

# Principles of glider flight

[ Lecture 1: Lift, drag & glide performance ]

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# [ Recommended books ]

## 1 **Understanding Gliding**

Derek Piggott  
A & C Black, London

A good book to purchase just after going solo. Forms a natural progression from the pre-solo introductory texts. Clearly written and oozing with wisdom.

ISBN: 0-7136-6147-X

## 2 **Gliding**

The BGA Manual  
A & C Black, London

A comprehensive, cleanly written tutorial text with copious diagrams.

ISBN: 0-7136-5947-5

## 3 **Mechanics of flight**

A. C. Kermode  
Prentice hall

Not specifically a gliding book. Contains some equations. Worthwhile if you want some insight into powered flight as well.

ISBN: 1-4058-2359-3

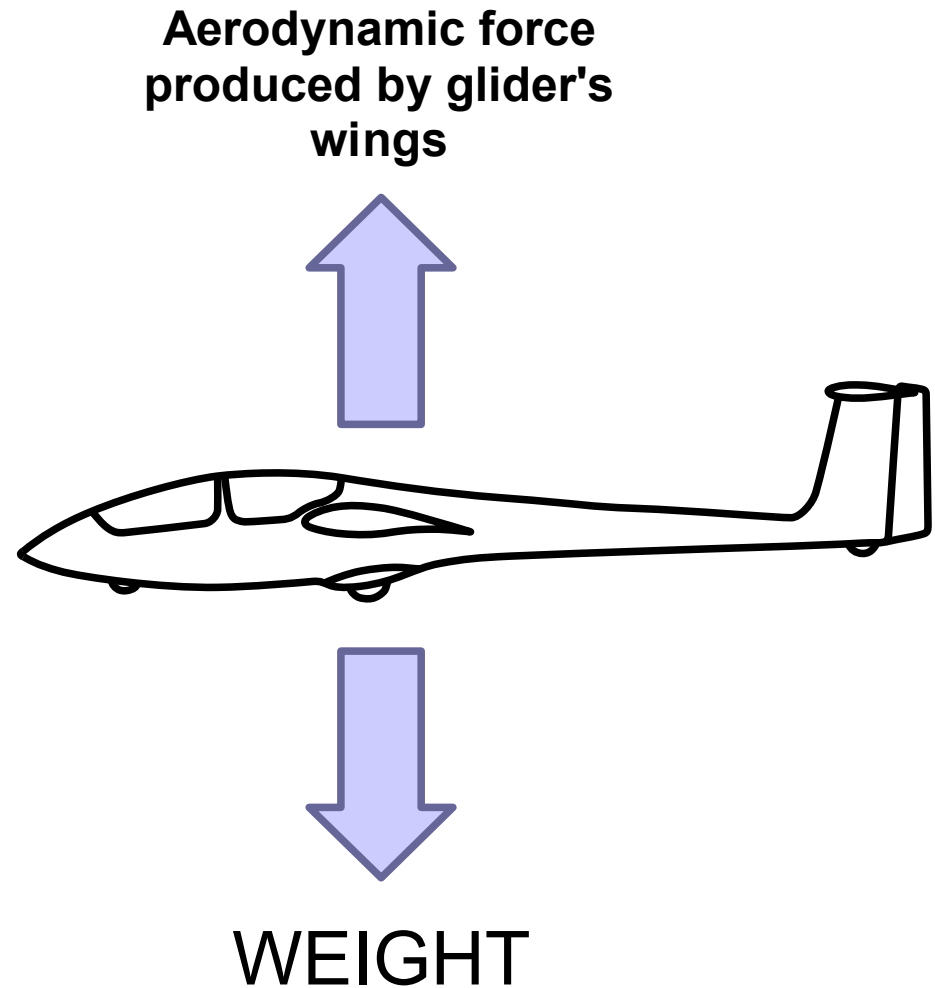
**[ The basics ]**

# [ Keeping a glider in the air ]

1 The Earth's gravitational attraction creates a “weight” force that attempts to pull the glider toward the centre of the Earth.

2 Newton's first law suggests that for the glider to remain in steady wings level flight, it needs to produce an equal and opposite force to counterbalance the “weight” force.

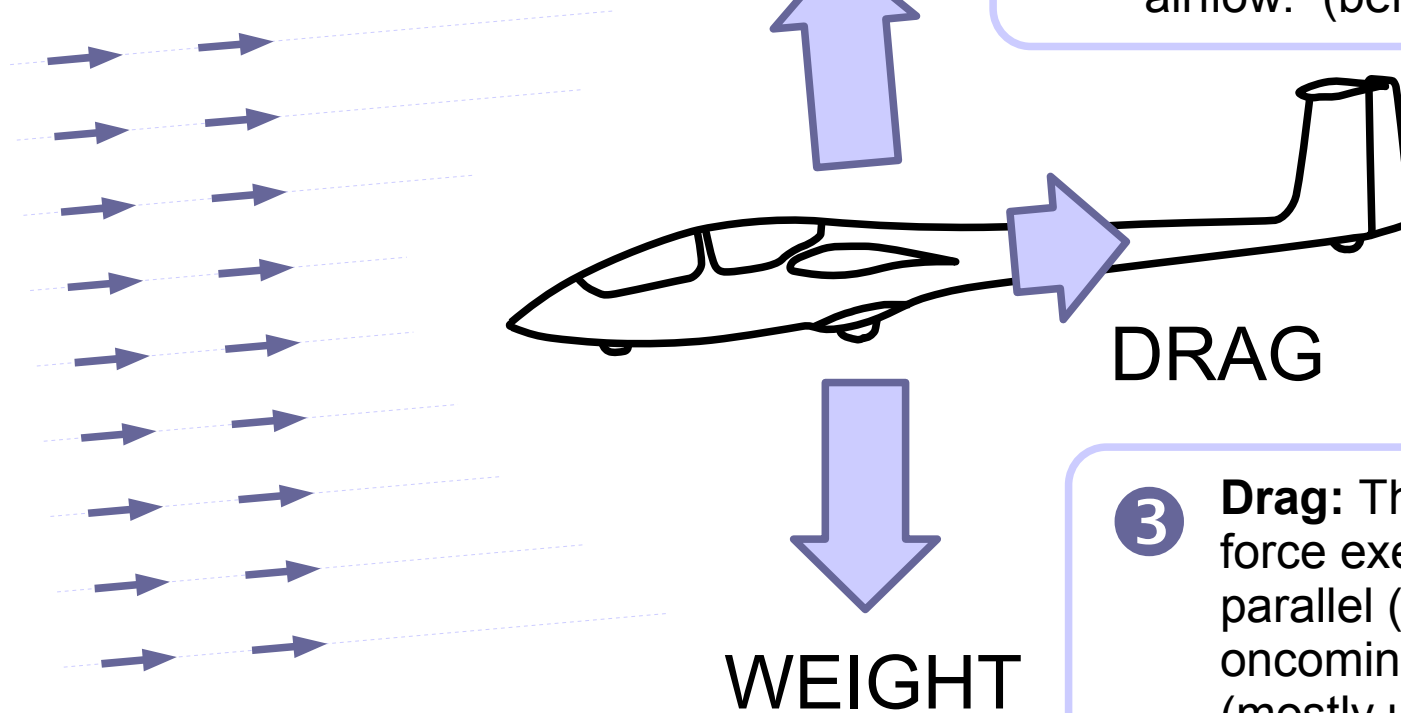
3 This counterbalance is provided by the aerodynamic force produced when air flows across a glider's wings.



# [ Lift and drag ]

1 Aerodynamicists divide the force produced by a glider's wings into two parts. They call these "Lift" and "Drag".

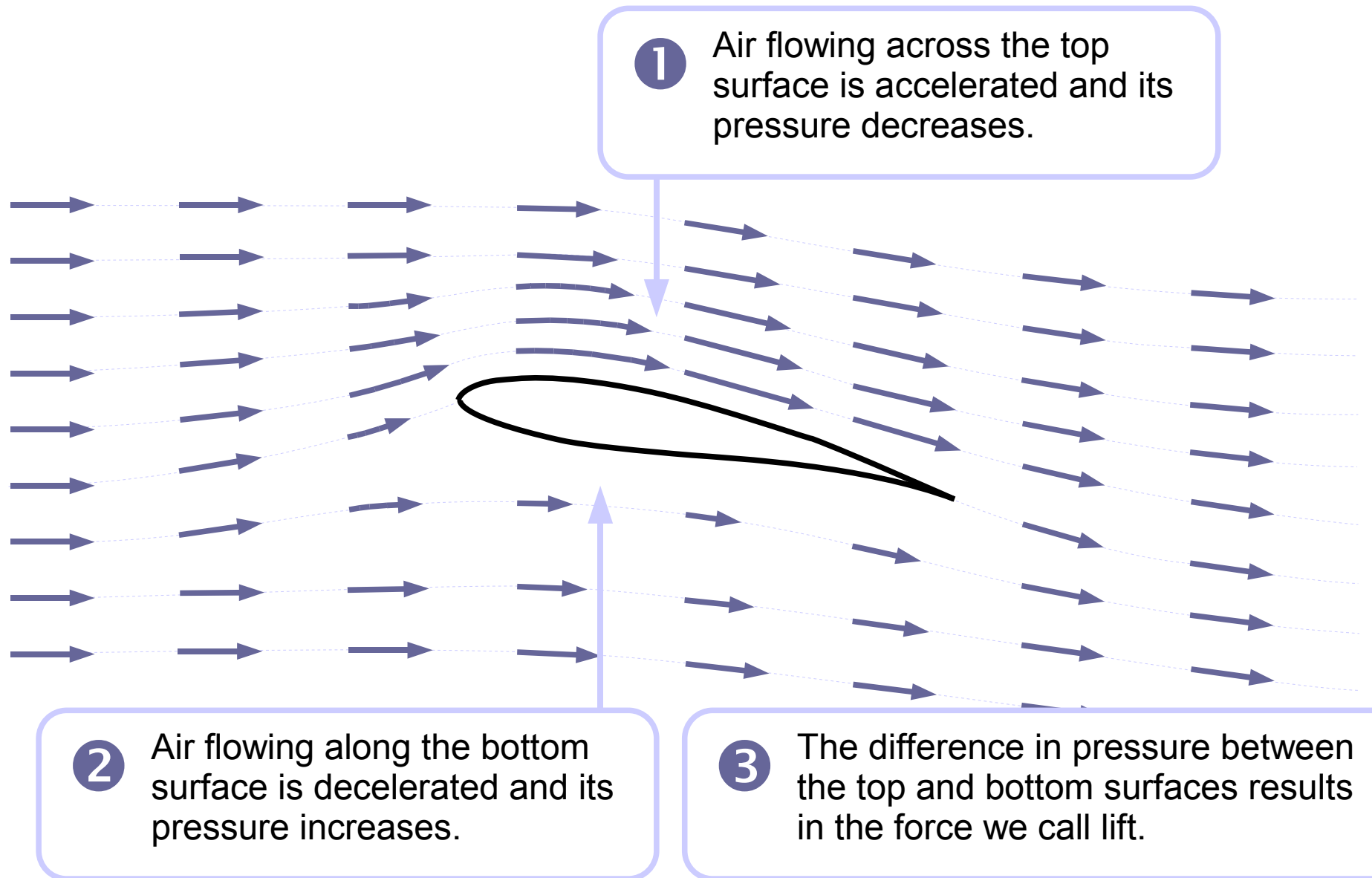
2 **Lift:** The aerodynamic force produced by the wings perpendicular (at right angles) to the oncoming airflow. (beneficial)



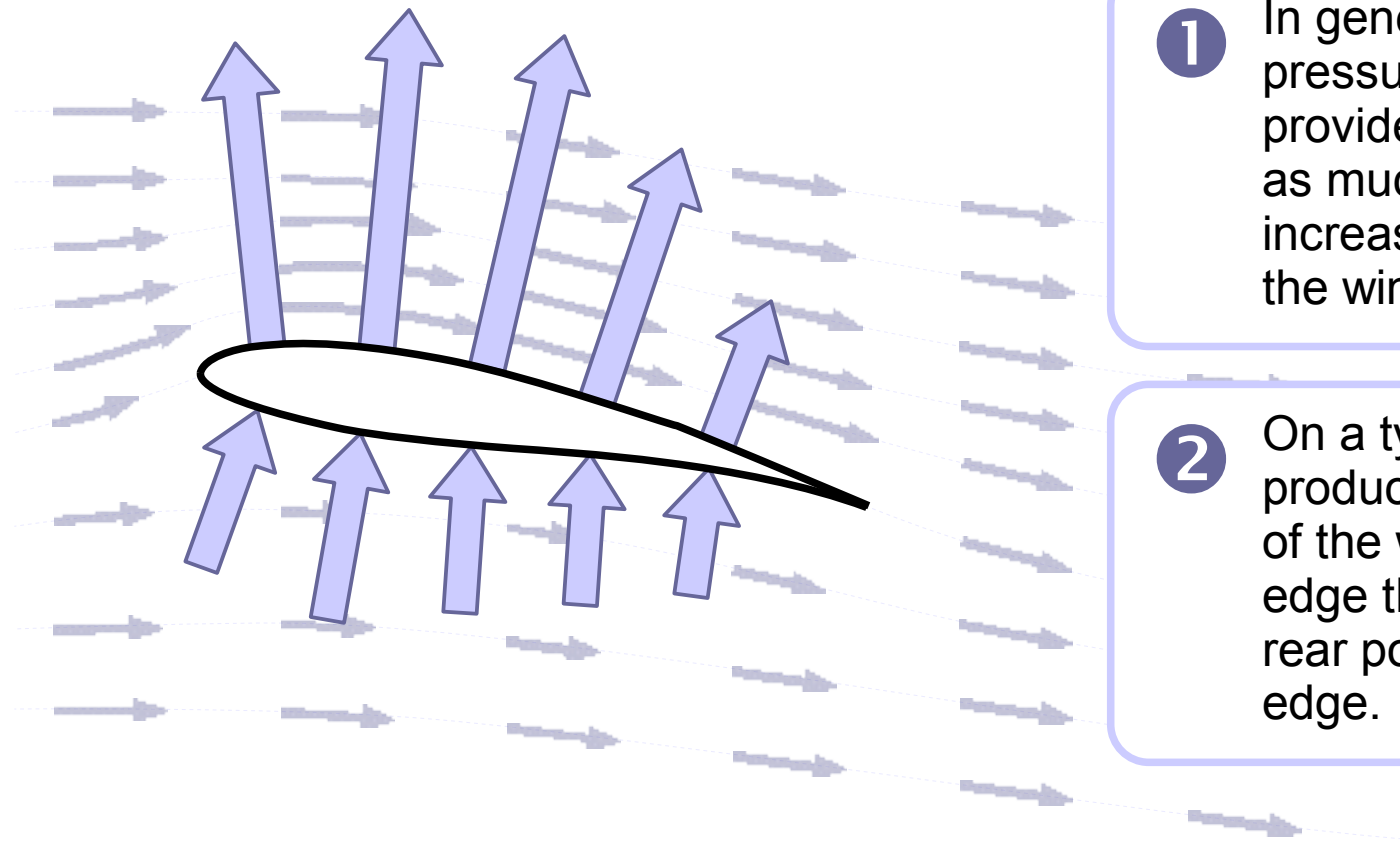
3 **Drag:** The aerodynamic force exerted on the wings parallel (in line) with the oncoming airflow. (mostly undesirable)

**[ Lift ]**

# [ How does a wing generate lift? ]



# [ The distribution of lift around a wing ]



1 In general the decrease in pressure above the wing provides approximately twice as much lift force as the increase in pressure below the wing.

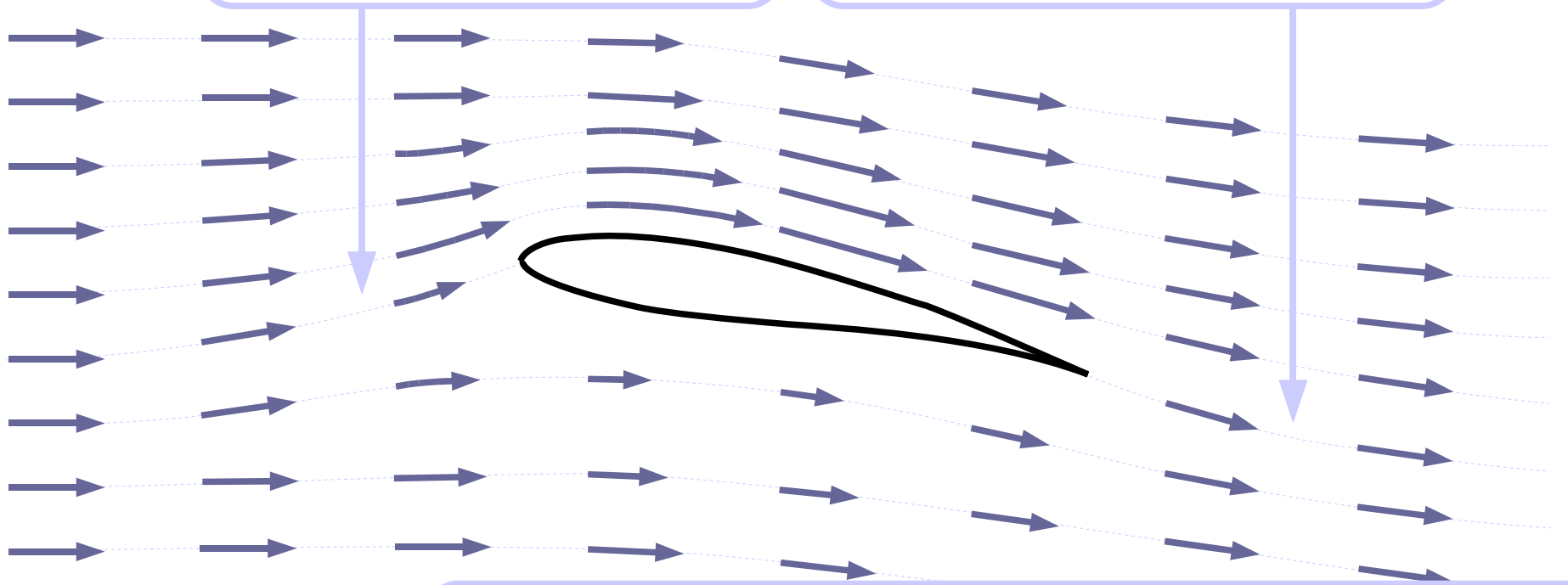
2 On a typical wing, more lift is produced by the front portion of the wing toward the leading edge than is produced by the rear portion toward the trailing edge.



# [ The wing's effect on the surrounding air ]

1 There is a slight up flow of air in front of the wing.

2 Behind the wing the air is deflected down below its original position.



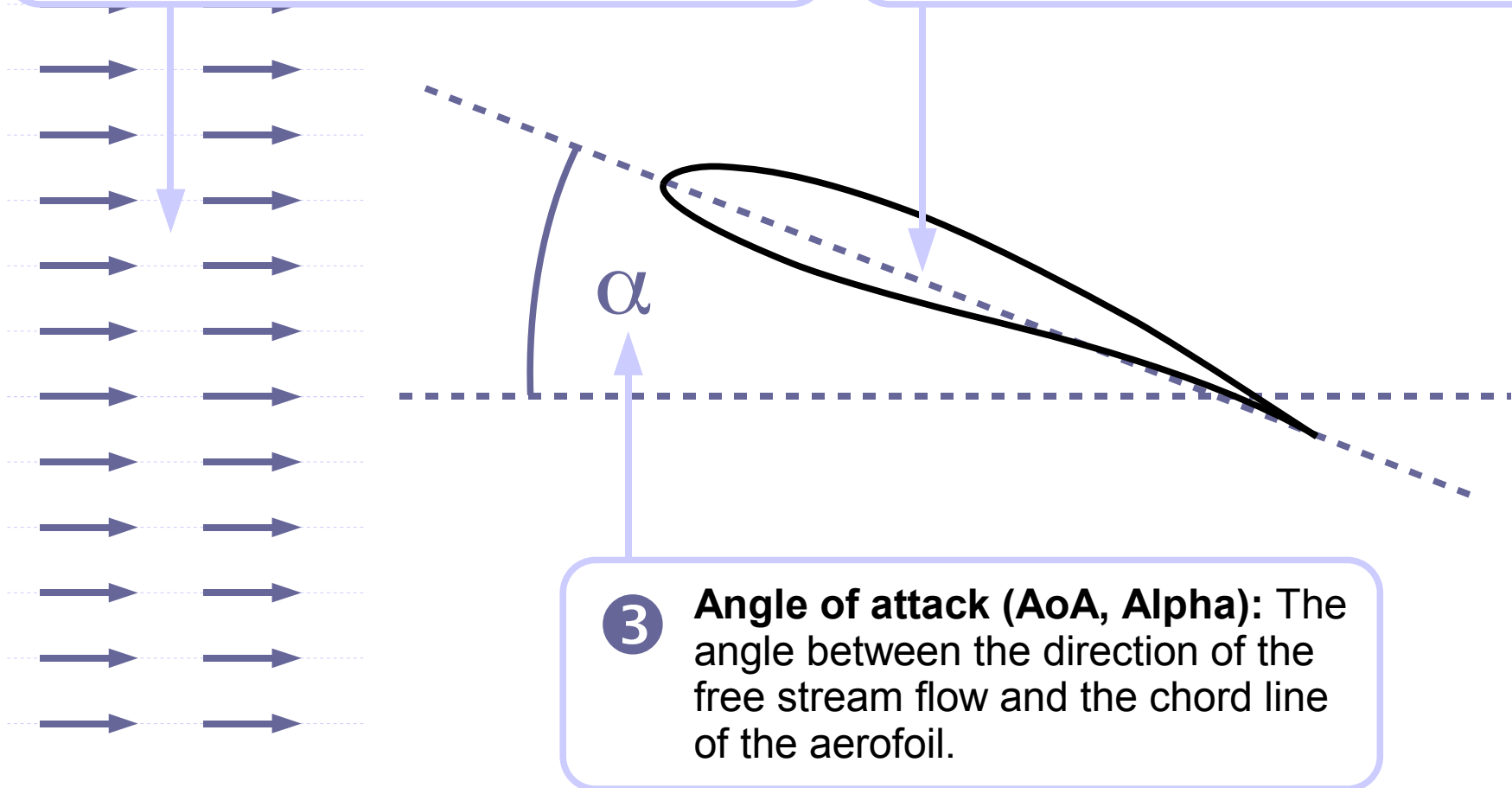
3 Therefore another way of thinking about a wing is as a deflection device. Where "lift" is the wing's equal and opposite reaction to the force it is exerting to deflect the air downwards.

# [ Aerofoil terminology ]

**1 Free stream flow:** Oncoming air that is sufficiently far away from an aerofoil to not be influenced by its presence.

**2 Chord line:** A fixed reference line on a particular aerofoil. Generally it is taken to be the line joining the leading and trailing edges.

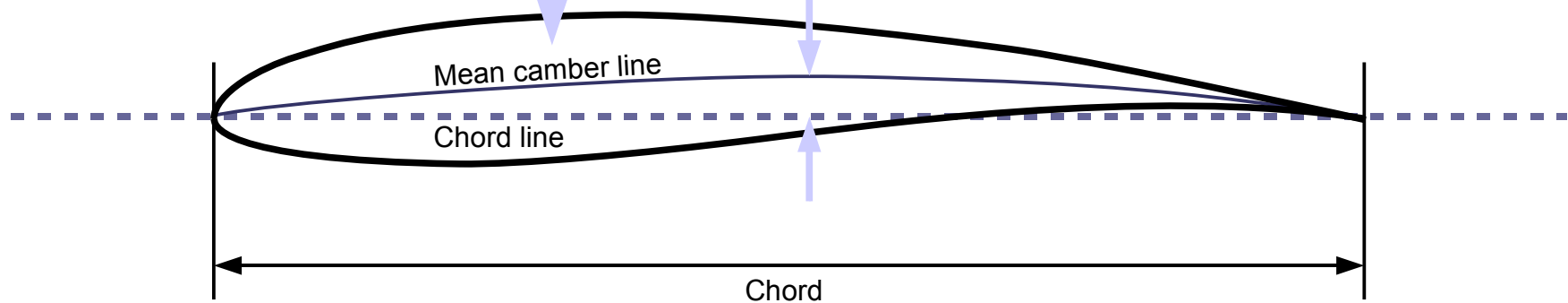
**3 Angle of attack (AoA, Alpha):** The angle between the direction of the free stream flow and the chord line of the aerofoil.



# [ Aerofoil terminology ]

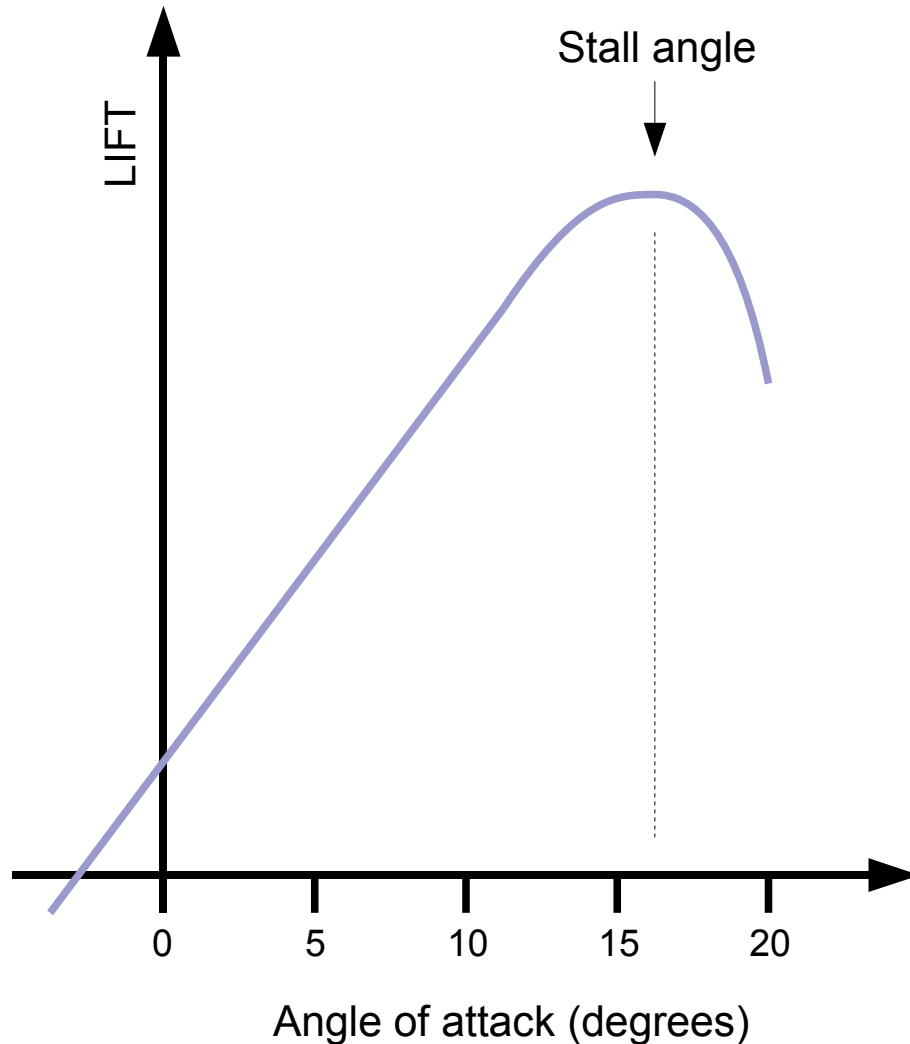
**1 Mean camber line:** A line at the mid point between the top and bottom surfaces of the aerofoil.

**2 Camber:** The maximum distance between the chord line and the mean camber line measured at right angles to the chord line.



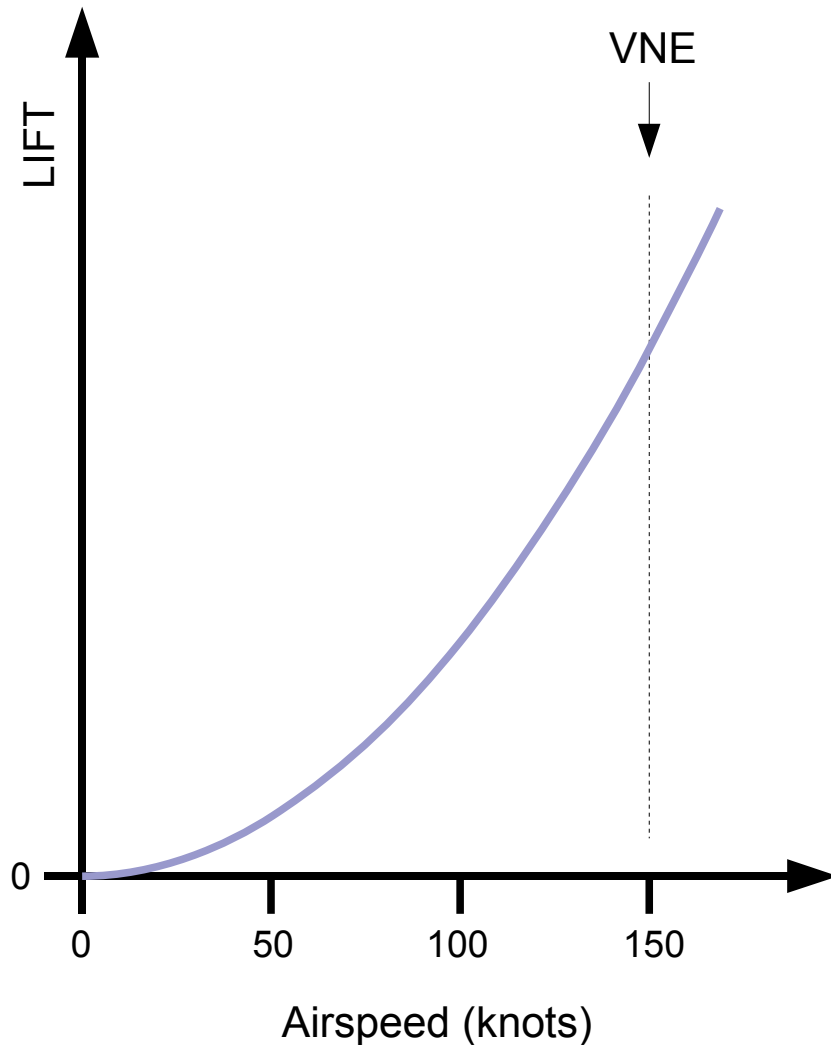
**3 Chord:** The length of the aerofoil measured between leading to trailing edge along the chord line.

# [ Controlling lift : method 1 - AoA ]



- 1 For a given airspeed, the amount of lift produced by a wing can be increased by increasing its angle of attack to the oncoming air flow.
- 2 **“Lift generated increases linearly with the angle of attack.”**
- 3 However increasing a wing's angle of attack also increases the amount of drag it produces ...
- 4 ... and eventually the wing will stall. At which point the amount of lift that the wing produces decreases rapidly.

# [ Controlling lift : method 2 - airspeed ]

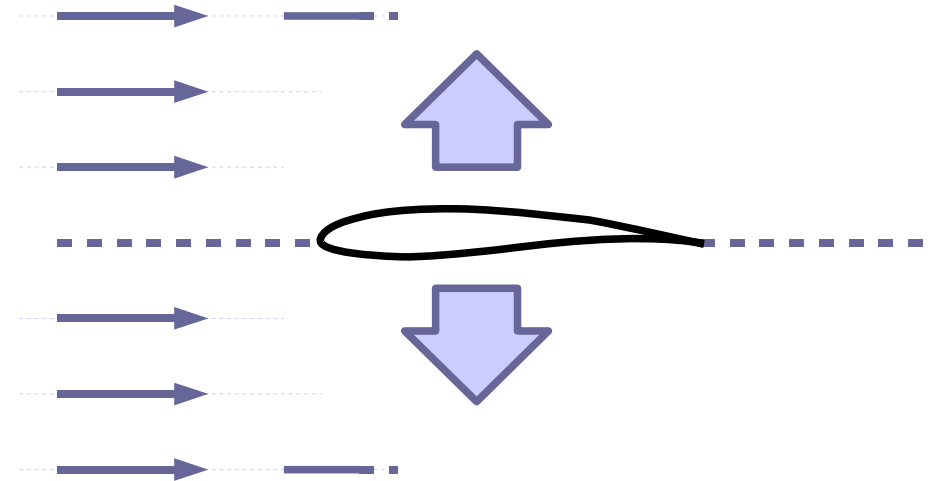
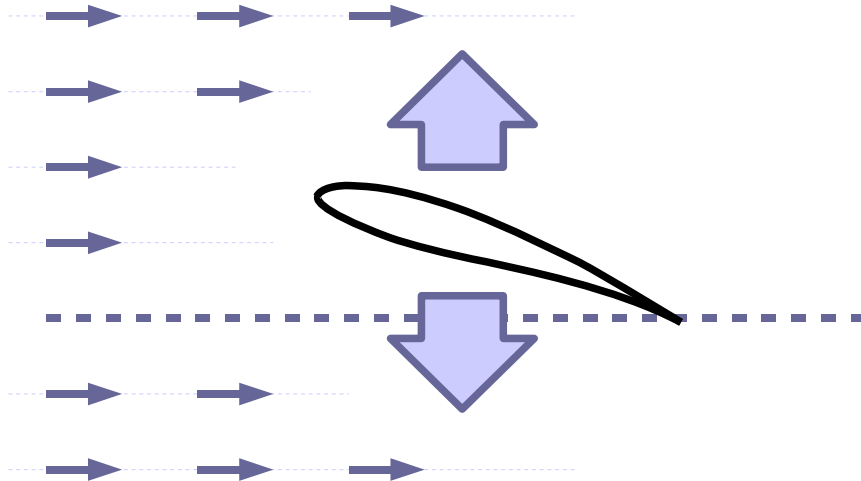


- 1 For a given angle of attack, the amount of lift produced by a wing can be increased by increasing the speed of the air flowing across it.
- 2 **“Lift generated is directly proportional to the square of the airspeed.”**
- 3 However increasing a wing's airspeed also increases the amount of drag it produces.
- 4 Eventually a speed will be reached where the lift and drag forces become so large that they begin to structurally damage the aircraft.

# [ Counteracting gravity ]

1 An aircraft flying slowly will require a high angle of attack in order to generate enough lift to counteract gravity.

2 Conversely an aircraft flying fast will need to use a low angle of attack otherwise it will generate too much lift and start to climb.

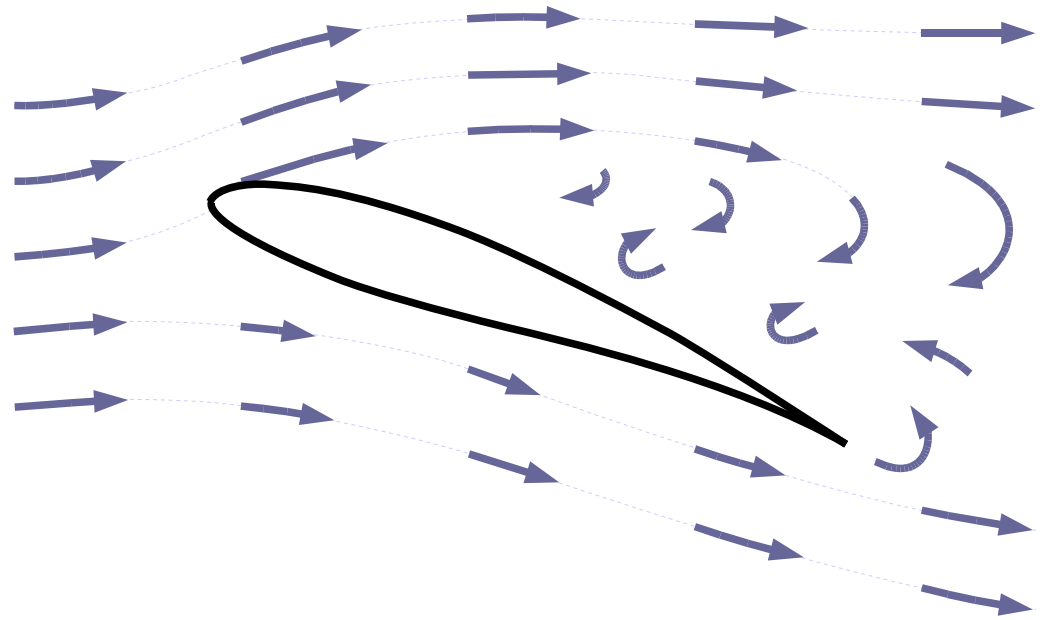


Note: In steady wing's level flight, for every airspeed there is a corresponding angle of attack that will provide just the right amount of aerodynamic force to counteract gravity.

# [ The stall ]

**1** **The stall:** As the angle of attack is increased, an angle is reached at which the air is no longer able to make the change of direction required to follow the contour of the aerofoil's top surface. The airflow separates from the top surface and the air beneath the separated flow becomes turbulent.

**2** When a aerofoil stalls the lift produced by the top surface drops dramatically and drag increases rapidly.



# [ The stalling angle ]

**1** **The stalling angle:** The angle at which an aerofoil stalls. (usually somewhere between 10 and 20 degrees.)

**2** **An aerofoil will always stall at its stalling angle regardless of airspeed.**

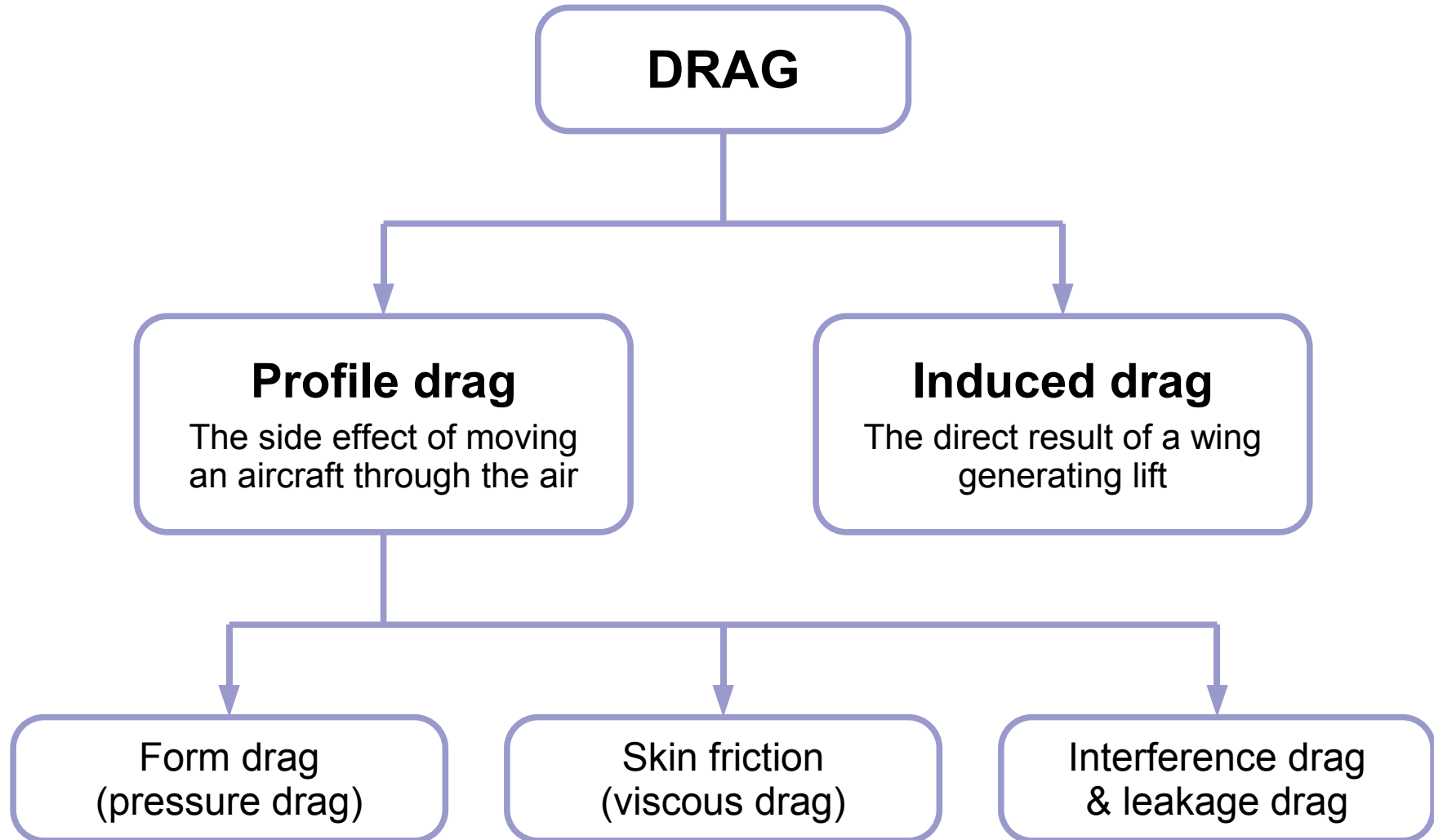
**3** Therefore a glider travelling at 100knots will stall if a manoeuvre violent enough to increase the angle of attack above the stalling angle is performed.

**4** Stalls are more typically associated with slow speeds because at slow speeds a high angle of attack is required to generate enough lift to counteract gravity. Therefore the wing is already very close to its stalling angle and it doesn't take much to tip it over the edge.

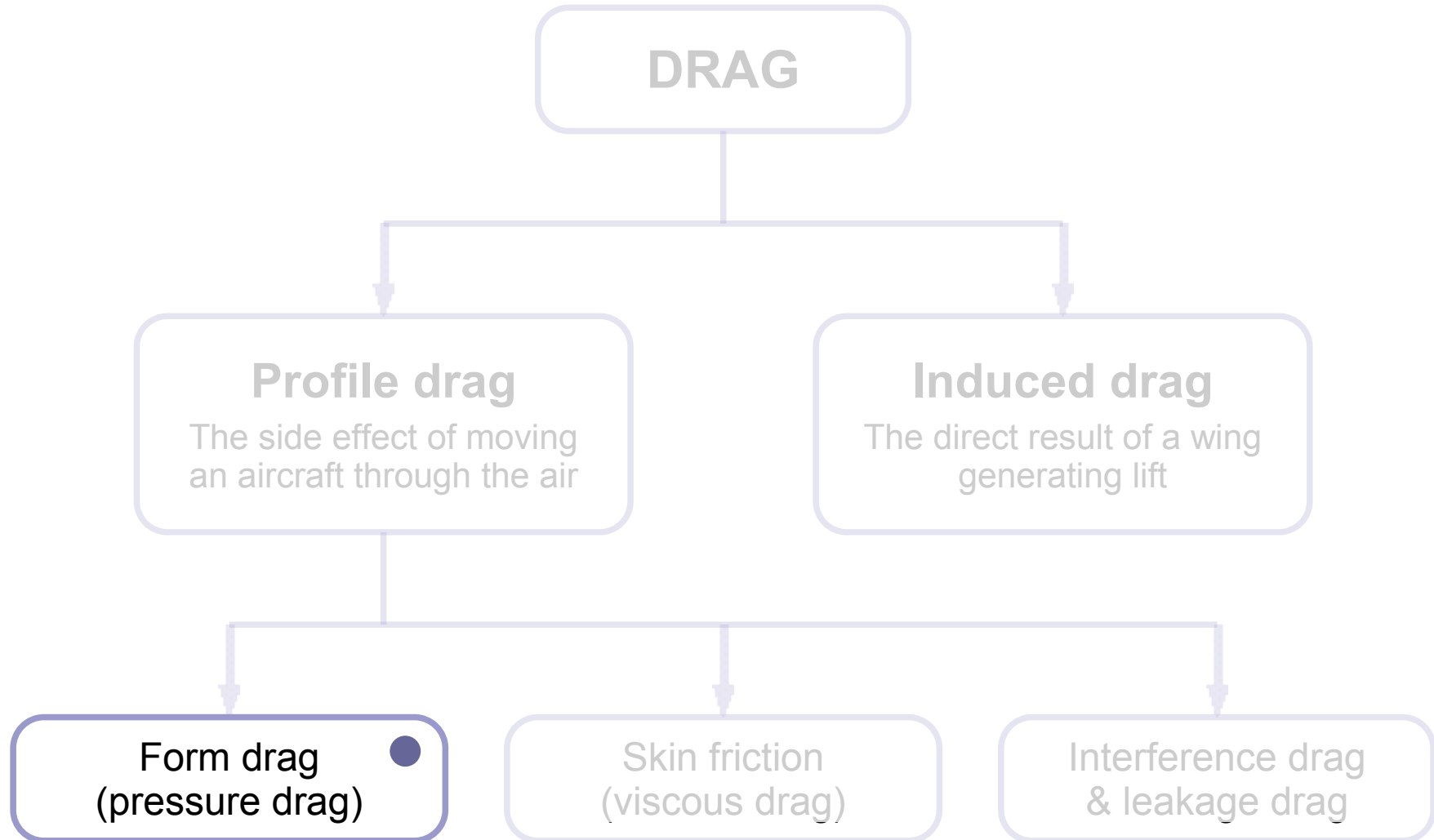


**[ Drag ]**

# [ Drag family tree ]



# [ Drag family tree ]



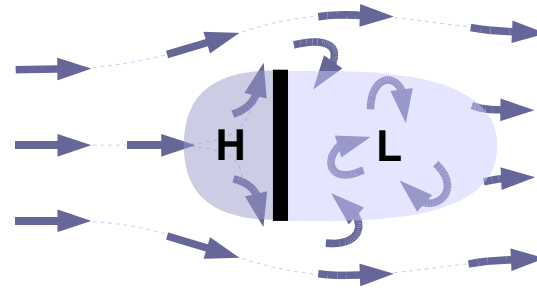
# [ Form drag (pressure drag) ]

1 Any object moving through the air has to push the air in front of it out of the way. This causes a build-up of pressure in front of the object.

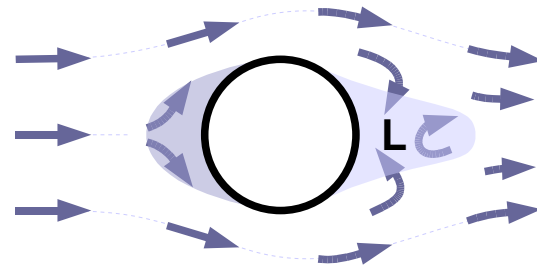
2 Similarly the object will leave a low pressure void in its wake.

3 This difference in pressure between the front and back surfaces of the object results in the force we call form drag.

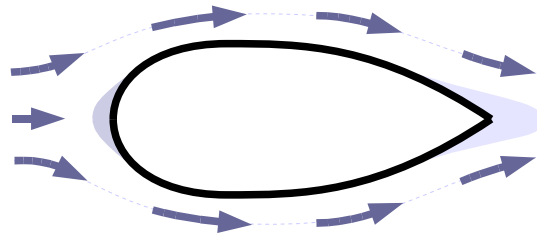
4 Form drag can be reduced by reducing the object's cross sectional area or by streamlining it.



**Flat plate**

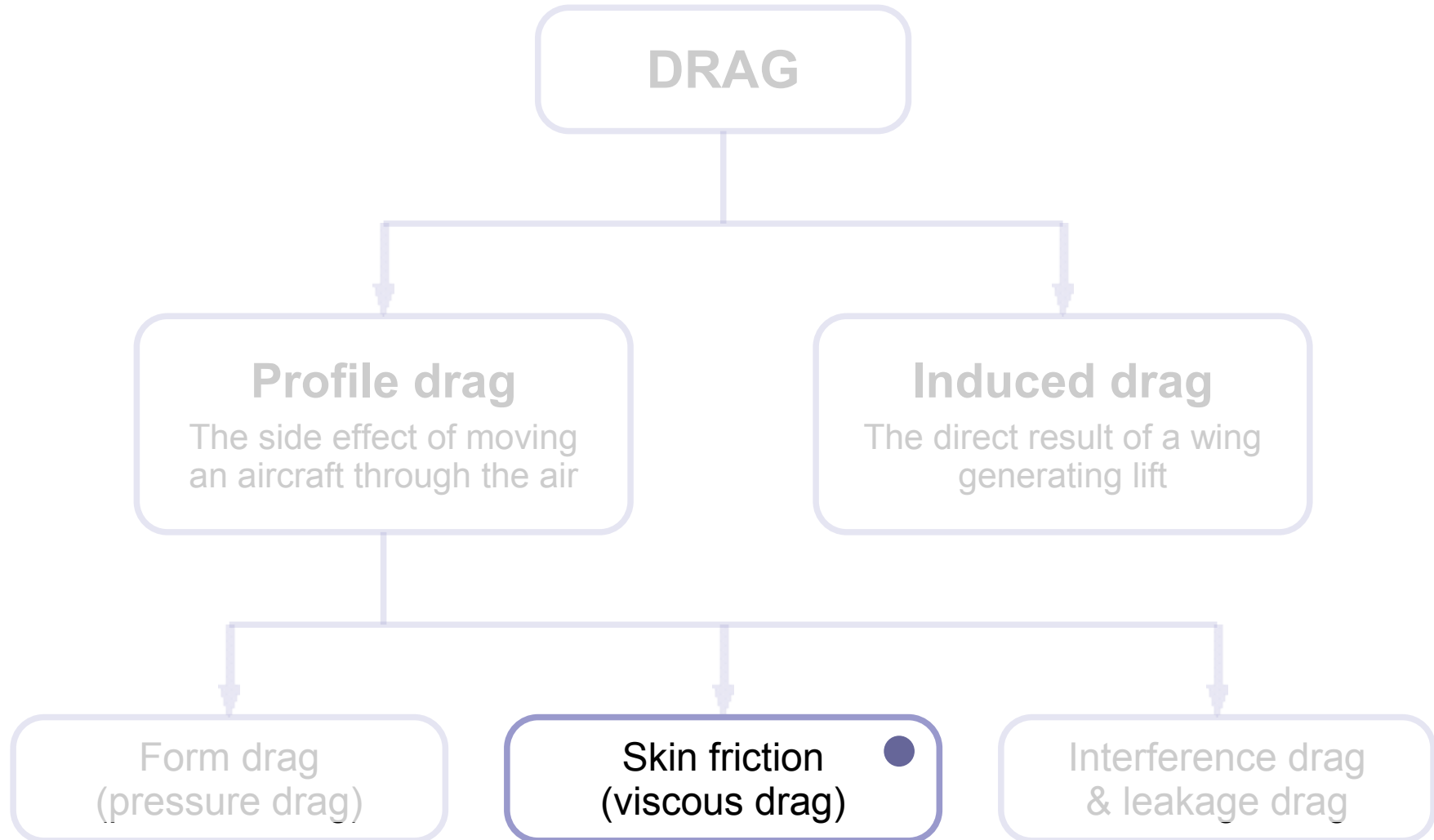


**Cylinder:**  
50% of the form drag  
of a flat plate.



**Streamlined shape:**  
10% of the form drag  
of a flat plate.

# [ Drag family tree ]



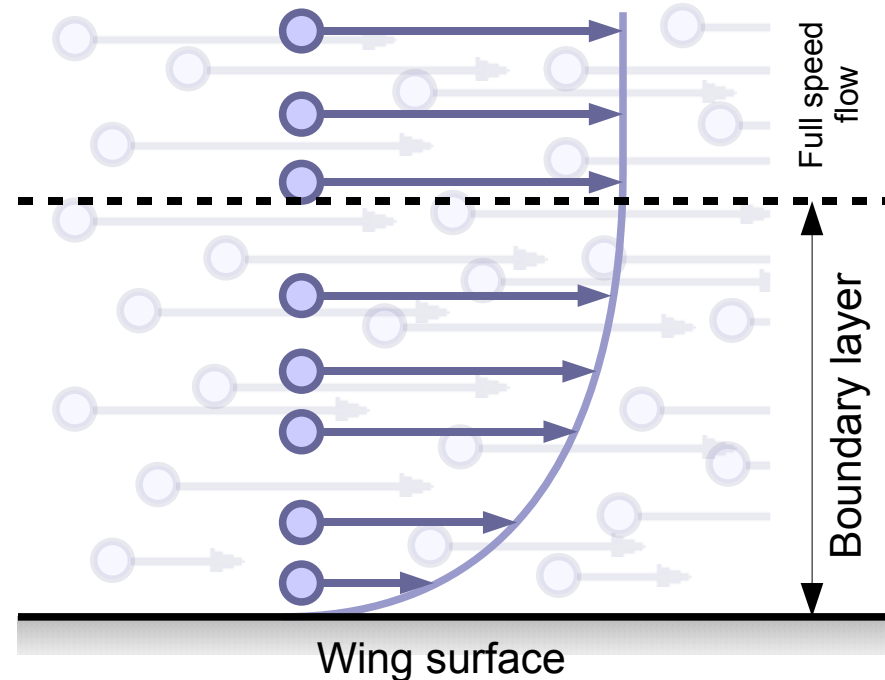
# [ Skin friction and the boundary layer ]

1 As air flows across a wing, friction brings the layer of air molecules directly in contact with the surface to a standstill.

2 Air is a viscous fluid (E.g. It's a bit like treacle). Hence the stationary layer of air on the wing's surface slows the layer above it, but not as much. This layer then slows the layer above it, but again not as much, and so on.

3 The velocity of the flow therefore increases with distance from the surface until the full speed of the flow is reached.

4 This layer of decelerated air is called the **boundary layer**. The frictional forces that create the boundary layer create an equal and opposite **skin friction** (a.k.a. viscous drag) force on the glider.



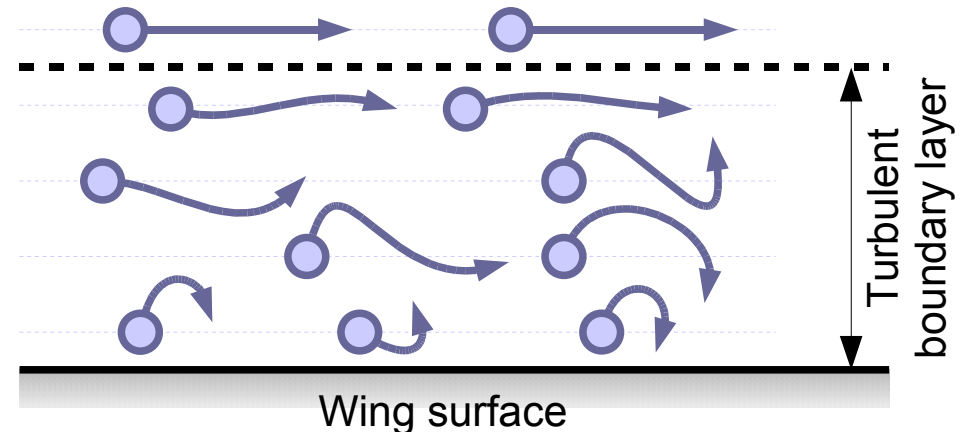
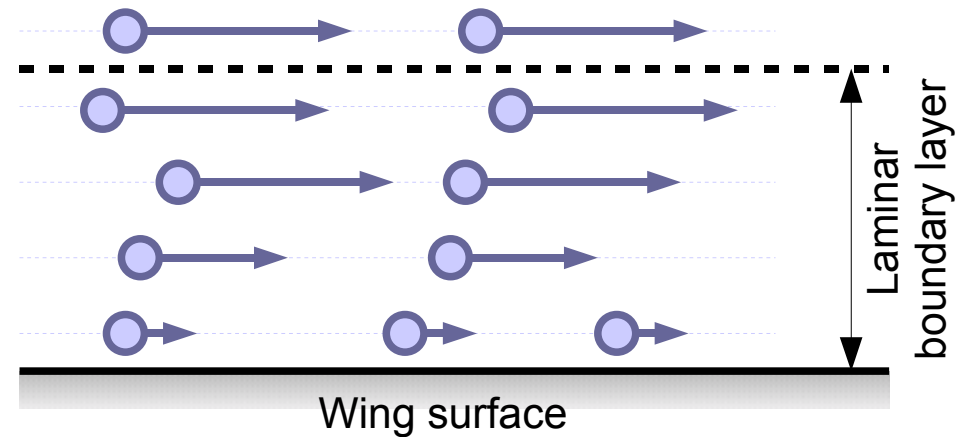
# [ Types of boundary layer ]

1 The boundary layer can take on two distinct forms:

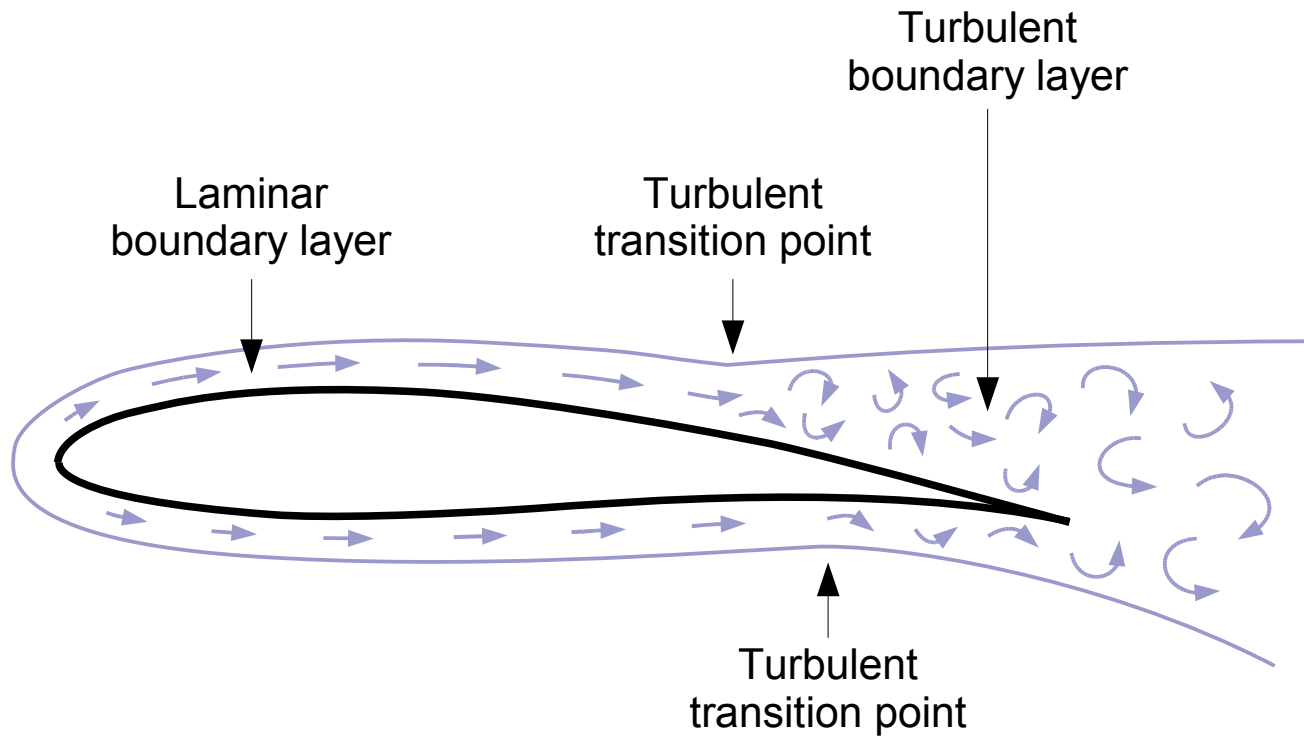
**Laminar boundary layer:**  
Each layer of air molecules slides smoothly over its neighbours.

**Turbulent boundary layer:**  
Dominated by eddies and irregular turbulent flow.

2 Turbulent boundary layers generate **5 to 10** times more skin friction drag than the equivalent laminar boundary layer. Therefore glider designers try to maintain laminar flow across as much of the aircraft as possible.

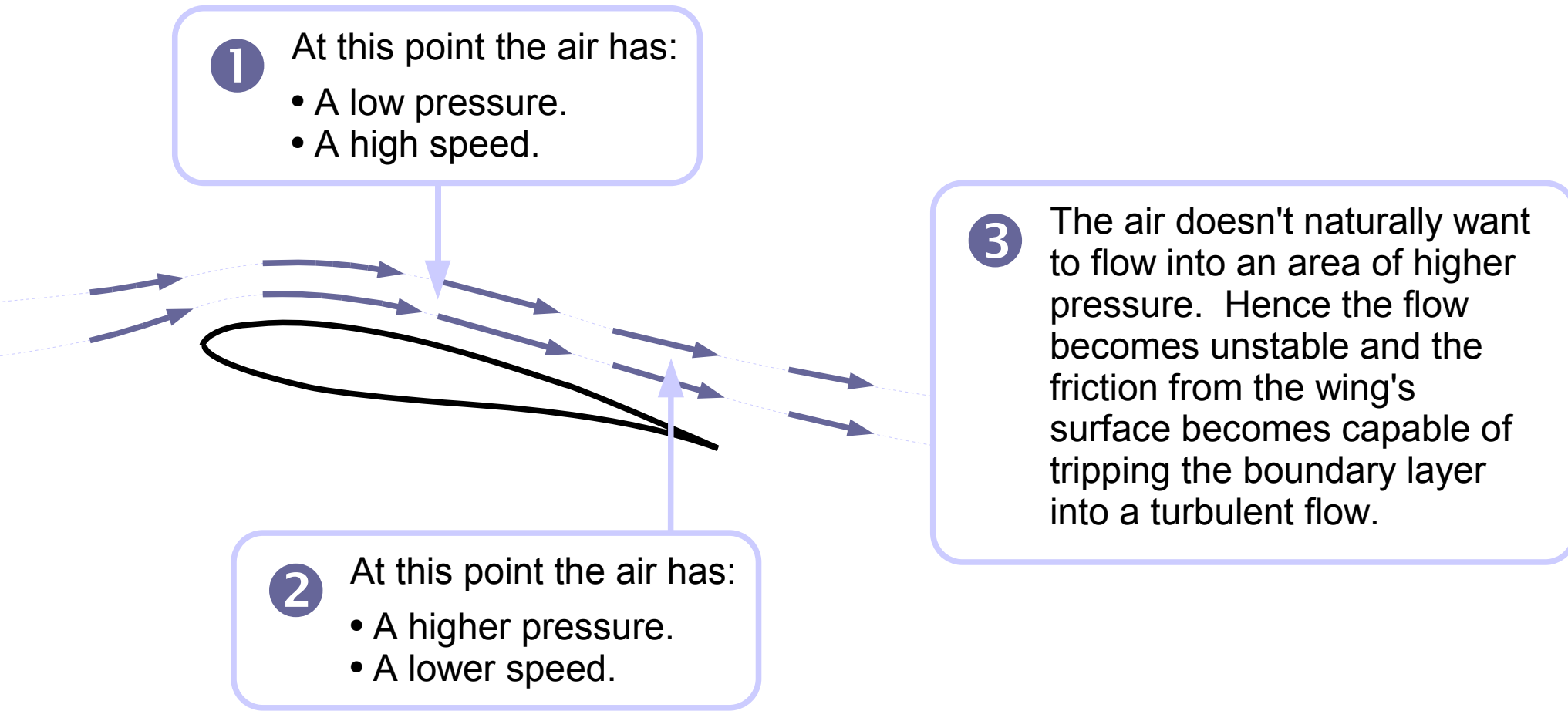


# [ Boundary layer around a typical wing ]





# [ Why does turbulent transition occur? ]

- 1** At this point the air has:
- A low pressure.
  - A high speed.
- 
- A diagram illustrating the transition of air flow over a wing. The wing is shown in profile, with a dashed line representing the leading edge and a solid line for the trailing edge. Blue arrows represent the flow direction. A blue box labeled '1' points to the leading edge, indicating high speed and low pressure. A blue box labeled '2' points to the upper surface of the wing, indicating higher pressure and lower speed. A blue box labeled '3' points to the trailing edge, indicating that the flow becomes unstable due to friction and the inability to flow into a higher pressure area, leading to turbulent flow.

- 2** At this point the air has:
- A higher pressure.
  - A lower speed.

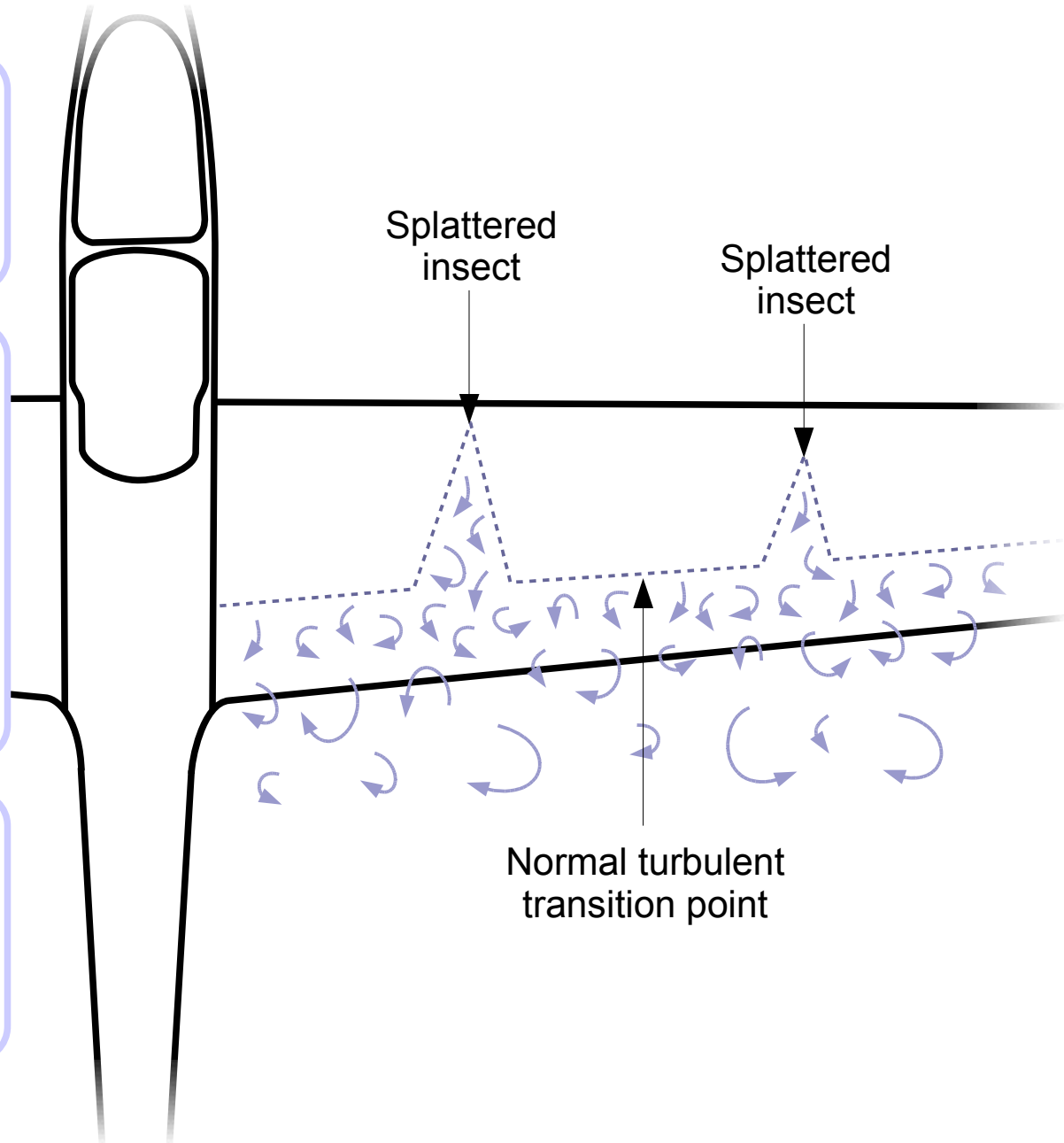
- 3** The air doesn't naturally want to flow into an area of higher pressure. Hence the flow becomes unstable and the friction from the wing's surface becomes capable of tripping the boundary layer into a turbulent flow.

# [ Rivets, insects, rain, ice and dust... ]

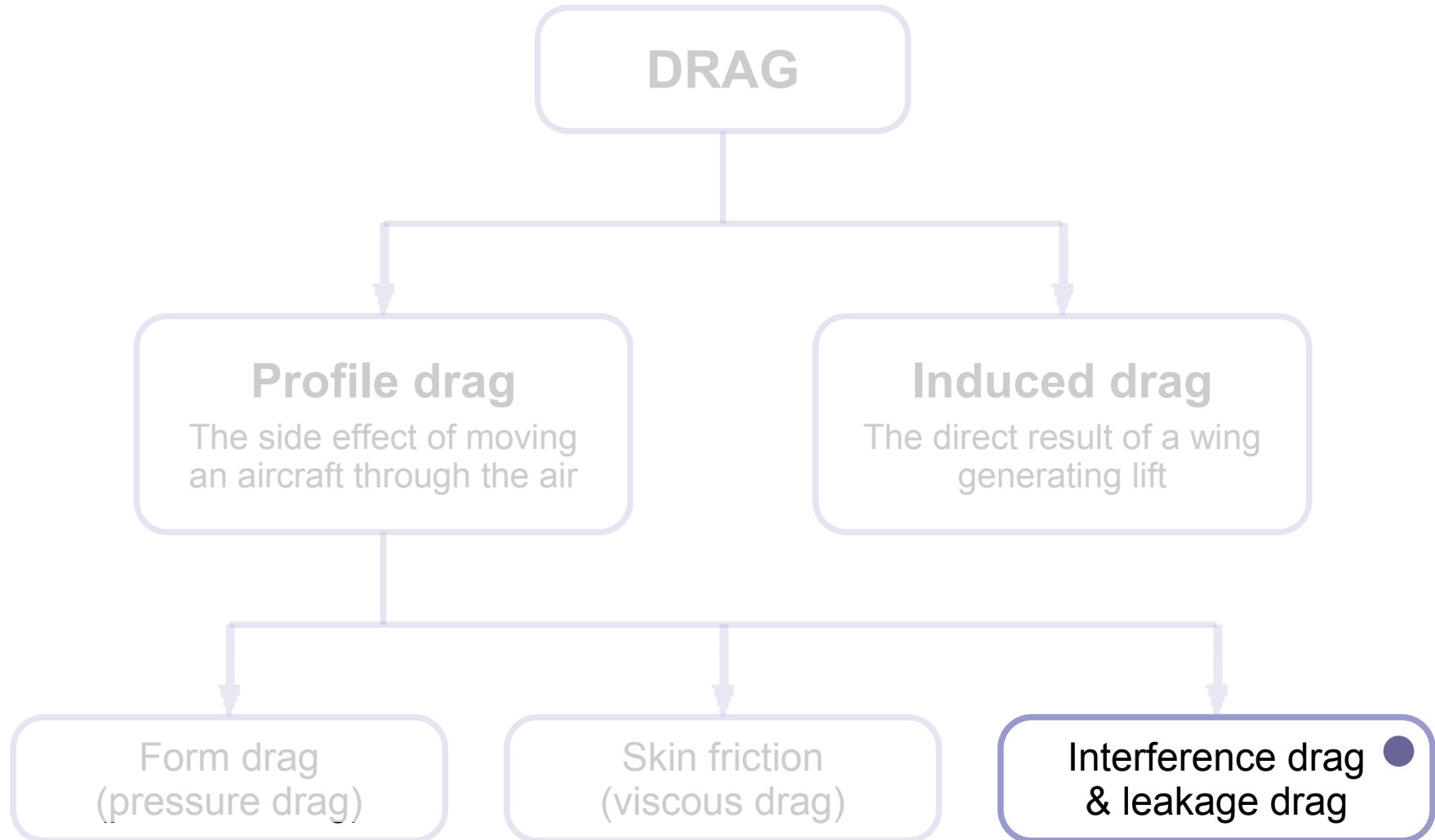
1 The boundary layer can also be tripped into a turbulent flow at any point by discontinuities on the wing's surface.

2 As the boundary layer is only of the order 1.0mm thick at the leading edge, objects such as rivets, splattered insects, rain drops, ice crystals and dust are all large enough to cause localised turbulent transition to occur.

3 It is important to keep wings clean and avoid rain and icing to prevent premature transition and the increase in drag that it causes.



# [ Drag family tree ]



# [ Interference and leakage drag ]

## 1 Interference drag:

Turbulence will be produced at any point on an aircraft at which airflows travelling at different speeds or in different directions meet.

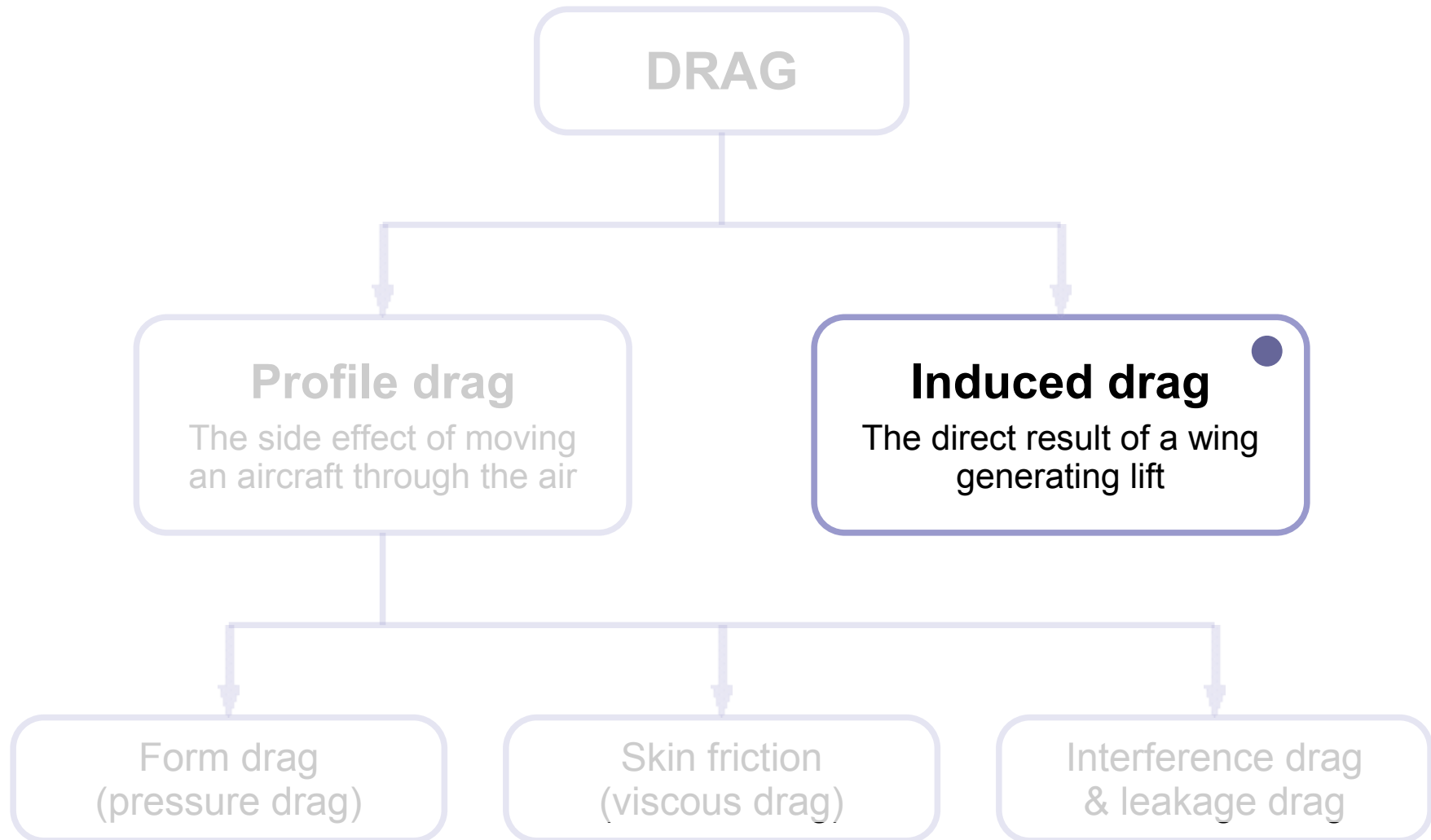
This turbulence causes drag.

## 2 Leakage drag:

If the joins between the wings and the fuselage are not completely sealed with tape, then high pressure air from below the wings will force its way up through the joins and create turbulence where it emerges on the top surface.

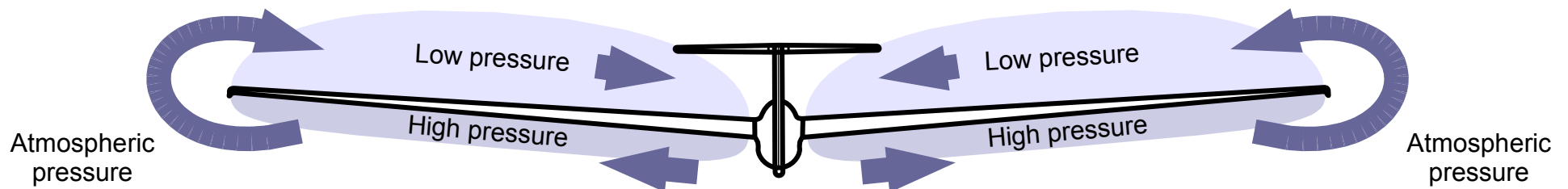
Not only does this turbulence cause drag but also a reduction in lift by disturbing the upper surface airflow.

# [ Drag family tree ]



# [ Lateral air flow around wings ]

1 The low pressure above the wings produces an inward lateral flow from the atmospheric pressure region at the tips.



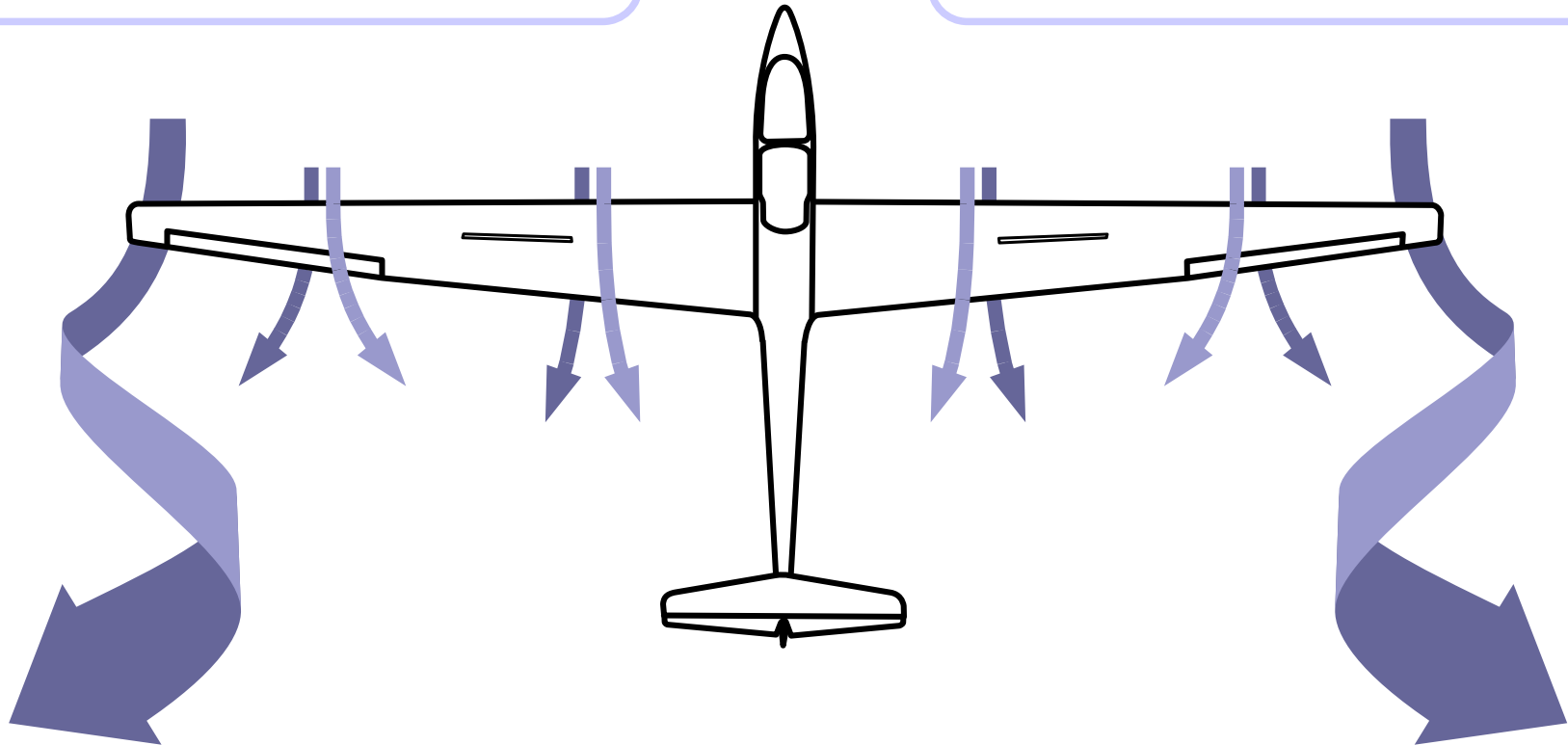
2 The high pressure beneath the wings produces an outwards lateral flow towards the atmospheric pressure region at the tips.

3 The outwards flow from beneath the wings rolls around the tips to feed the inbound flow above the wings.

# [ Wing tip vortices and induced drag ]

1 Because the aircraft is moving forward, the circular motion of the air around the wing tips is shed downstream as **tip vortices**.

2 Energy is required to produce these vortices. Hence their generation exerts a drag force on the glider's wings which is termed as **induced drag**.



# [ Methods of reducing induced drag ]

## 1 Aspect ratio:

The greater the aspect ratio of a wing the lower its induced drag.

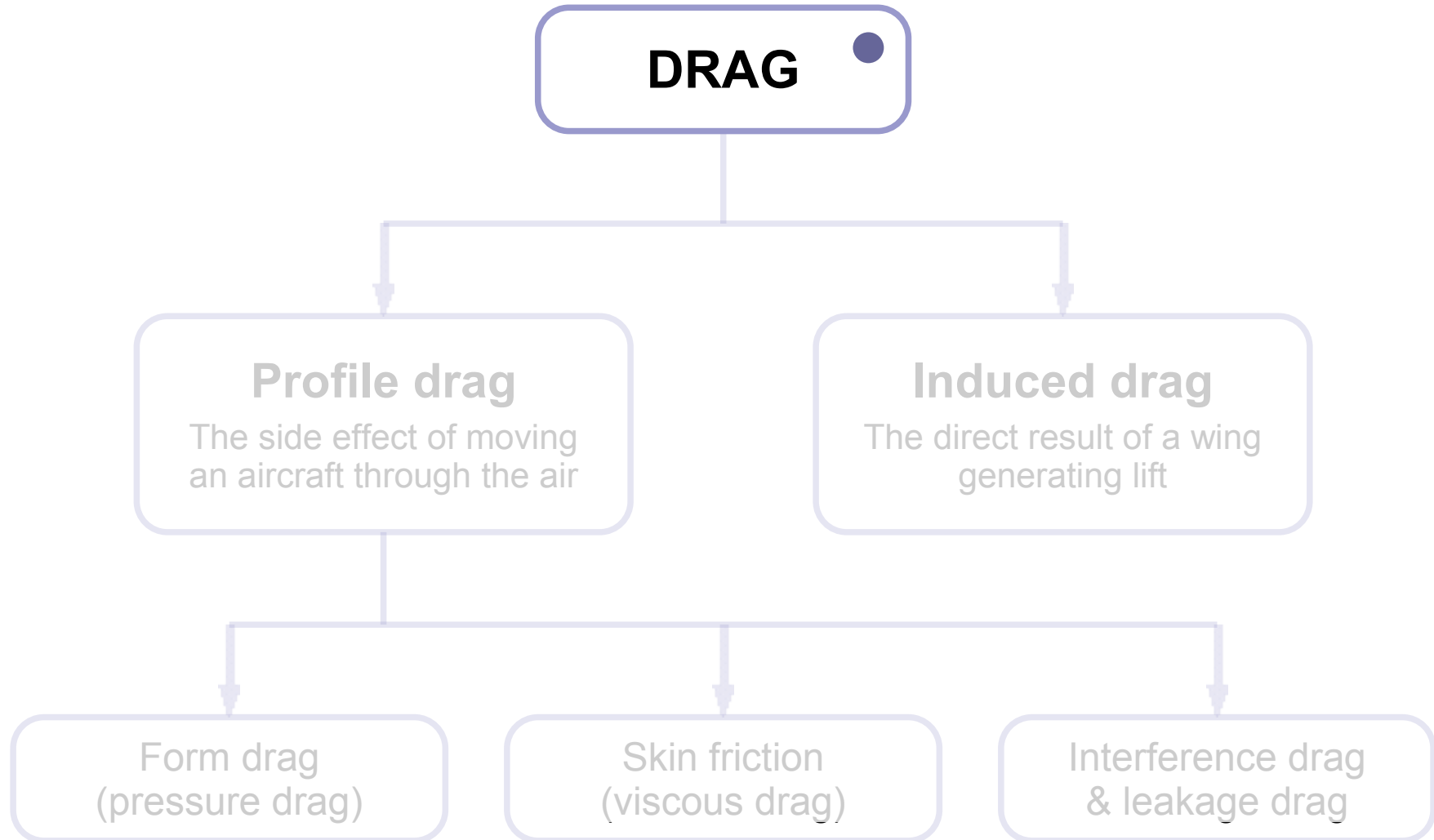
$$\text{Aspect ratio} = \frac{\text{Span}}{\text{Chord}}$$

## 2 Winglets:

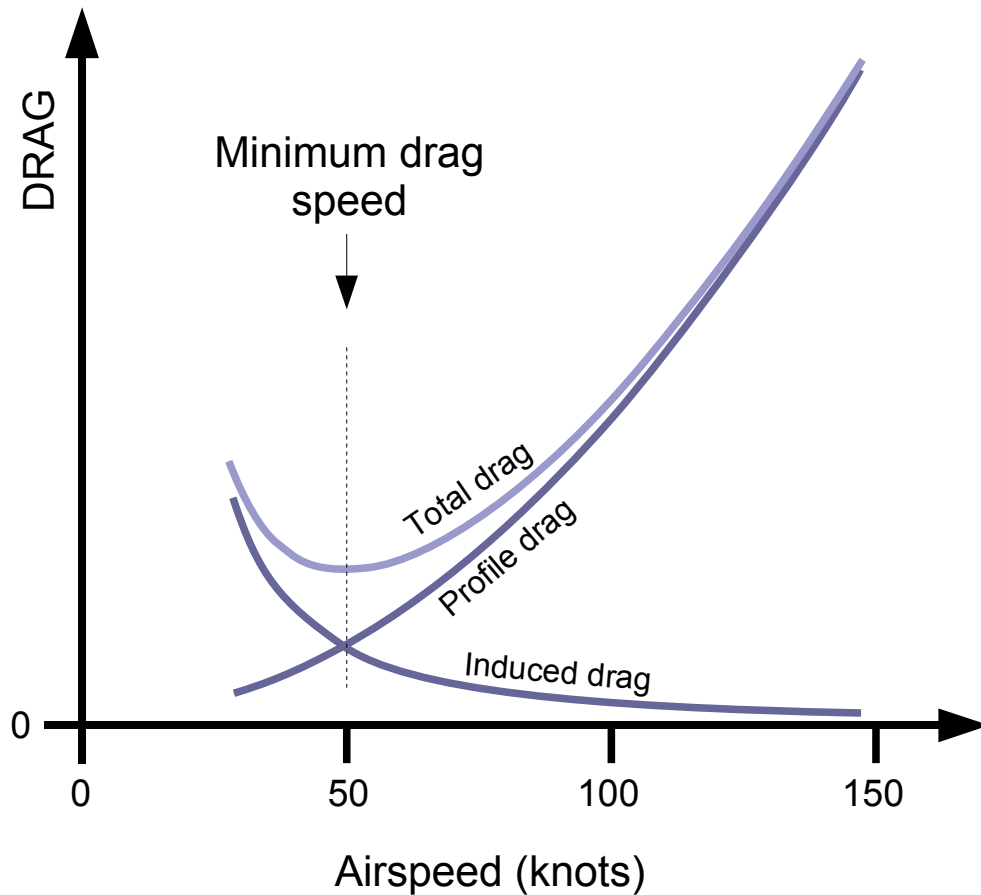
Diffuse the tip vortices hence reducing induced drag.



# [ Drag family tree ]



# [ Drag's relationship to speed ]



1 Induced drag increases with angle of attack. Hence in steady wings level flight:

**“Induced drag is inversely proportional to the square of the airspeed.”**

2 In steady wings level flight:

**“Profile drag is directly proportional to the square of the airspeed.”**

Note: This graph is only valid for steady wings level flight. It is not valid for manoeuvring flight.

**[ Glide performance ]**

# [ Glide ratio ]

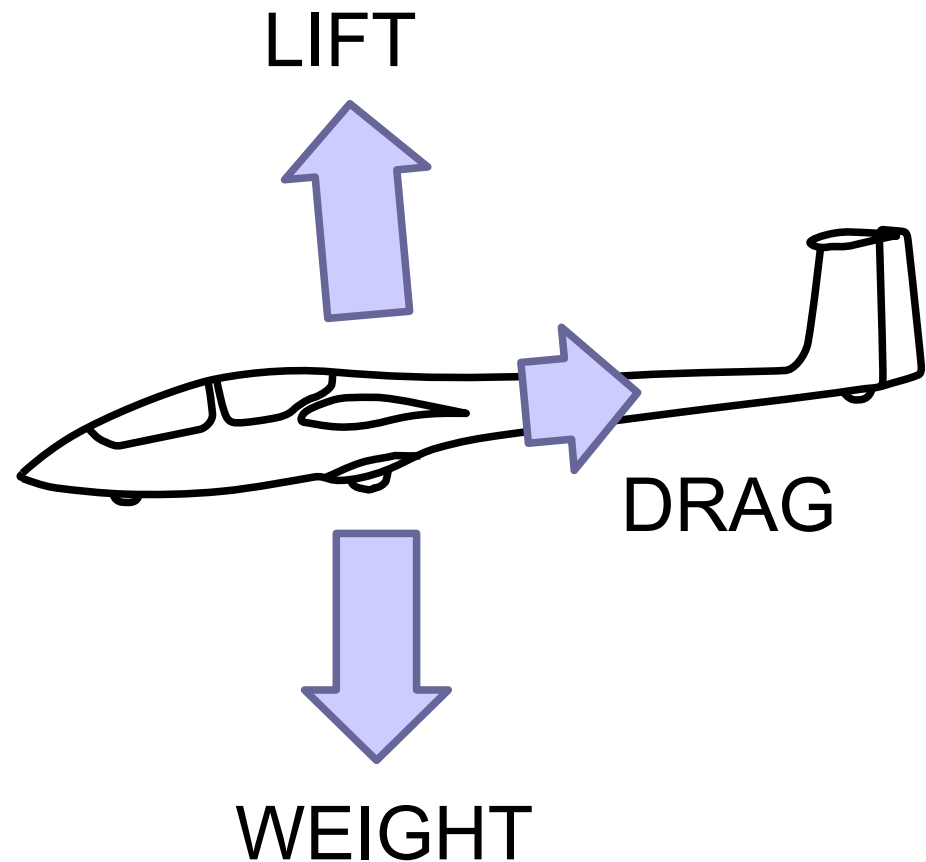
- 1** **Glide ratio:** The number of foot a glider will travel horizontally in still air for every foot of altitude lost.

Therefore if a glider has a 50:1 glide ratio, then it can travel 50 foot for every foot of altitude lost.

- 2** **Glide ratio** =  $\frac{\text{Lift}}{\text{Drag}}$  : 1

...this explains why minimising drag is so critically important.

Note: because drag varies with airspeed, glide ratio must also vary with airspeed.



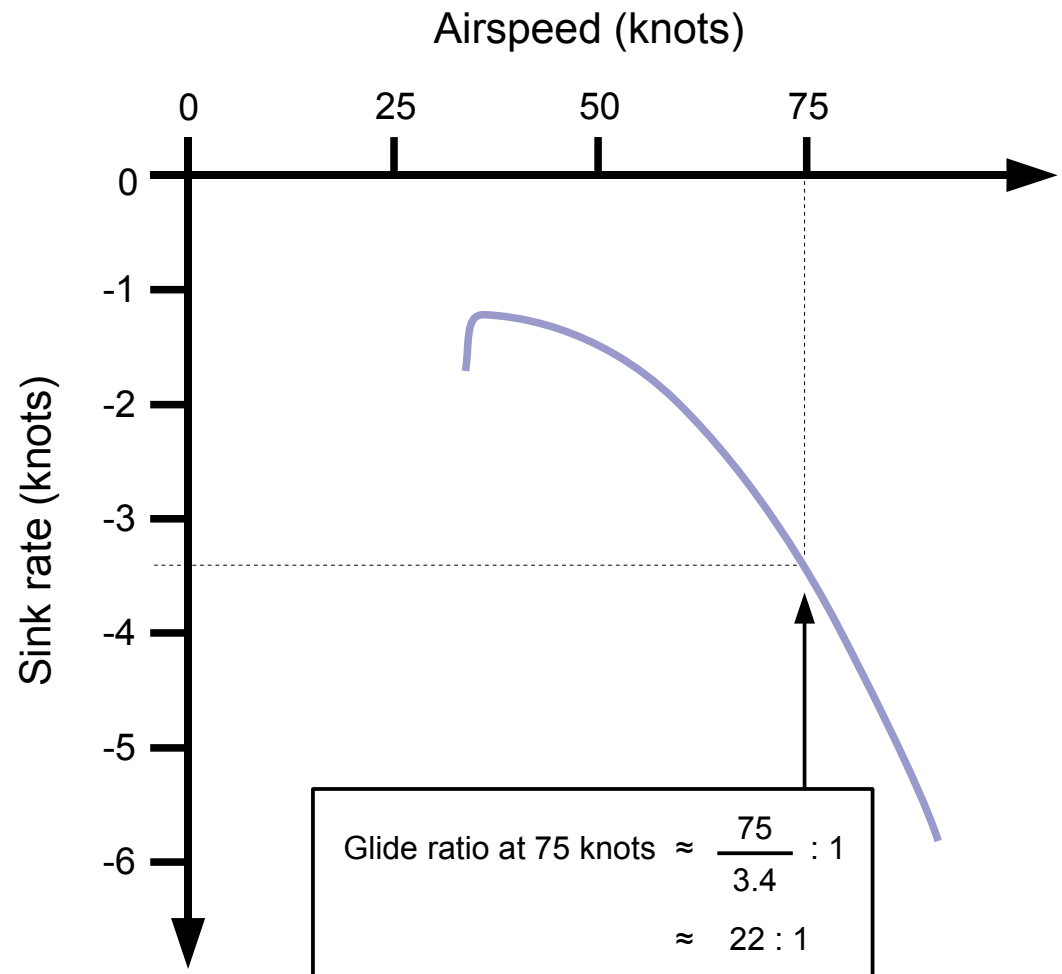
# [ Glide polar ]

**1** **Glide polar:** A graph, normally provided in a glider's flight manual, which details its still air sink rate at airspeeds within its flight envelope.

**2** The glide ratio at a particular airspeed can be estimated from the glide polar using:

$$\text{Glide ratio} \approx \frac{\text{Airspeed}}{\text{Sink rate}} : 1$$

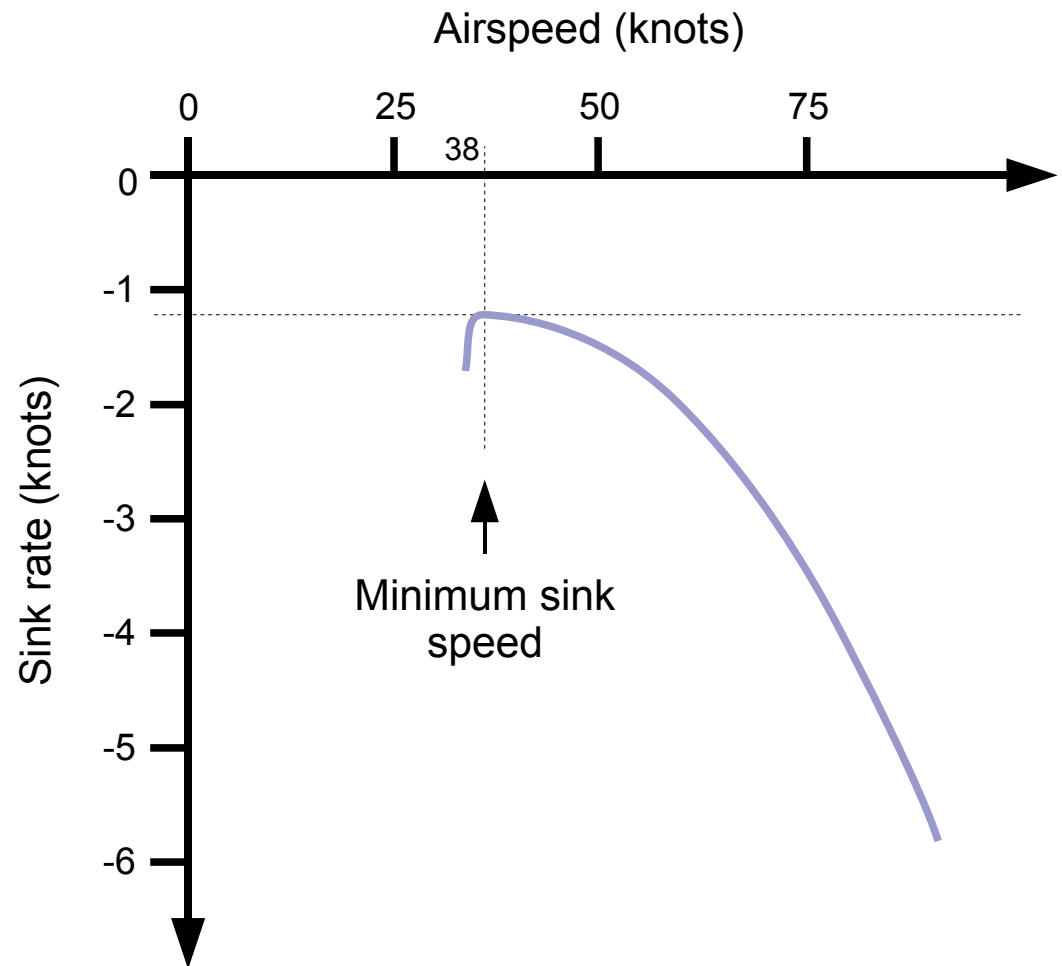
Warning: Airspeed and sink rate must both be in the same units. For example knots.



# [ Minimum sink speed ]

**1** **Minimum sink speed:** The airspeed at which the glider loses altitude at the lowest rate.

**2** It can be determined from the polar by locating the point on the graph with the lowest sink rate and reading off the corresponding airspeed.

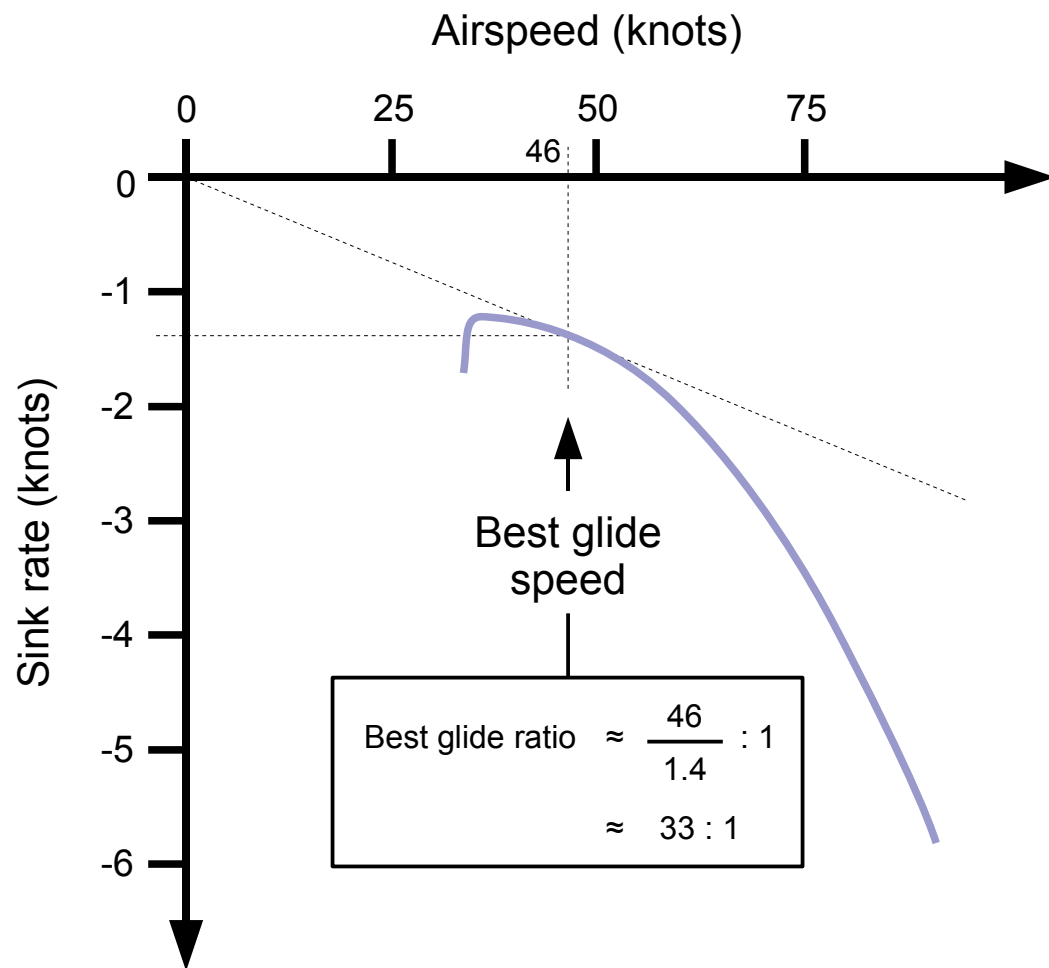


# [ Best glide speed ]

**1 Best glide speed:** The airspeed at which in still air the glider will achieve its best glide ratio. Also known as the best L/D (Lift/Drag) speed.

**2** Can be determined from the polar by drawing a line from the origin that is tangential to the curve (e.g. just touching). The point of contact is the best glide speed and the glide ratio at this speed can be calculated as previously described.

**3** In still air the glider should be flown at this speed to get from A to B with minimum height loss.

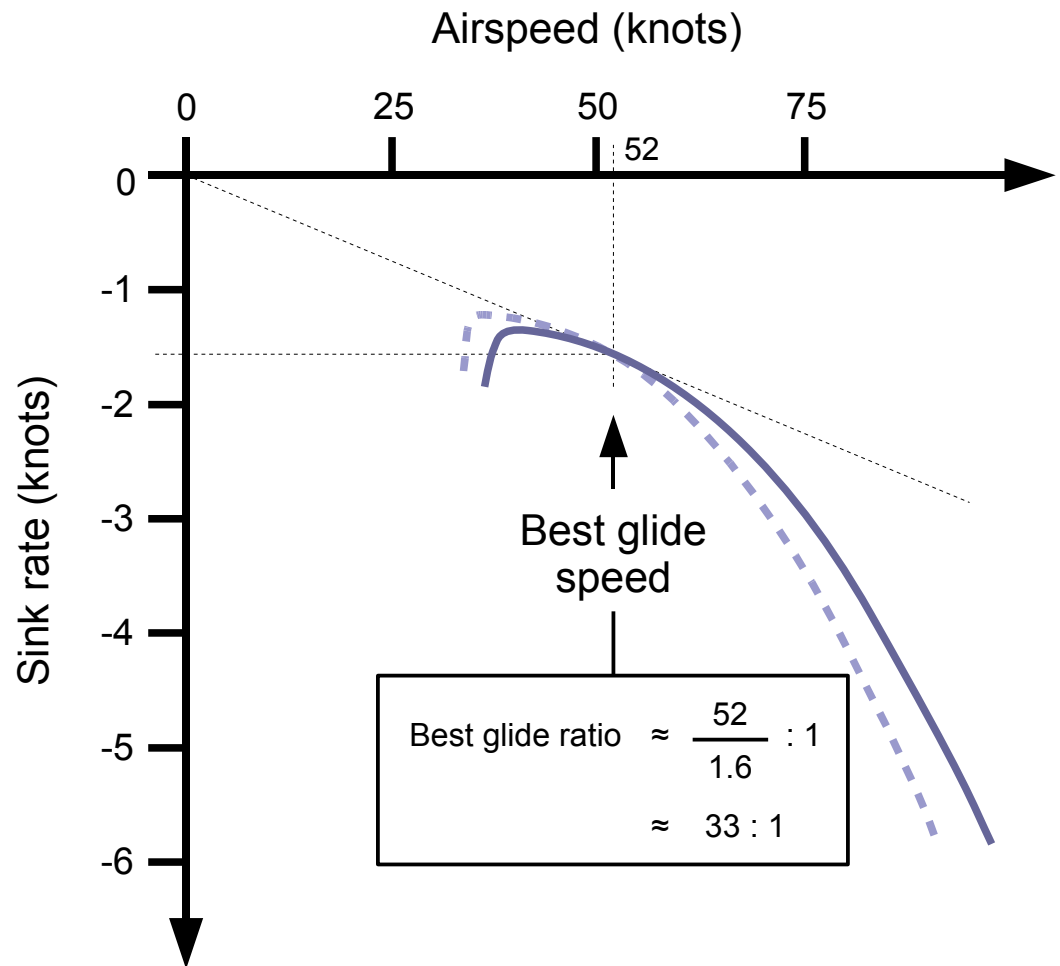


# [ Water ballast ]

1 Increasing the mass of a glider, by for example adding water ballast, shifts the glide polar down and to the right.

2 The minimum sink rate is therefore increased, so as you would expect, the extra weight makes it harder to climb in thermals.

However the best glide ratio remains approximately the same, but now occurs at a higher airspeed. Therefore if the thermals are strong enough to compensate for the poor climb performance then water ballast allows a faster inter thermal cruise.





**[ Any questions? ]**

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