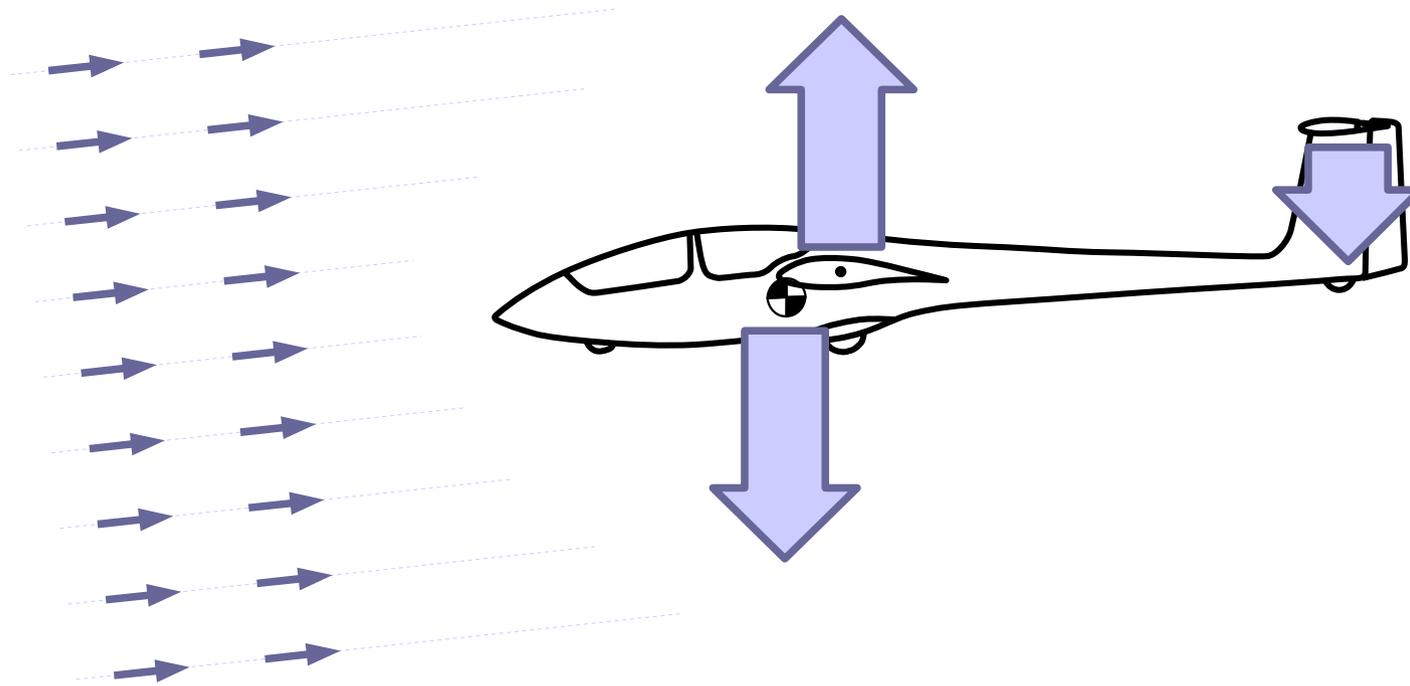
- 1 To balance the rotational torque produced by the locations of the CP and CG, the tailplane therefore needs to produce a counter torque.
- 2 **If CP in front of CG:**
Tailplane needs to generate an up force.
If CP behind CG:
Tailplane needs to generate a down force.
- 3 When you trim a glider you are setting the elevator to a position that will cause the tailplane to generate the up or down force required to counteract the torque produced by the CP and CG.



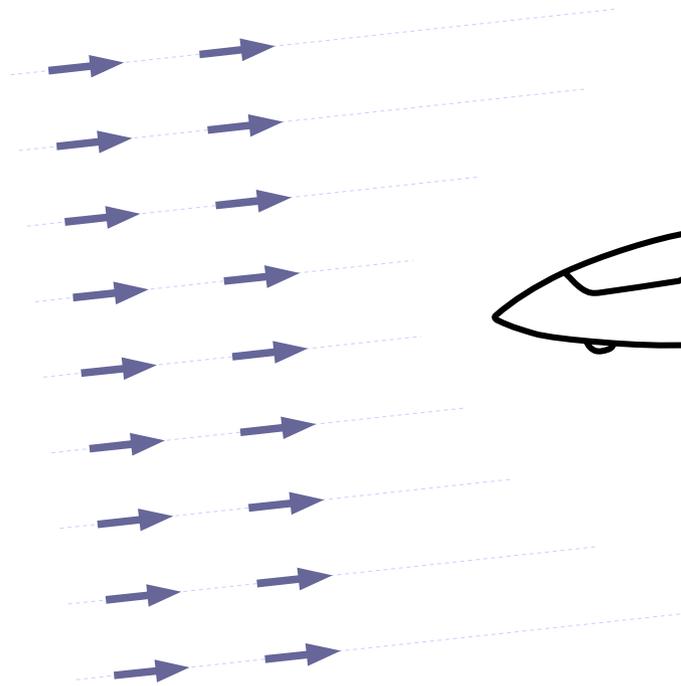
[Control]

[Effect of the elevator]

- 1 Consider an aircraft that is trimmed and flying wings level.

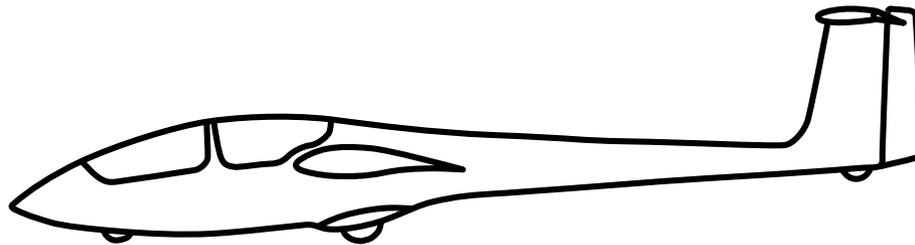


[Effect of the elevator]

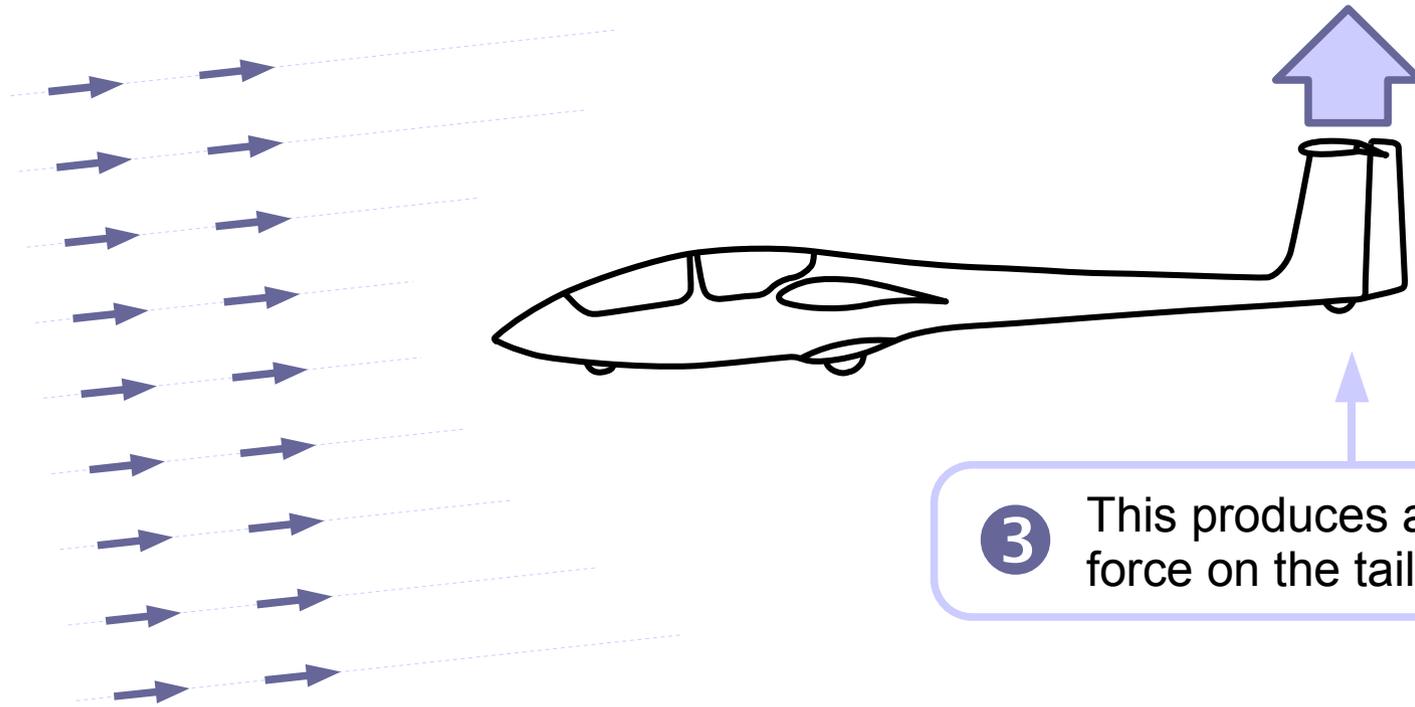


2

Stick is pushed forward which deflects the elevator down.



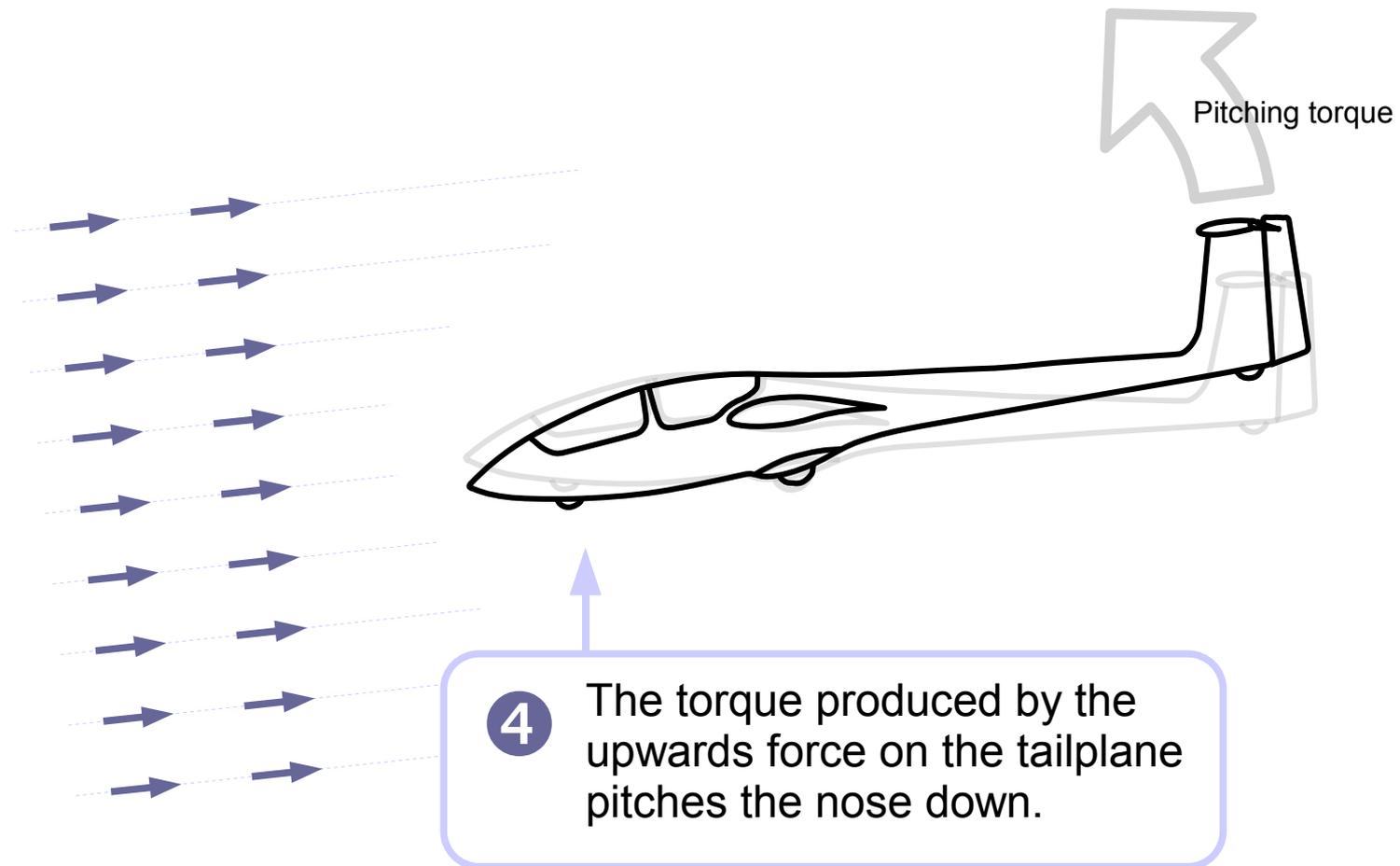
[Effect of the elevator]



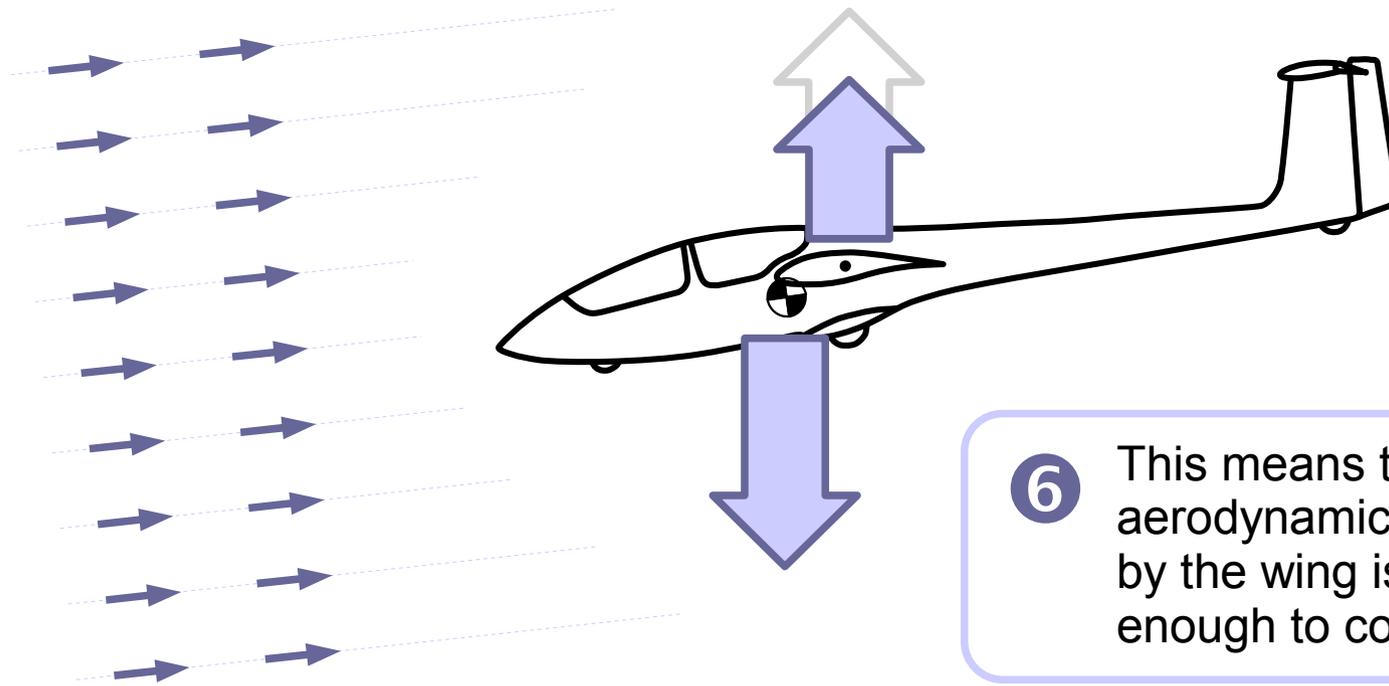
3

This produces a net upwards force on the tailplane.

[Effect of the elevator]



[Effect of the elevator]

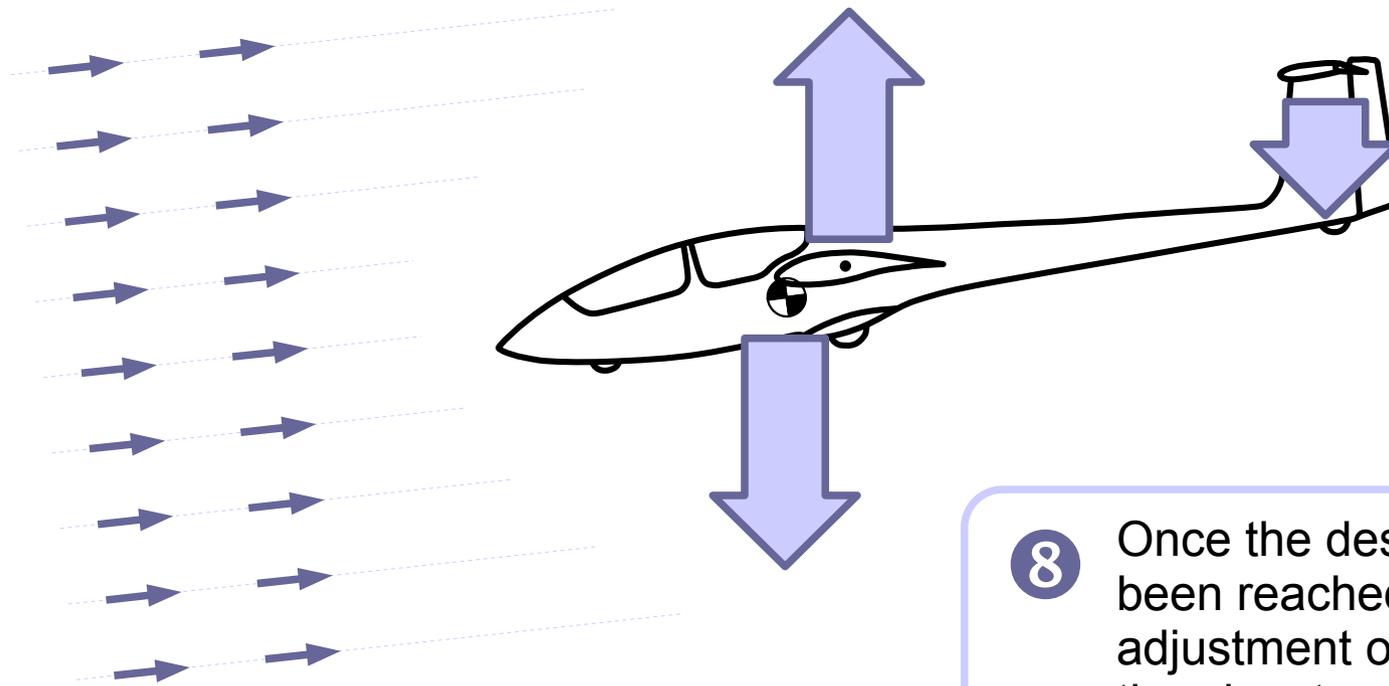


5 The pitching down of the nose reduces the angle of attack of main wing. Hence decreasing the amount of lift it is producing.

6 This means that the aerodynamic force produced by the wing is no longer large enough to counteract gravity.

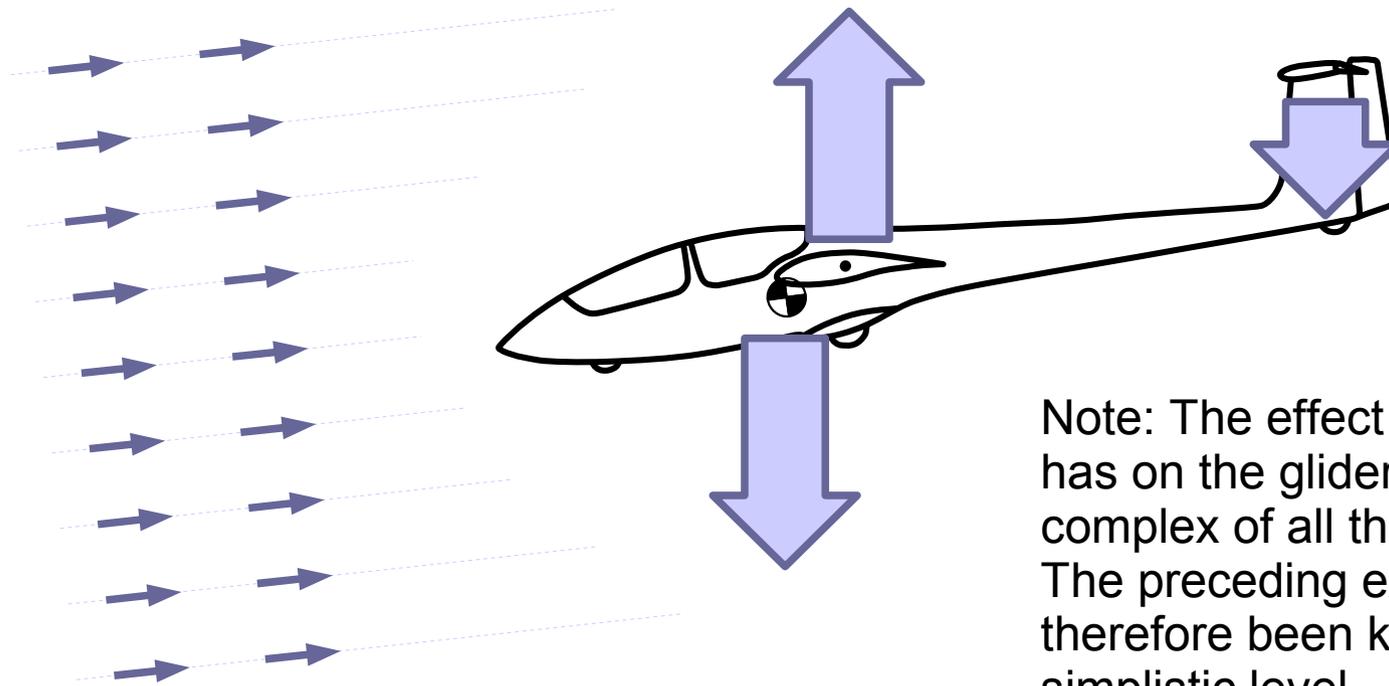
7 The glider therefore starts to fall and accelerate.

[Effect of the elevator]



- 8 Once the desired speed has been reached a slight adjustment of the position of the elevator might be required to correctly hold and trim the glider at the new speed.

[Effect of the elevator]

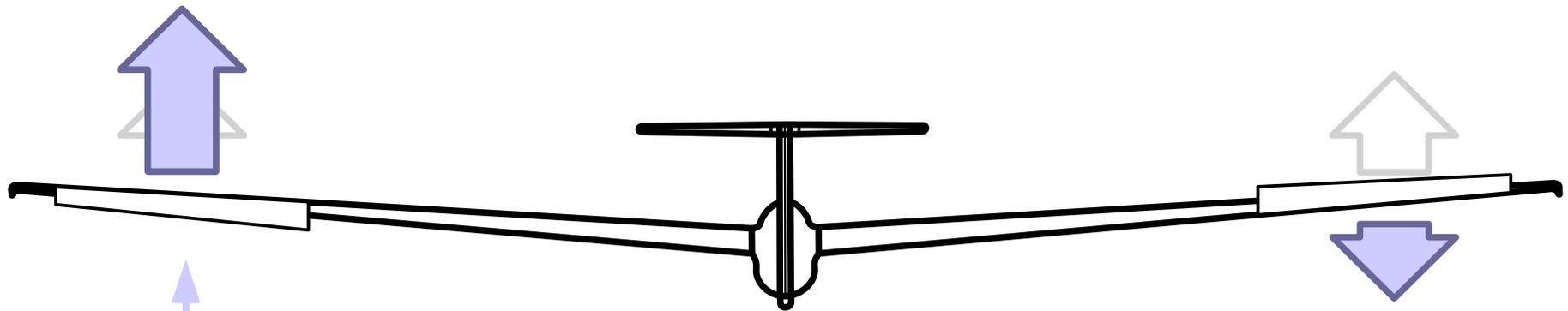


Note: The effect that the elevator has on the glider is the most complex of all the control surfaces. The preceding explanation has therefore been kept at a fairly simplistic level.

Interested students may like to lookup the **Phugoid**.

[Primary effect of the ailerons]

1 Aircraft is trimmed and flying wings level. **Stick is pushed to the right.**



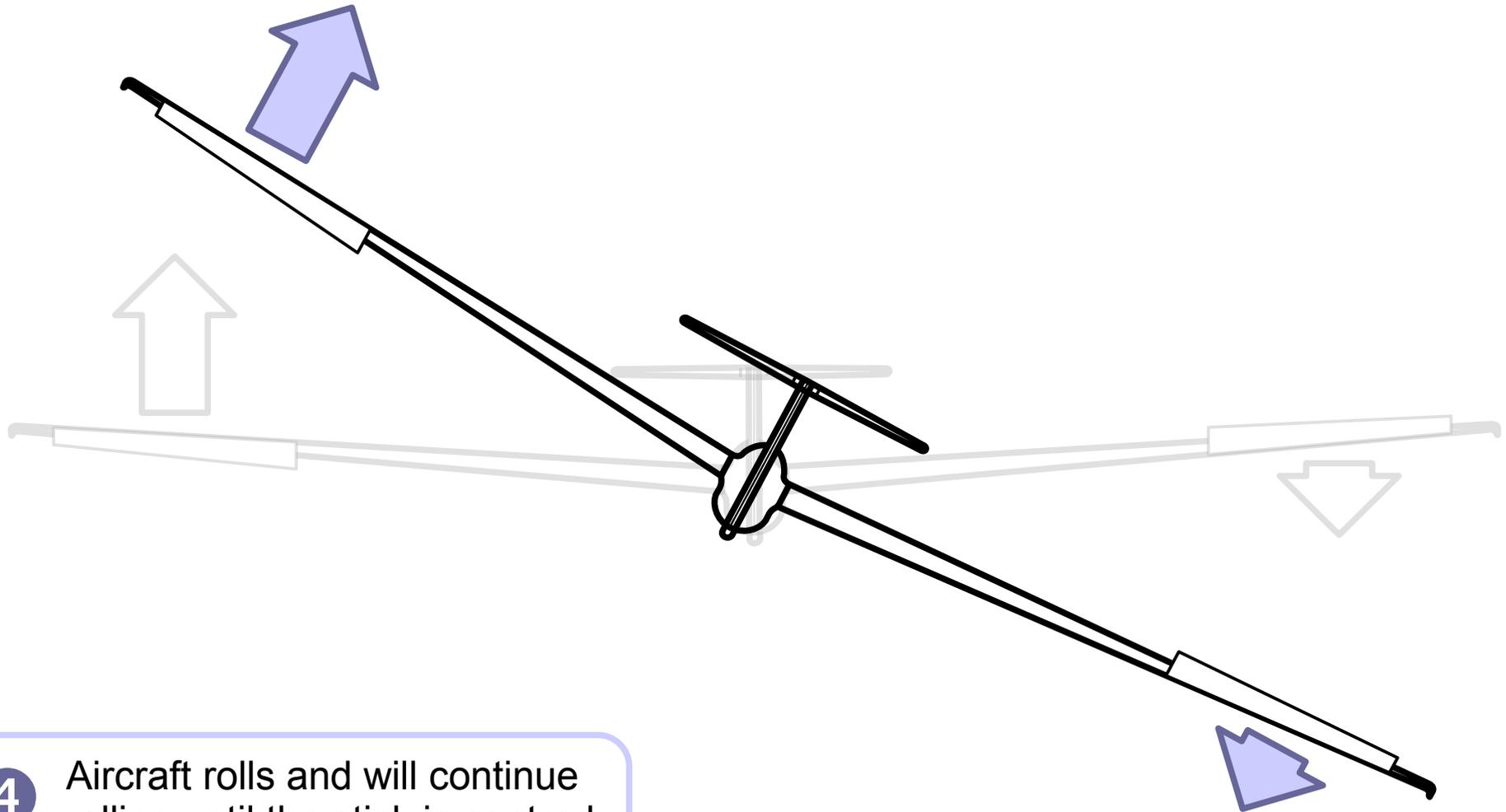
2

- Left aileron deflected down.
- Angle of attack increased.
- **Lift increased.**

3

- Right aileron deflected up.
- Angle of attack decreased.
- **Lift reduced and possibly made slightly negative.**

[Primary effect of the ailerons]



- 4 Aircraft rolls and will continue rolling until the stick is centred and the ailerons return to their neutral position.

[Secondary effect of the ailerons]

1 of 2

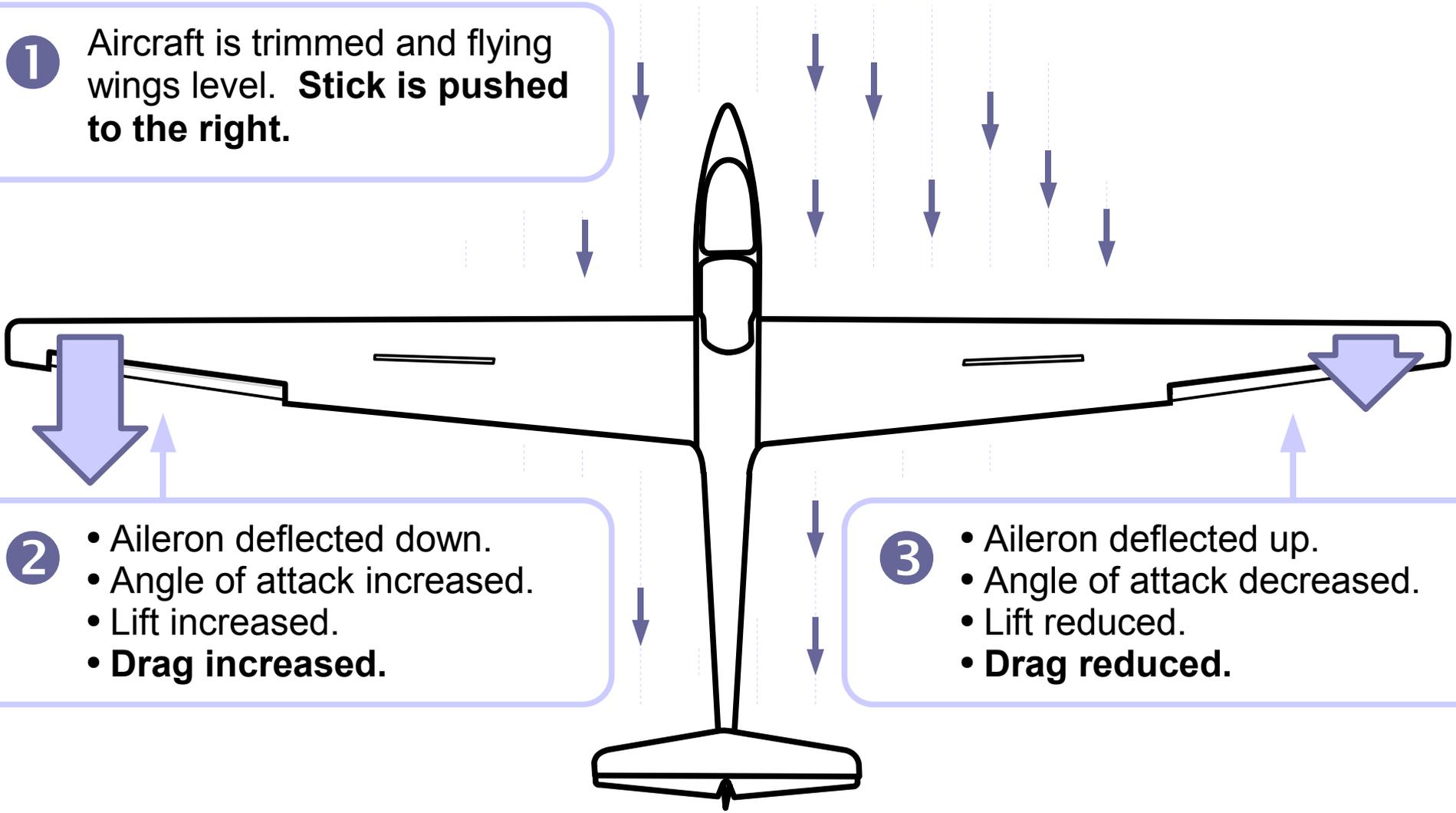
1 Aircraft is trimmed and flying wings level. **Stick is pushed to the right.**

2

- Aileron deflected down.
- Angle of attack increased.
- Lift increased.
- **Drag increased.**

3

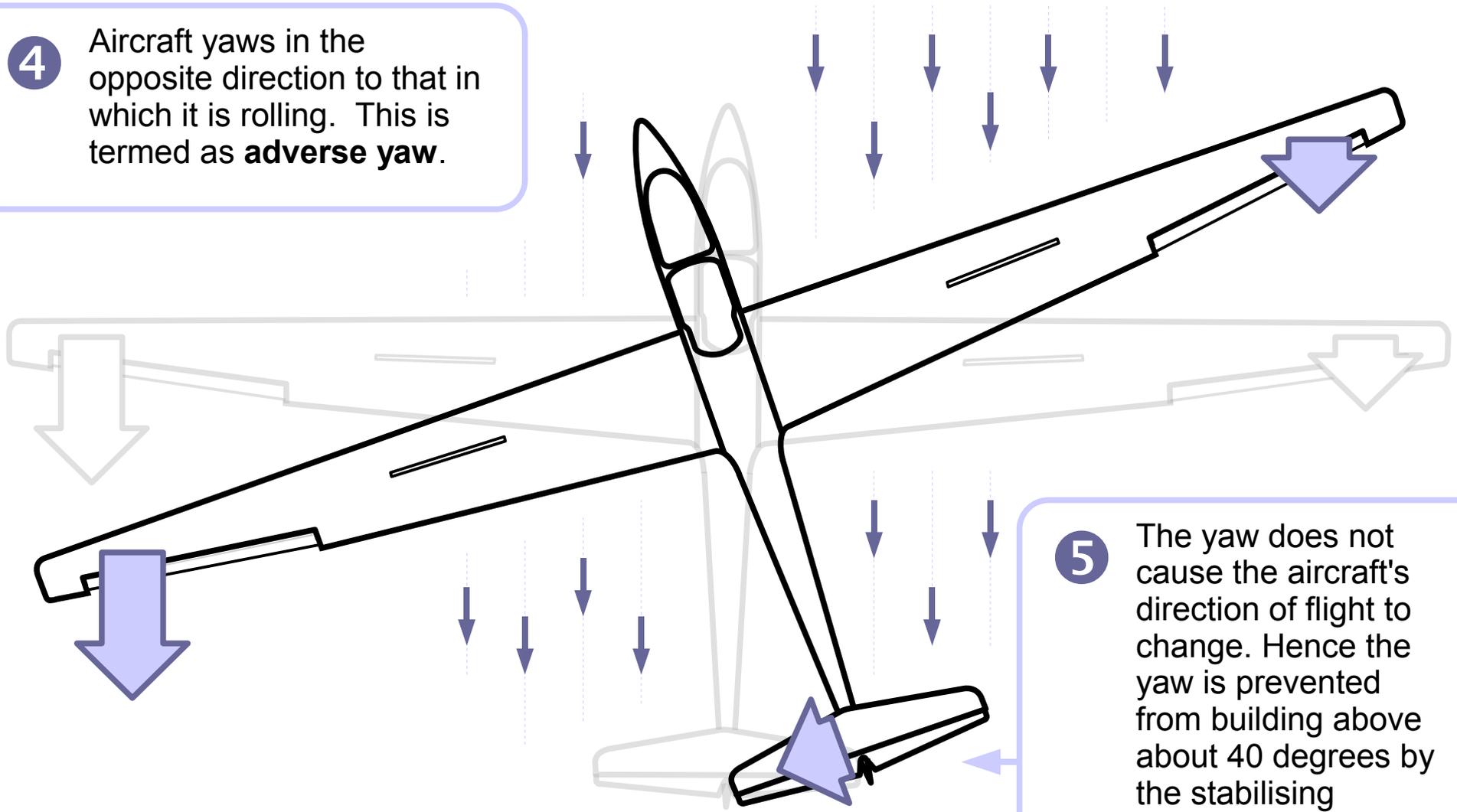
- Aileron deflected up.
- Angle of attack decreased.
- Lift reduced.
- **Drag reduced.**



[Secondary effect of the ailerons]

2 of 2

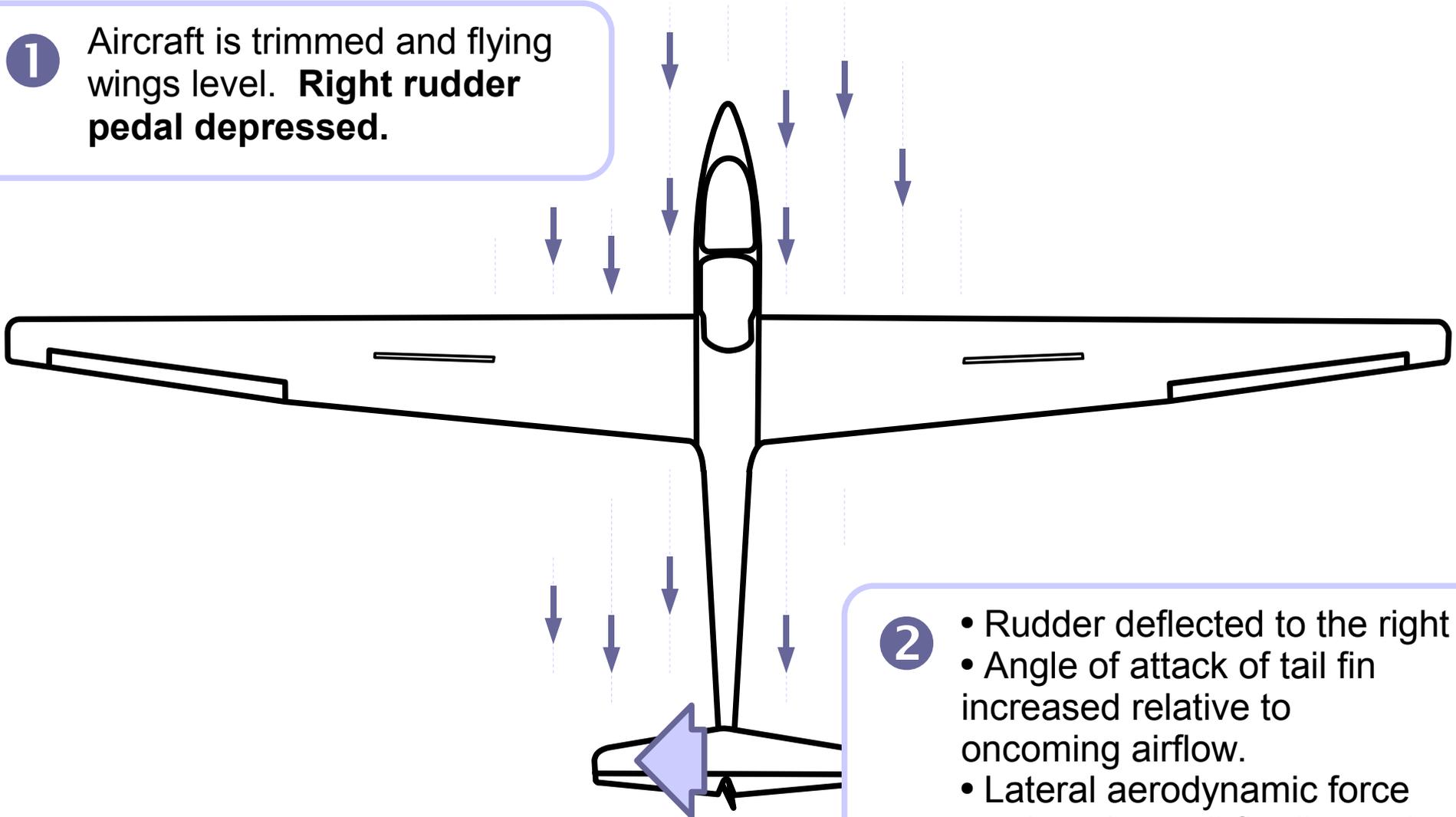
4 Aircraft yaws in the opposite direction to that in which it is rolling. This is termed as **adverse yaw**.



5 The yaw does not cause the aircraft's direction of flight to change. Hence the yaw is prevented from building above about 40 degrees by the stabilising weathercock effect of the vertical fin.

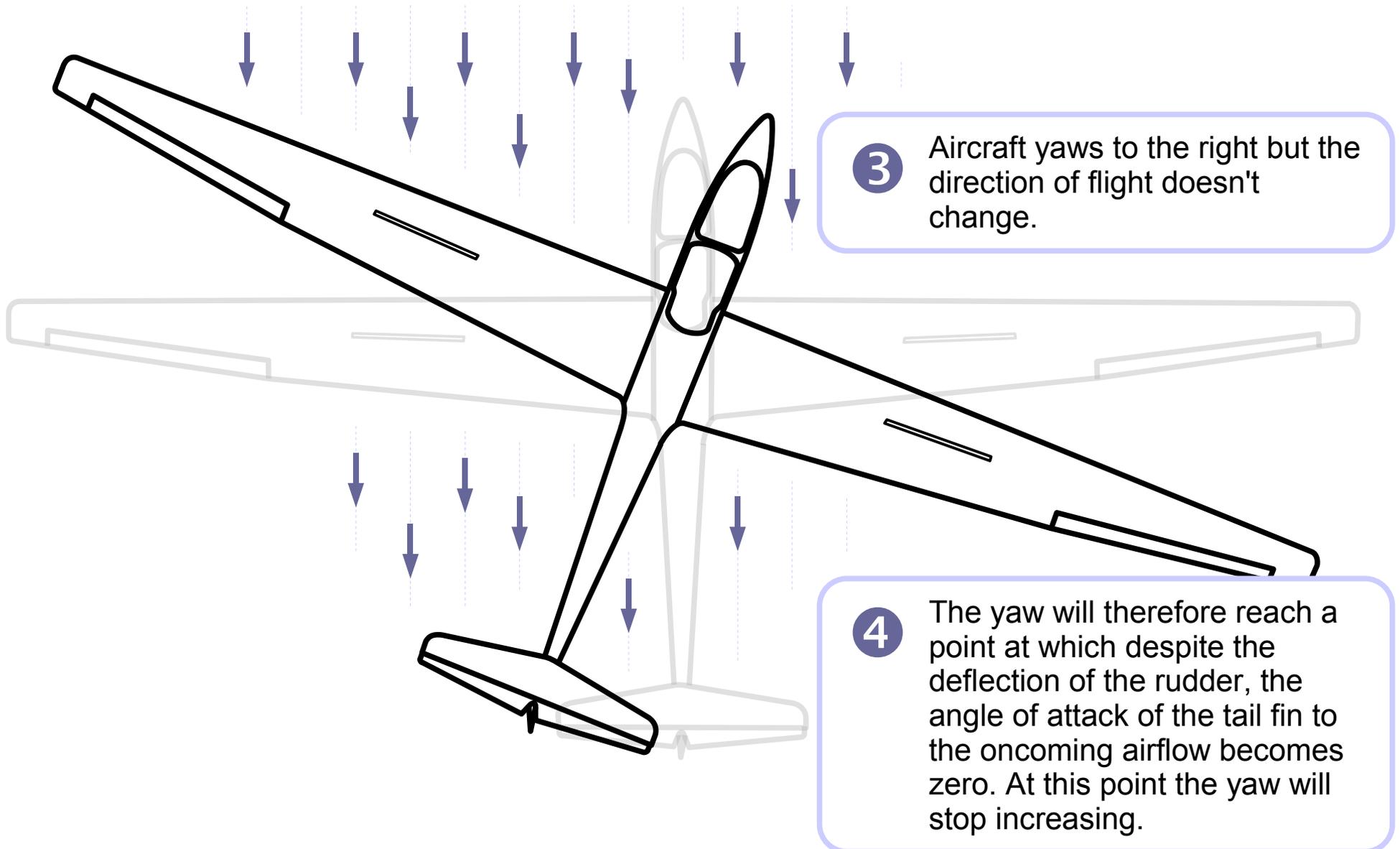
[Primary effect of the rudder]

1 Aircraft is trimmed and flying wings level. **Right rudder pedal depressed.**

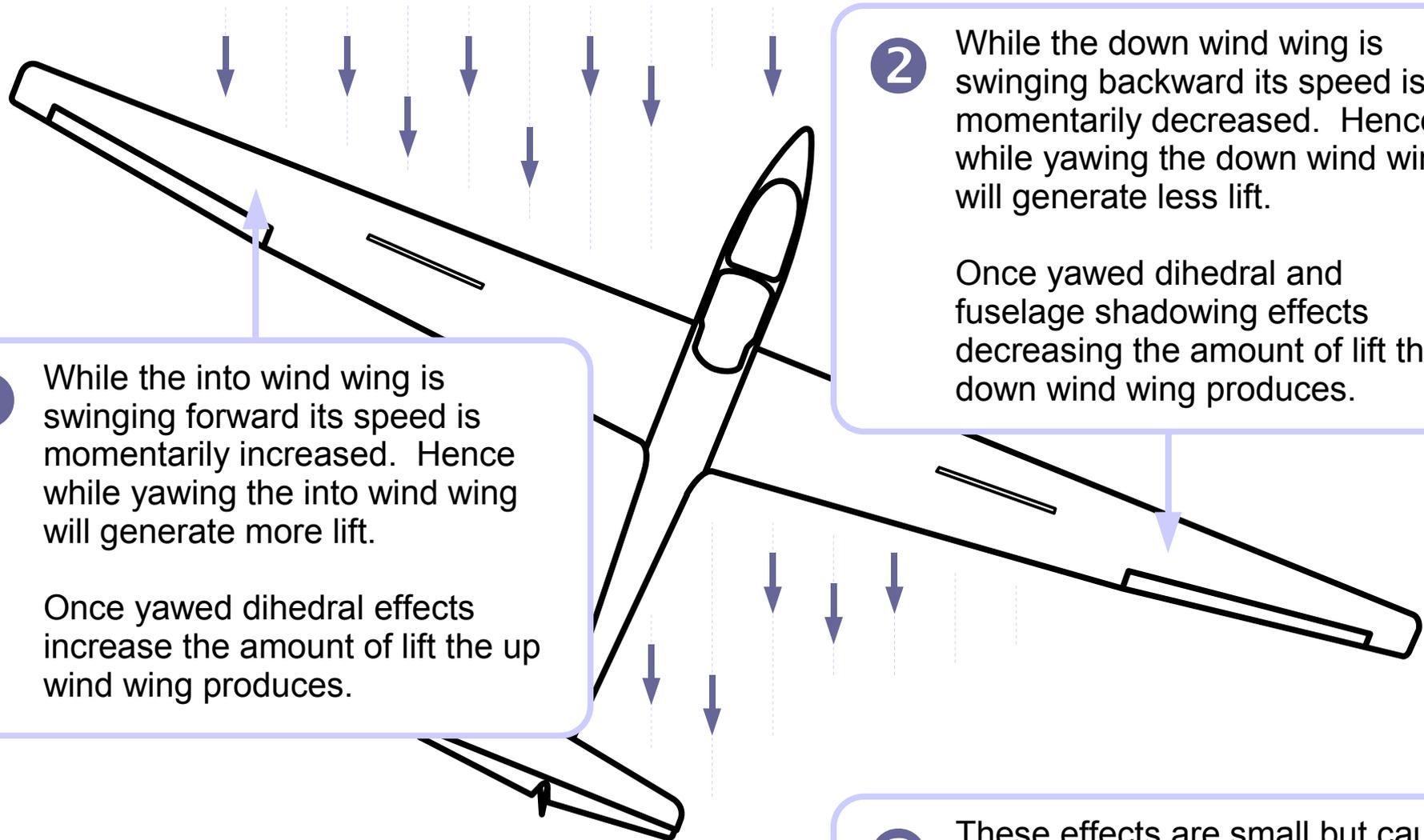


- 2
- Rudder deflected to the right
 - Angle of attack of tail fin increased relative to oncoming airflow.
 - Lateral aerodynamic force produced on tail fin directed to the left.

[Primary effect of the rudder]



[Secondary effect of the rudder]



1 While the into wind wing is swinging forward its speed is momentarily increased. Hence while yawing the into wind wing will generate more lift.

Once yawed dihedral effects increase the amount of lift the up wind wing produces.

2 While the down wind wing is swinging backward its speed is momentarily decreased. Hence while yawing the down wind wing will generate less lift.

Once yawed dihedral and fuselage shadowing effects decrease the amount of lift the down wind wing produces.

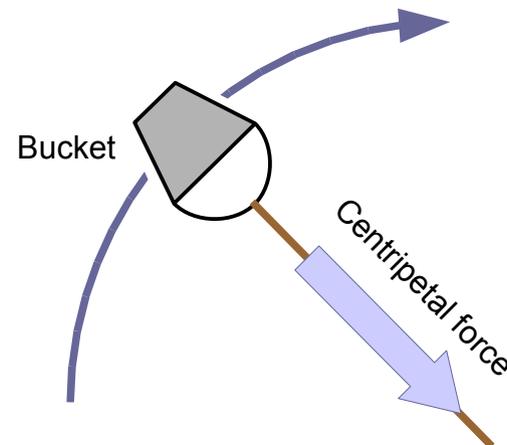
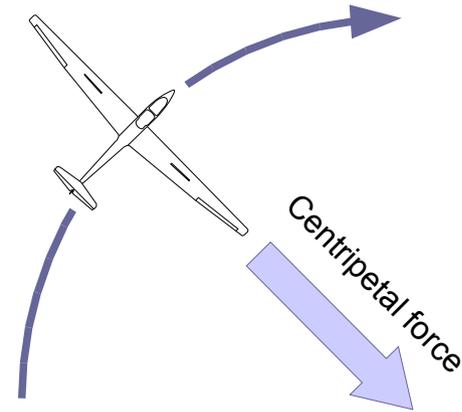
3 These effects are small but cause a gentle rolling of the glider in the direction of the yaw.

[Manoeuvring]

[Centripetal force]

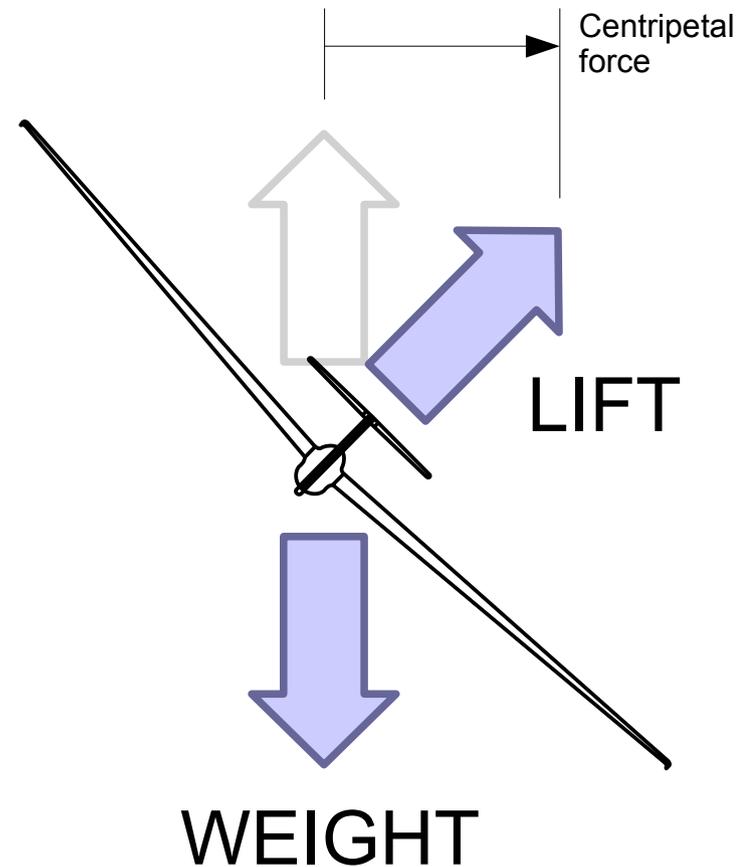
1 The laws of physics state that for a glider to fly along a circular path (E.g. when thermalling or simply turning through 90 degrees) there must be a force acting on the glider toward the centre of the circle. This force is called a **centripetal force**.

2 The force required to turn a glider is exactly the same kind of force as the tension in a piece of string if you have bucket attached to the end of it and you are swinging it around your head.



[Turning]

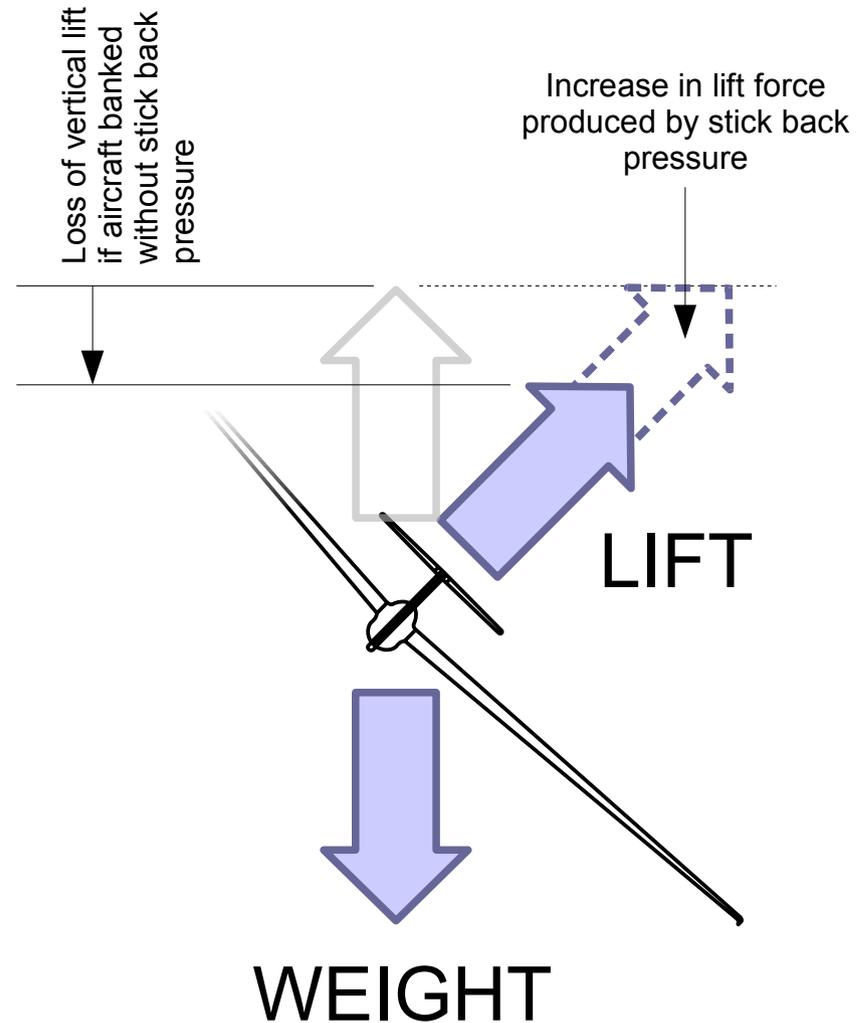
- 1 There is only one force produced by a glider that is large enough to provide enough centripetal force to turn the glider. This is the lift force produced by its main wings.
- 2 To use the main wing's lift force as a centripetal force, the glider must be banked over so that some of the lift force is pushing the glider toward the centre of the circle.



[Stick back pressure during turns]

1 During a turn, if the main wing's lift force is inclined over to the side to provide a centripetal force. Then less of the lift force will be acting vertically to counteract the force of gravity.

2 Stick back pressure is therefore required during a turn to increase the main wing's angle of attack, hence increasing the size of the lift force produced by the wing, such that the component of the wing's lift force that is acting vertically up is once again large enough to counteract the force of gravity.



[Load factor (n,G)]

- 1 Load factor is a measure of the number of times greater the lift force being produced by a wing is than the weight force produced by gravity.

$$\text{Load factor (n)} = \frac{\text{Lift}}{\text{Weight}} \text{ G}$$

- 2 **A glider in steady wings level flight will have a lift force which approximately counterbalances the weight force. It will therefore have a load factor of 1G.**

- 3 The wings of a glider performing a loop and pulling 2G will be generating a lift force that is twice as large as the weight force that is acting on the glider.

[Load factor's effect on stall speed]

1 The speed at which a glider stalls increases with load factor. The higher the load factor the higher the speed at which the glider will stall.

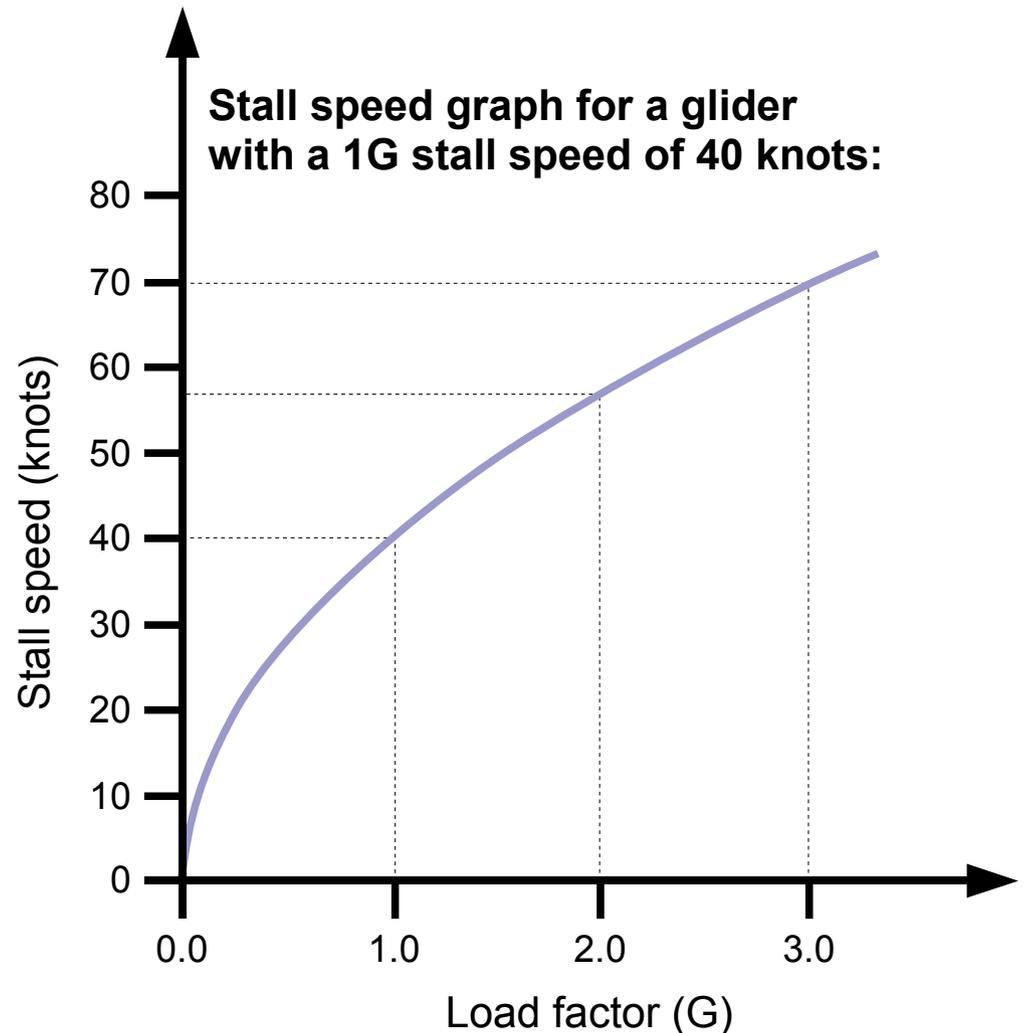
2 The stall speed at a particular load factor can be calculated using the equation:

$$\text{Stall speed} = \sqrt{n} \times (v_{\text{SL-STALL}})$$

n : Load factor

$v_{\text{SL-STALL}}$: 1G stall speed

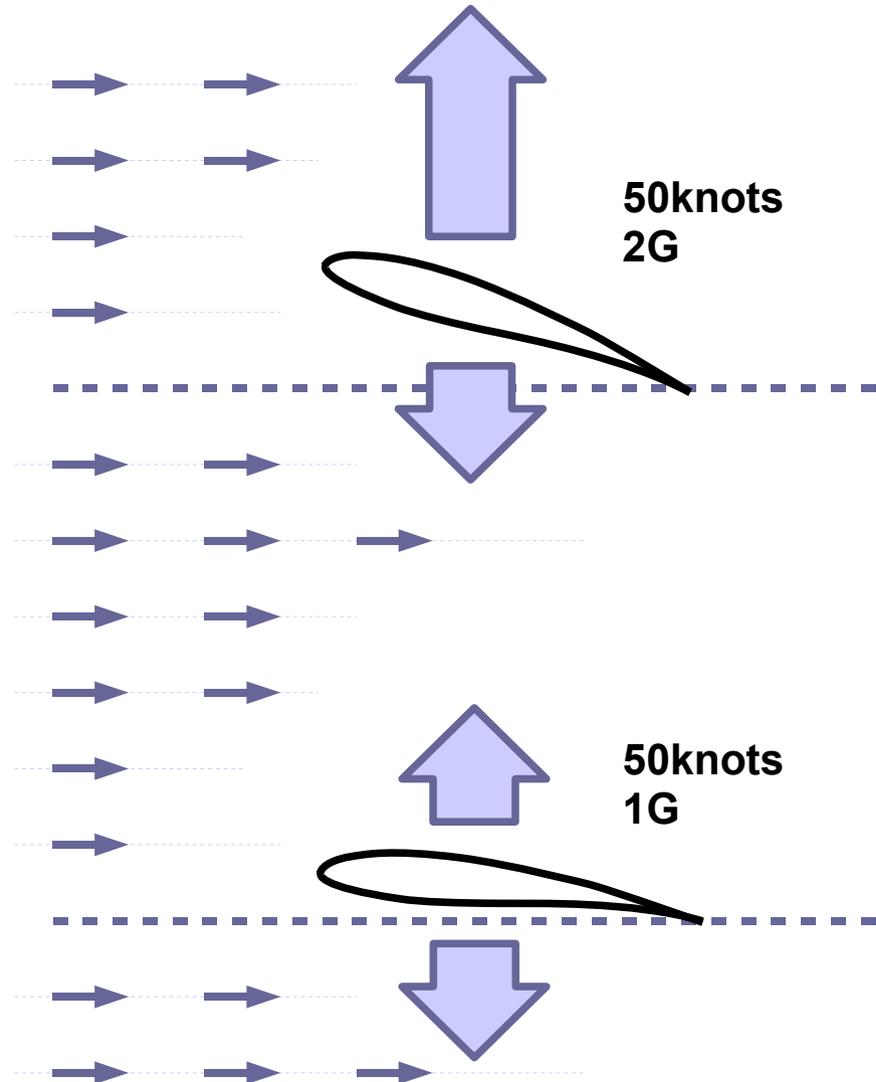
Note: The 1G stall speed is the steady wings level flight stall speed.



[Why does load factor increase stall speed?]

1 An aircraft travelling at 50knots and pulling 2G is by definition generating twice as much lift as a similar aircraft travelling at 50knots and pulling 1G. As the airspeed is the same in both cases the 2G aircraft will require twice the angle of attack on its wing to generate the 2G of lift as the aircraft that is only generating 1G of lift.

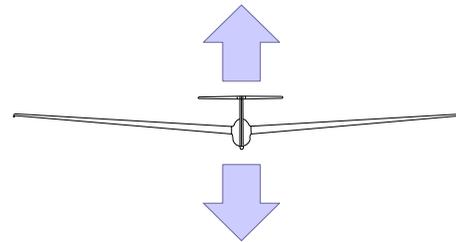
2 Whilst the wing of the 1G aircraft might be well below its stall angle, the increased angle of attack required by the other aircraft to generate 2G of lift may take the wing past it's stalling angle and stall it.



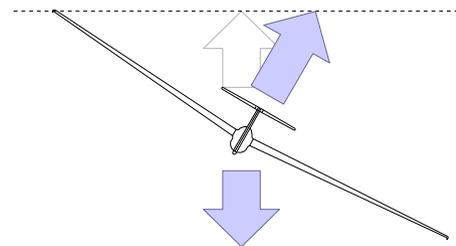
[Load factor and stall speed in a turn]

1 In a turn, as the bank angle increases, the lift force produced by the main wing needs to be made larger and larger by application of stick back pressure for it to maintain a great enough vertical component to counteract gravity.

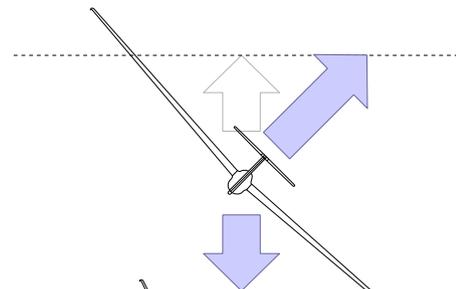
2 Therefore as bank angle increases so does the load factor and hence the stall speed.



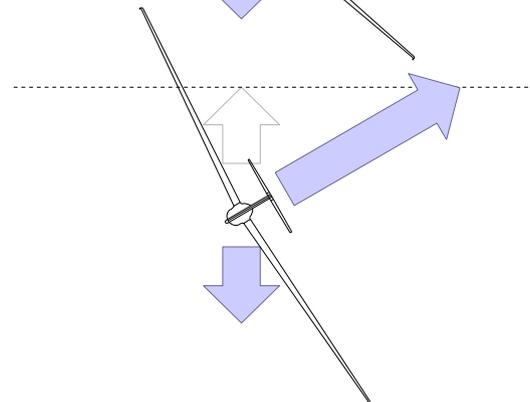
Bank angle : 0°
Load factor : 1G
Stall speed : 40kts



Bank angle : 30°
Load factor : 1.15G
Stall speed : 43kts



Bank angle : 45°
Load factor : 1.41G
Stall speed : 47kts



Bank angle : 60°
Load factor : 2.0G
Stall speed : 56kts

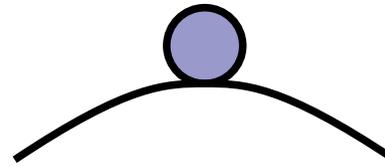
[Stability]

[What is stability?]

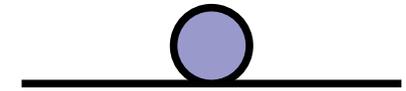
1 An object is termed as being stable if it tends to return to its original position after being disturbed.

2 We want a glider to be stable. So that when it's flying along and is disturbed by a gust, it won't go into a dive or roll onto its back. Instead, without pilot intervention, it will tend to return to whatever it was doing before being disturbed.

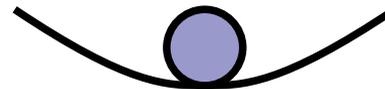
3 However we don't want a glider to be over stable otherwise we won't be able to manoeuvre it.



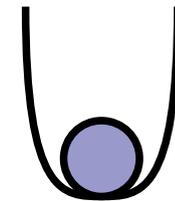
Unstable



Neutrally stable



Stable



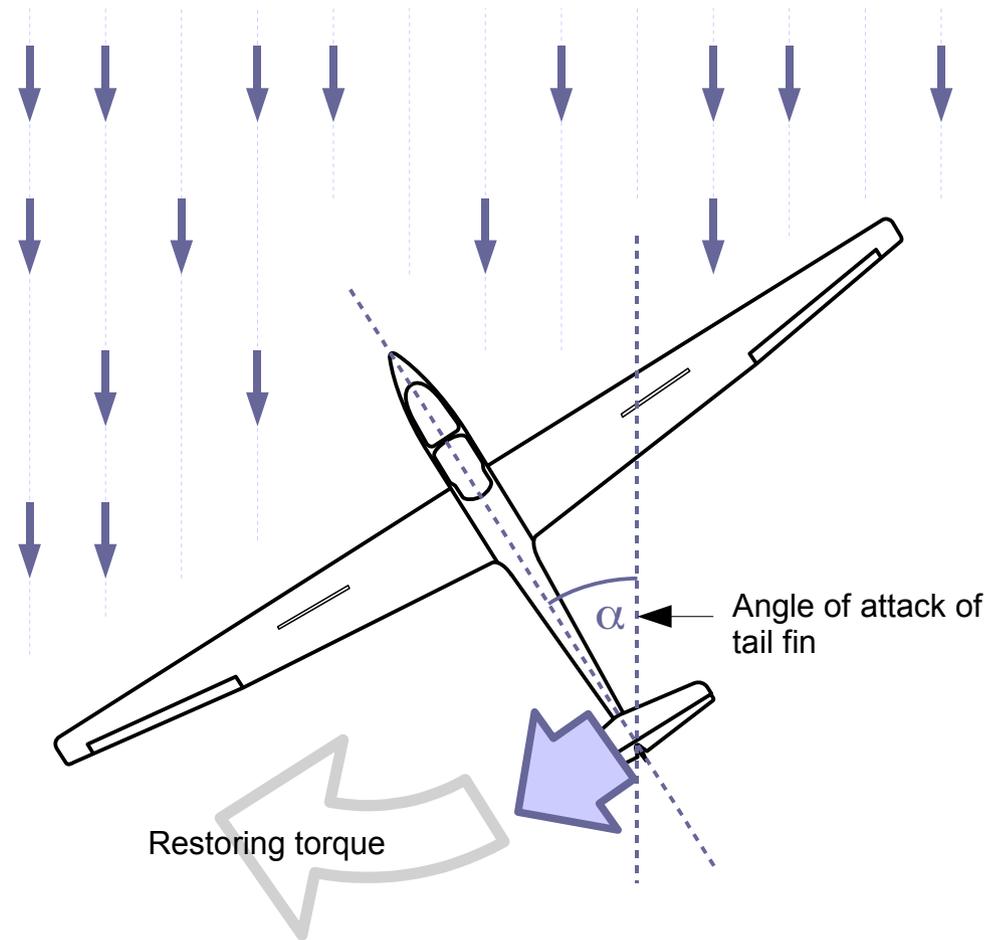
Over stable

[Yaw stability]

1 Due to an unplanned push on the rudder pedals the glider becomes yawed relative to the direction in which it is travelling (E.g. The oncoming air flow).

2 The tail fin (vertical stabiliser) now has an angle of attack relative to the oncoming airflow.

3 A lateral aerodynamic force is therefore produced on the tail fin that creates a torque which will tend to weathercock the glider back into line with the airflow.



[Roll damping]

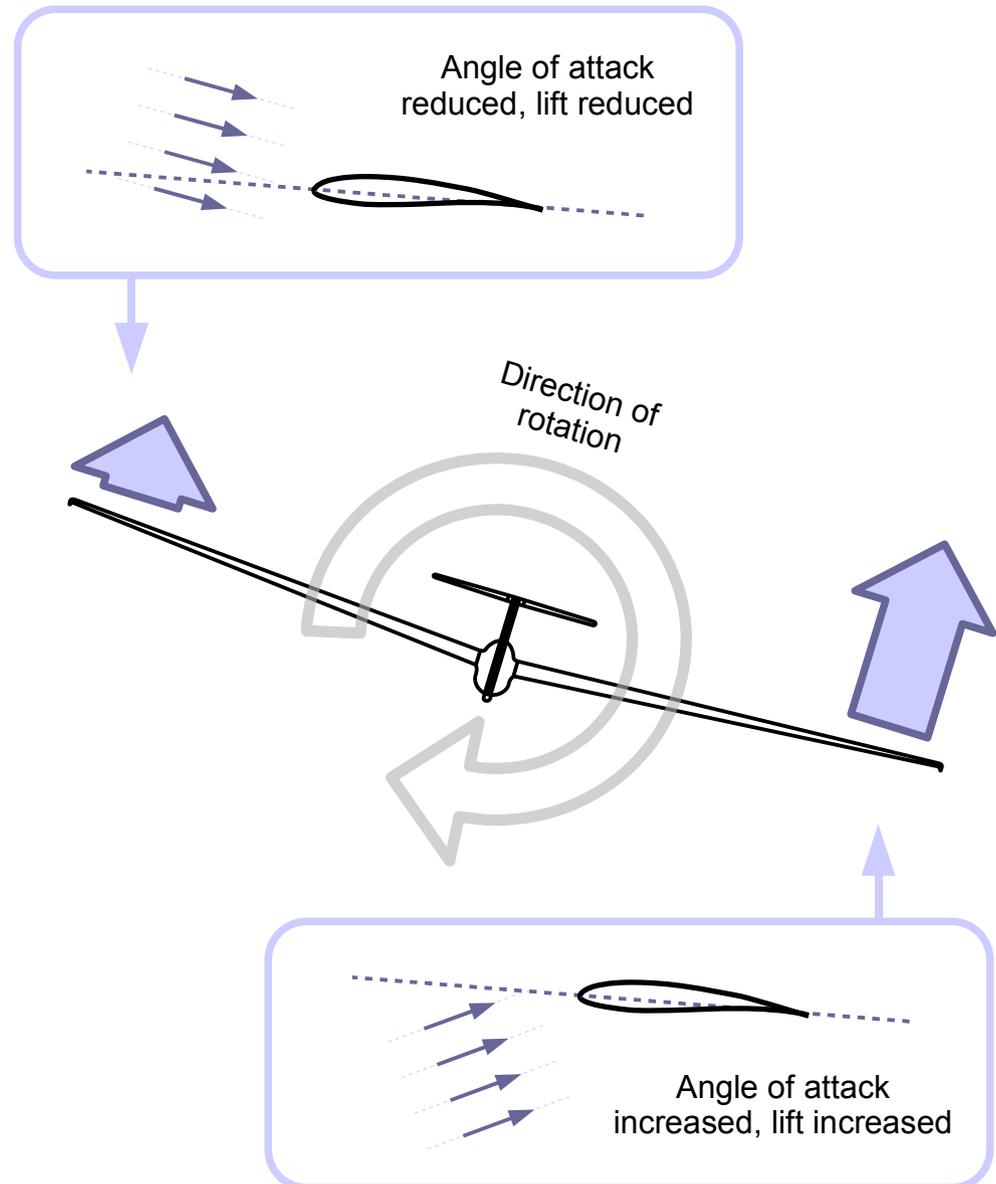
1 Due to a gust of wind, a wing is lifted and the glider starts to roll.

2 **Downward going wing:** Angle of attack increased because the wing is moving down and hence the air is moving up past it. Lift on this wing is therefore increased.

Upward going wing: Angle of attack reduced because the wing is moving up and hence the air is moving down past it. Lift on this wing is therefore reduced.

3 This produces a counter torque that damps out the rolling motion.

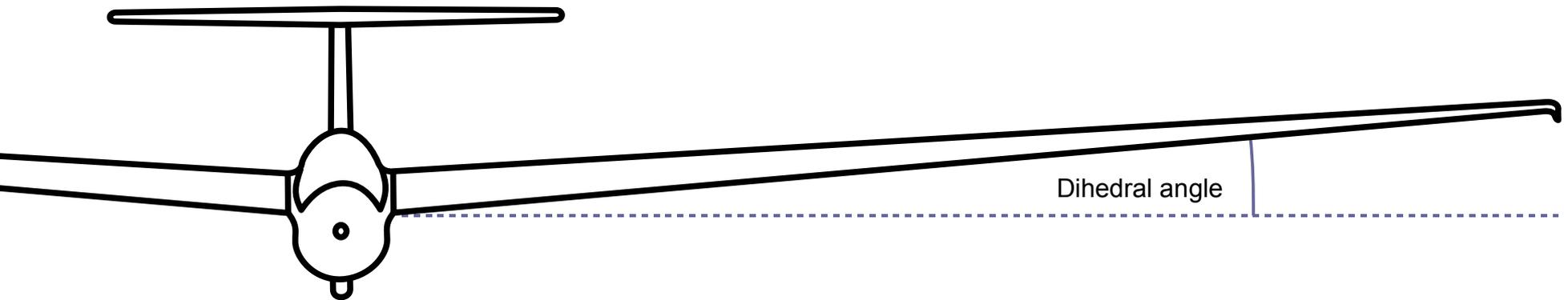
However this will not roll the glider back to wings level as the effect stops when the glider stops rolling.



[Dihedral]

1 If the tips of glider's wings are higher than their roots then the wings are said to have **dihedral**.

2 If the tips are below the roots then the wings are said to have **anhedral**.



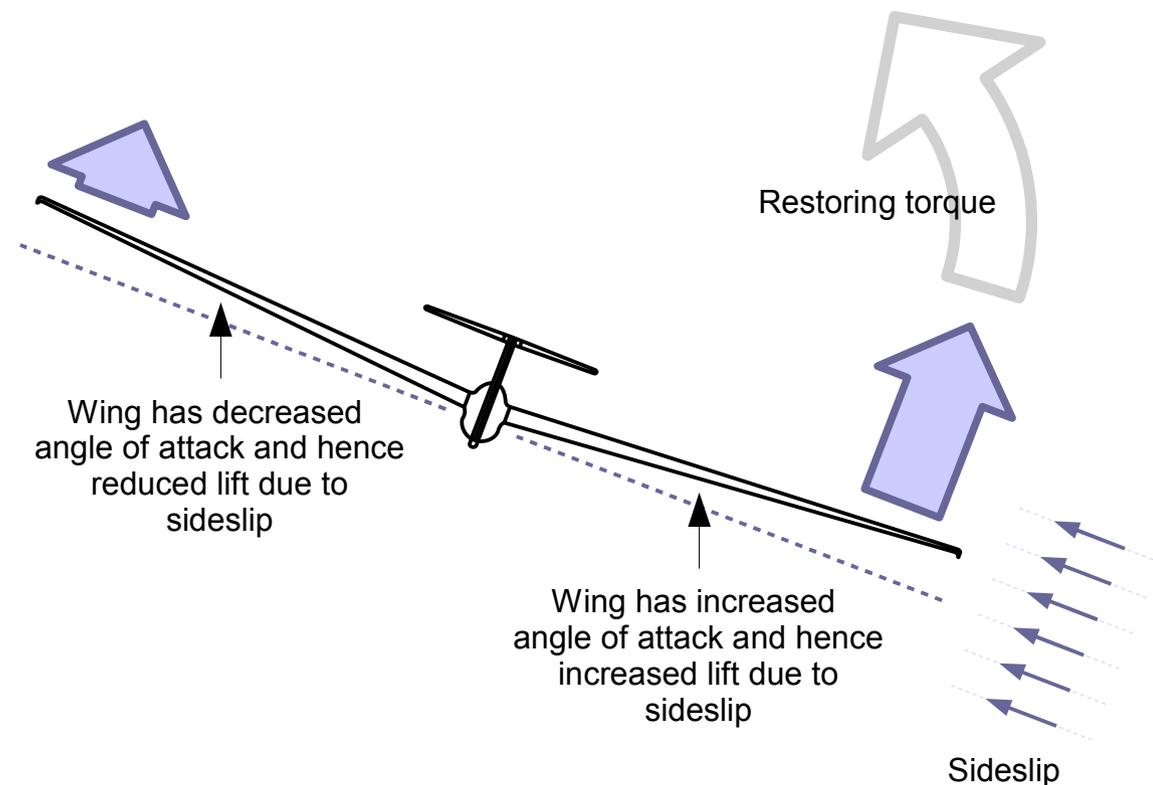
[Dihedral and roll stability]

1 If a glider is banked over but insufficient stick back pressure is applied to create enough lift to counteract gravity, then the glider will slip sideways through the air.

2 If the glider has dihedral, then the wing facing into the sideslip will have its angle of attack increased by the air flowing in from the side due to the sideslip. The lift on this wing is therefore increased.

Conversely the wing facing away from the sideslip will have its angle of attack reduced and hence the amount of lift it is producing will drop.

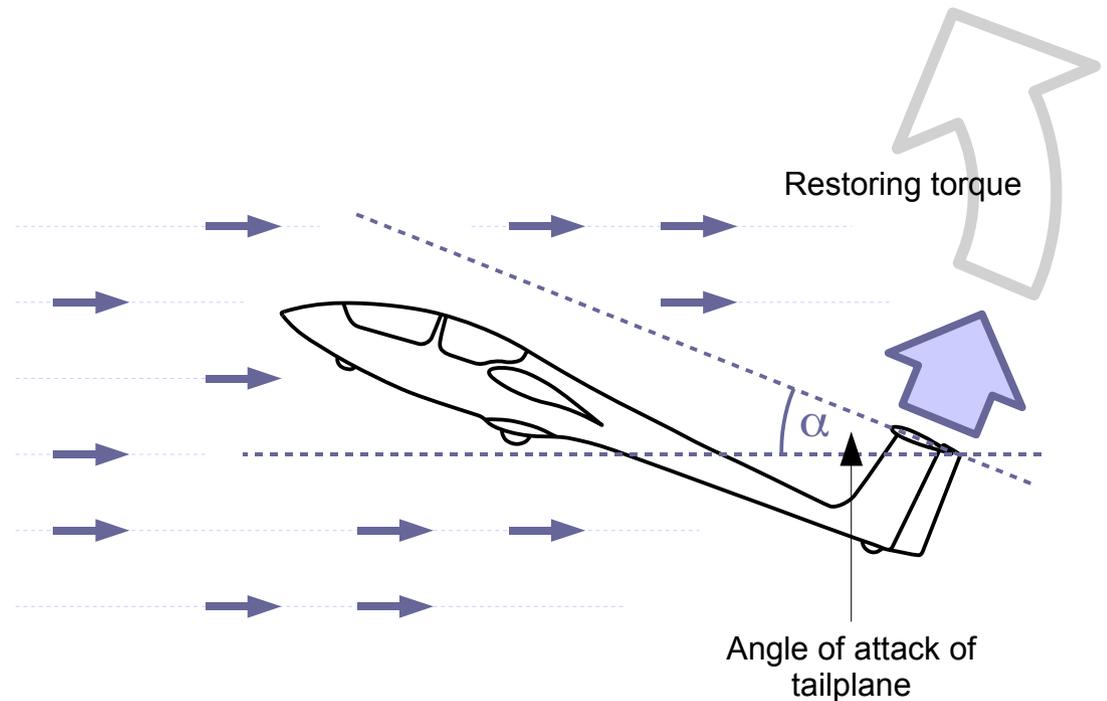
3 This produces a torque on the glider that will tend to roll it back to wings level.



Note: Anhedral will reduce roll stability.

[Pitch (longitudinal) stability]

- 1 Due to a gust of wind the glider's nose pitches up relative to the direction in which it is travelling. (E.g. The oncoming air flow).
- 2 The tailplane (horizontal stabiliser) now has a significant angle of attack relative to the oncoming airflow.
- 3 An aerodynamic force is therefore produced on the tailplane that creates a torque which will tend to weathercock the glider back into line with the airflow.



[Pitch stability C of G limits]

1 For the tailplane to correctly function as a pitch stabilising device, the glider's centre of gravity must be within the fore and aft limits specified by the manufacturer in the glider's flight manual.

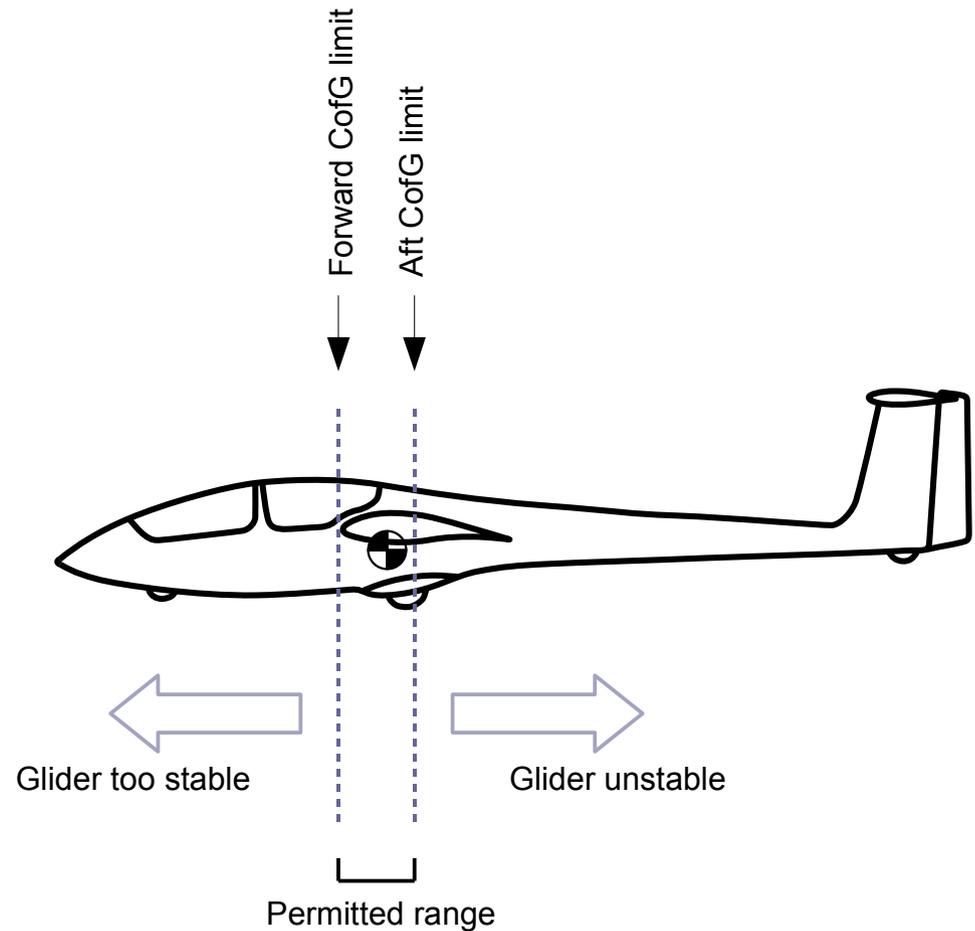
2 A heavy pilot will move the CG forward. A light pilot will move the CG backwards.

3 **CG behind aft limit :**

- Glider becomes unstable.
- Prone to spinning.

CG in front of forward limit :

- Glider becomes too stable.
- Elevator will not have enough effectiveness to round out.



[Any questions?]

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