BRONZE LECTURES

2016

Slides available as advertised

and on on bayriver.co.uk/gliding

STUDY

- Lectures only meant to be a stimulus
- and provide an opportunity for questions
- EXAM paper is multi-choice
    - with ? sections.

READING

BOOKS ?

Note: There is now a defined syllabus on the BGA website.

See:- http://www.gliding.co.uk/forms/bronzestudyguide.pdf

Also the **OLD** ‘Bronze Confuser’ *may* be of use.

Try:- http://www.esgc.co.uk/bronze.htm

or   http://www.bfgc.co.uk/Confuser/confuser.aspx

or just Google ‘gliding bronze confuser’

PRINCIPLES OF FLIGHT

Objectives:-

1. To pass the Bronze exam paper

   pretty low hurdle multi-guess exam!

2. To learn as much as possible about Principles of Flight

   If you are interested !

   (this may be the last time you ever get to learn anything on the subject !)

   - some of it might even make you more cautious about certain things

   - you might understand something of what the gurus are talking about in the restaurant.

PRINCIPLES OF FLIGHT

PART ONE

- How the wing works
- Lift and drag
- Airbrakes
- Flaps
- Turning
- Stalling & Spinning

PART TWO

- Stability
- Flight Envelope
- Polar Curves

- The exam

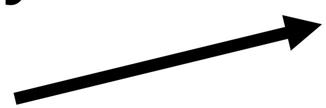
BRONZE LECTURES

PRINCIPLES OF FLIGHT

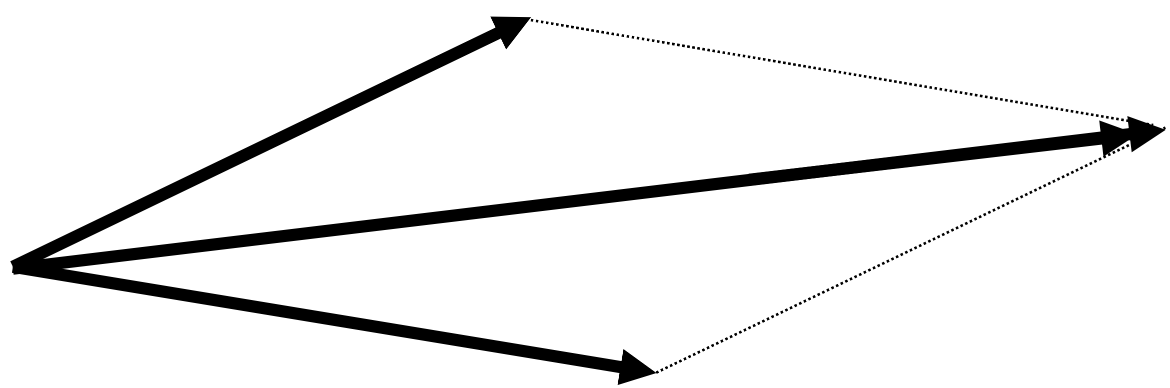
PART ONE

VECTORS

- Revision ? School/College ? Experiments ? Or just believe it !
- A Force can be represented in magnitude and direction by an arrow (length $\propto$ magnitude)

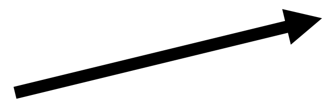


- Adding forces together (parallelogram law)



VECTORS

- Revision ? School/College ? Experiments ? Or just believe it !
- A Force can be represented in magnitude and direction by an arrow (length ∝ magnitude)



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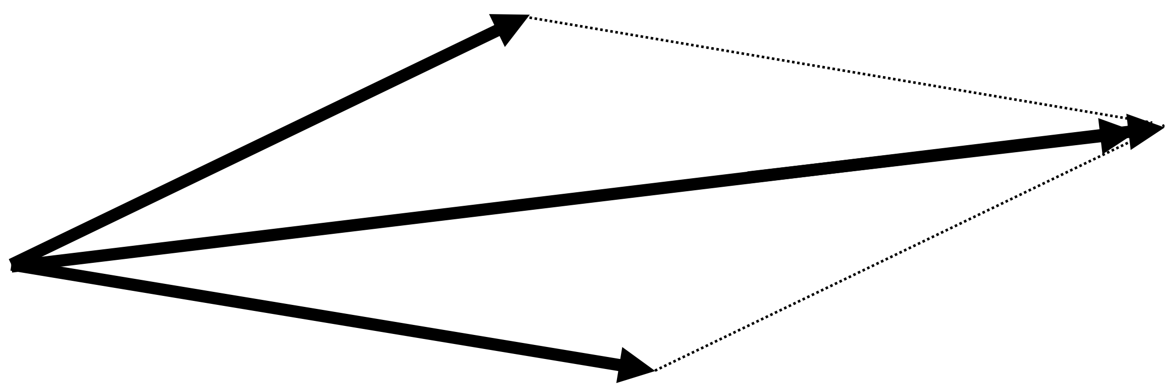
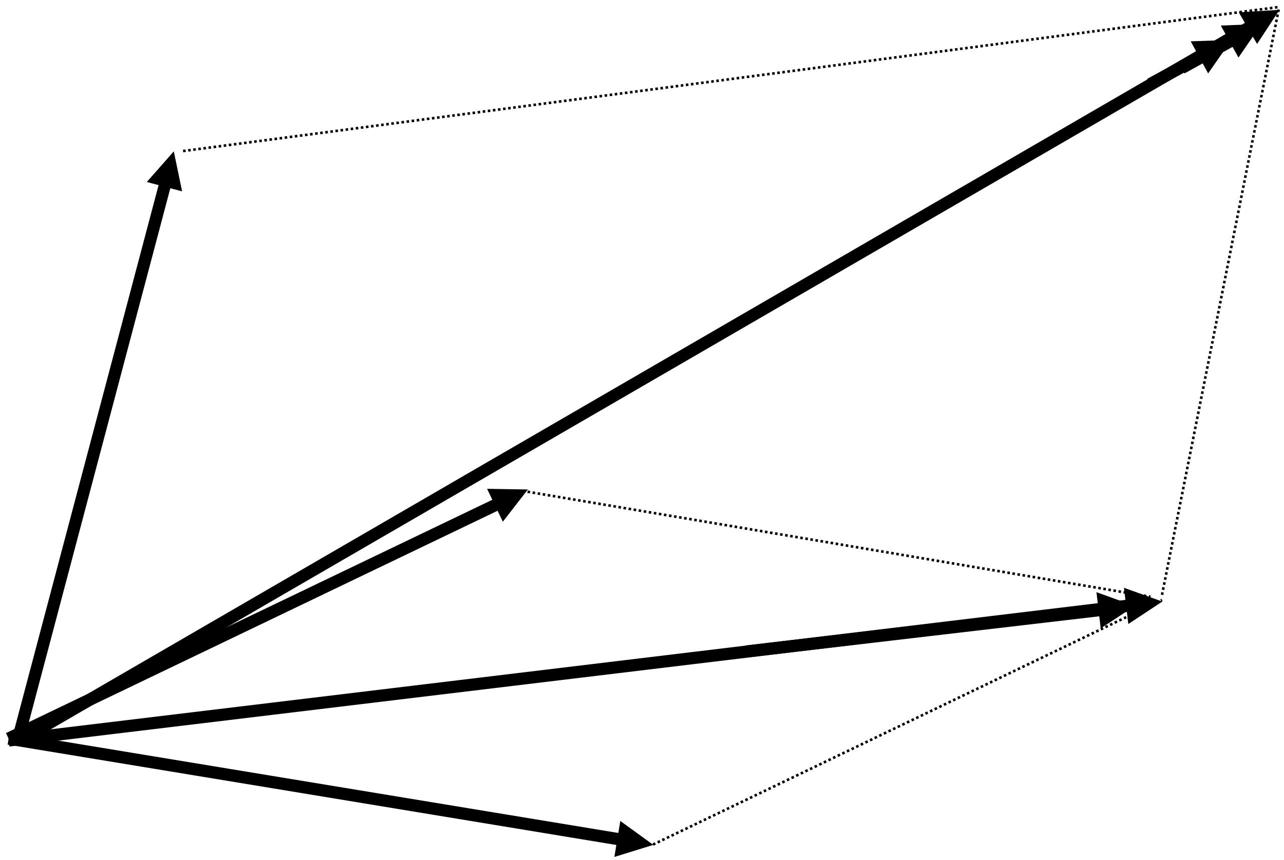
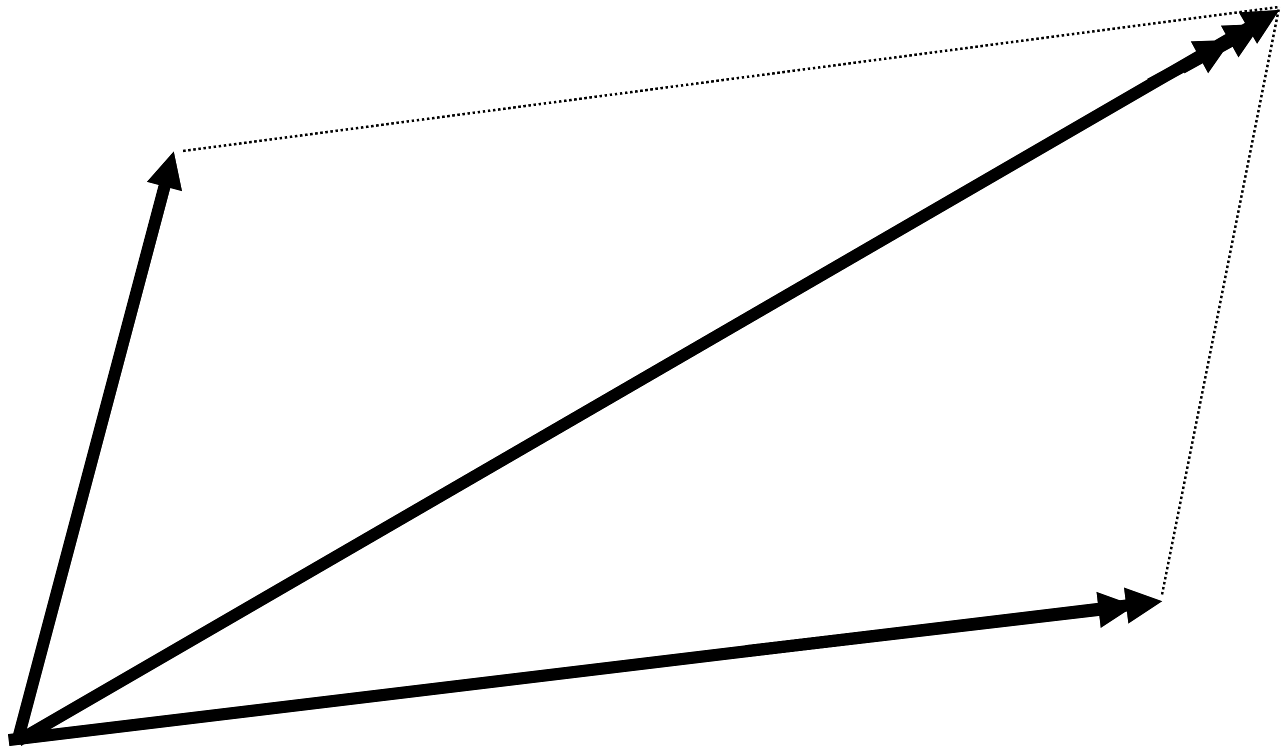


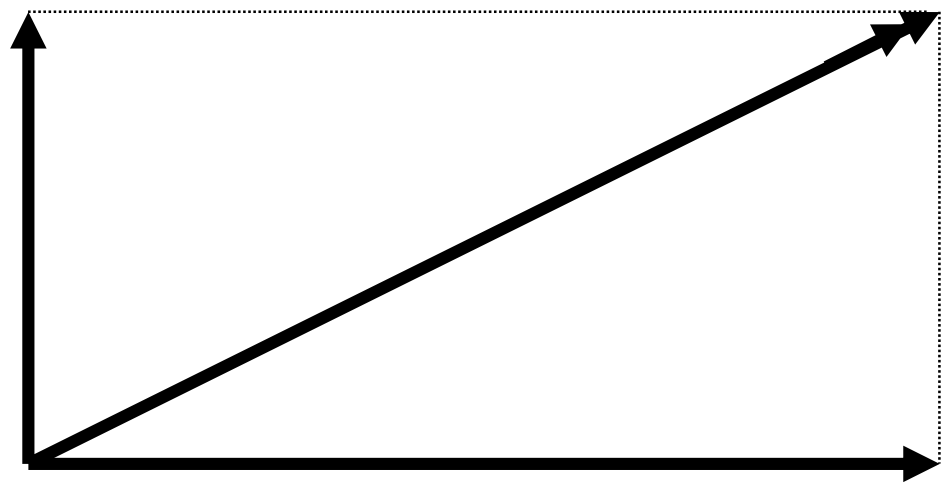
- Any* two forces can be replaced by a single force which will have exactly the same effect on the object (line of action and magnitude).
- We can subsequently combine this with a third force etc etc and so combine as many forces as we like into a single force.
- We end up with a single ‘resultant’ force

* As long as they are not parallel !





Special case when forces are at 90 degrees (rectangle law)



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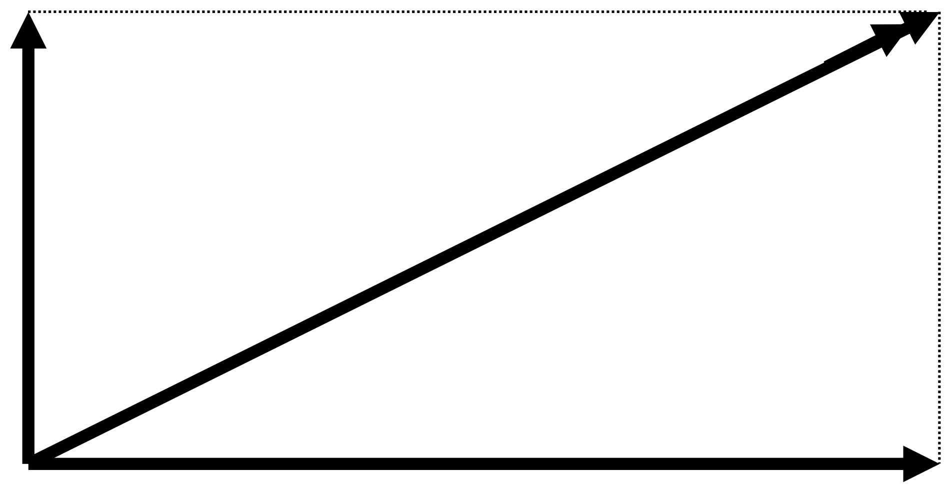
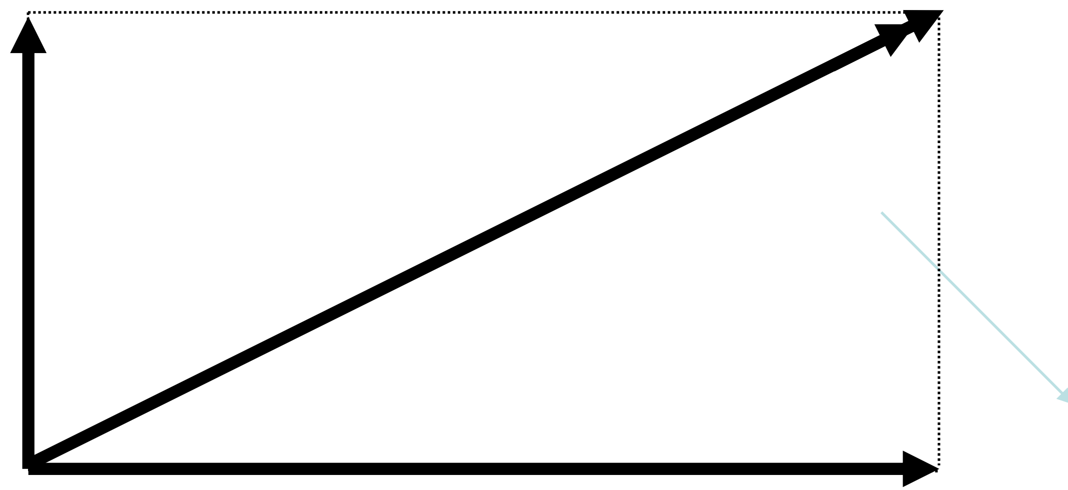
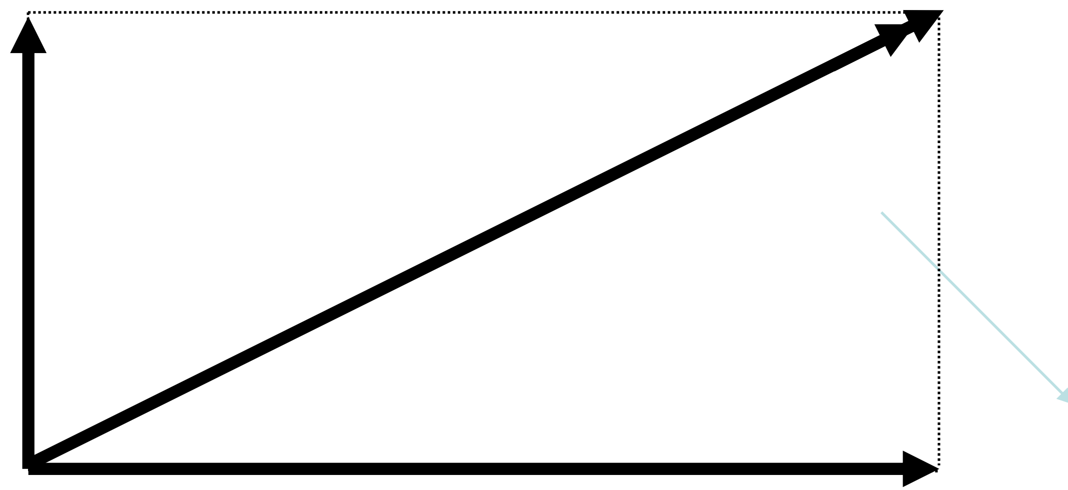


Resolving forces



Resolving forces



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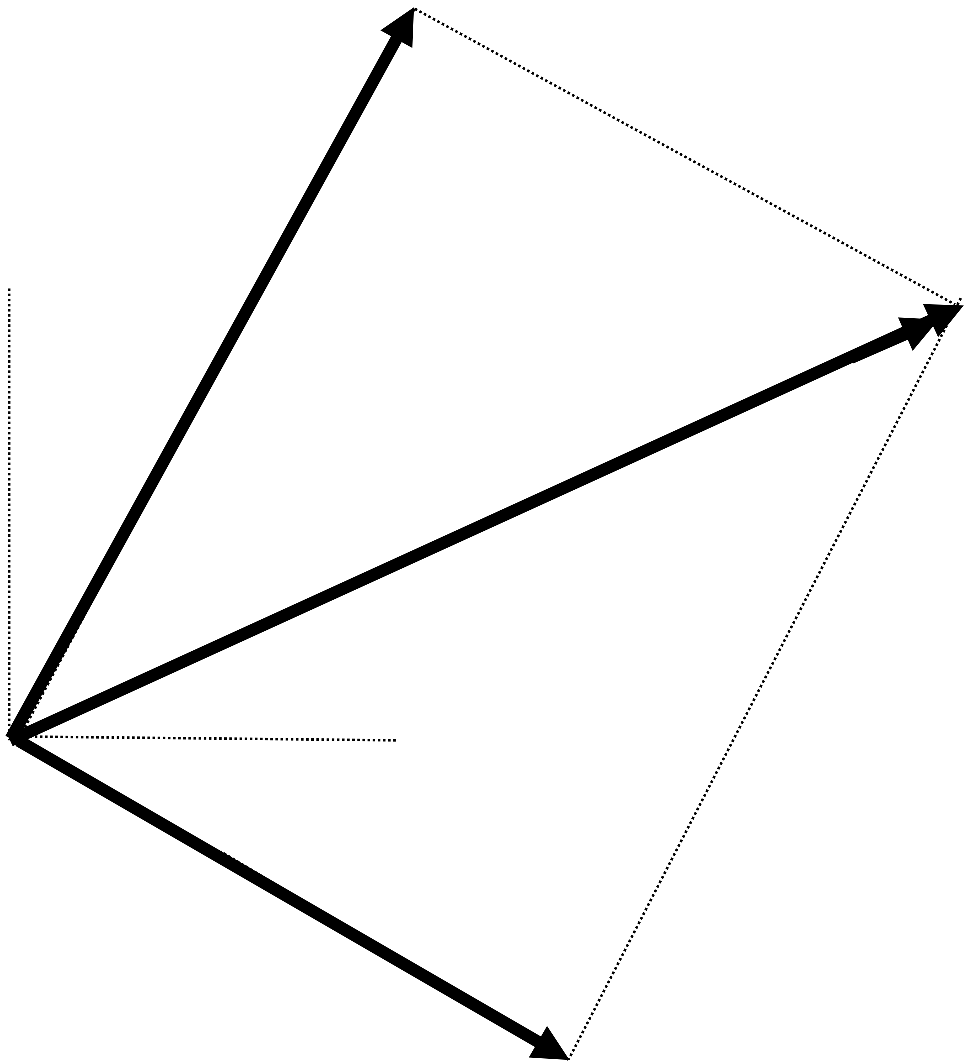
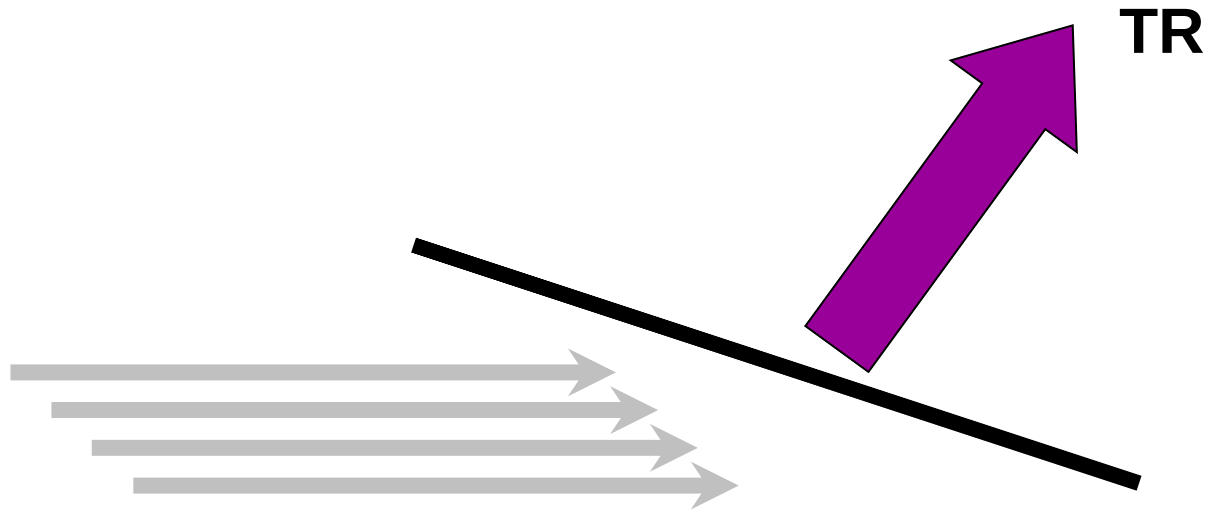


- Any force can be replaced by two forces at right angles, in any orientation, and they will have exactly the same effect as the original force
- The point about choosing them to be at right angles is that each component has no effect whatsoever in the direction of the other
- We call them ‘component’ forces

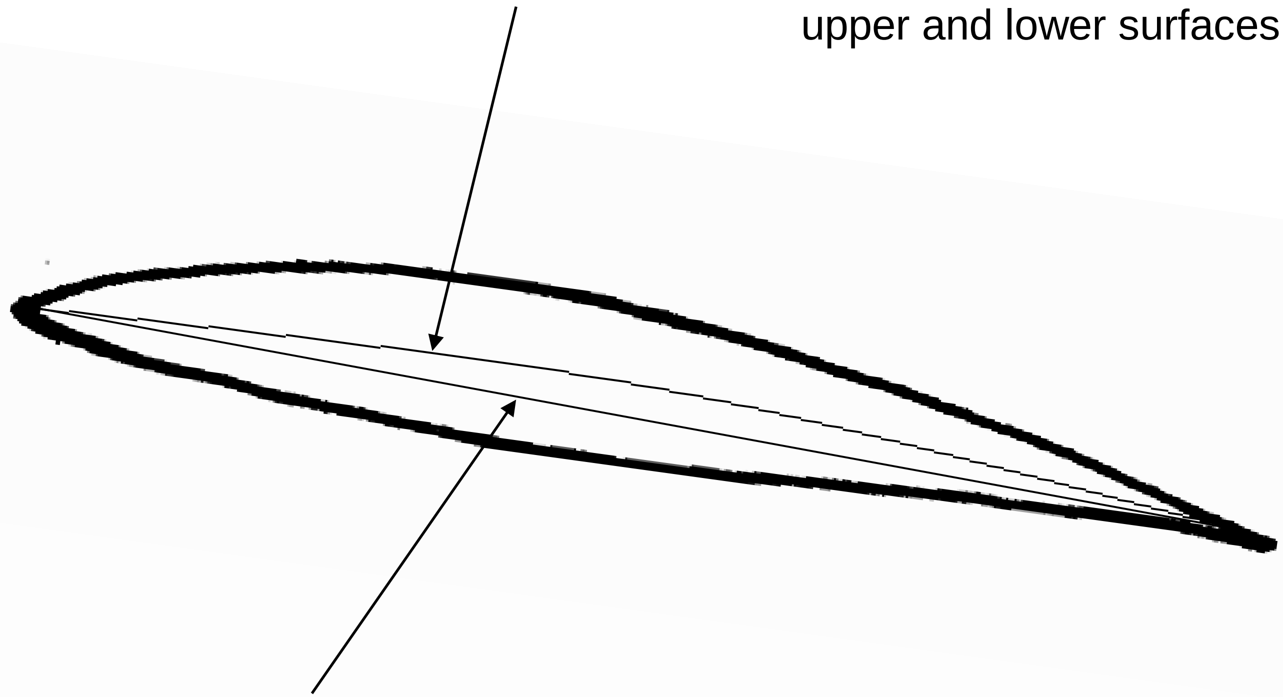
THE WING

- How does the wing work ?
  - Apparently it <u>does</u> !

A Flat Plate would work (but not very well)



Mean Camber line = a curve half way between upper and lower surfaces

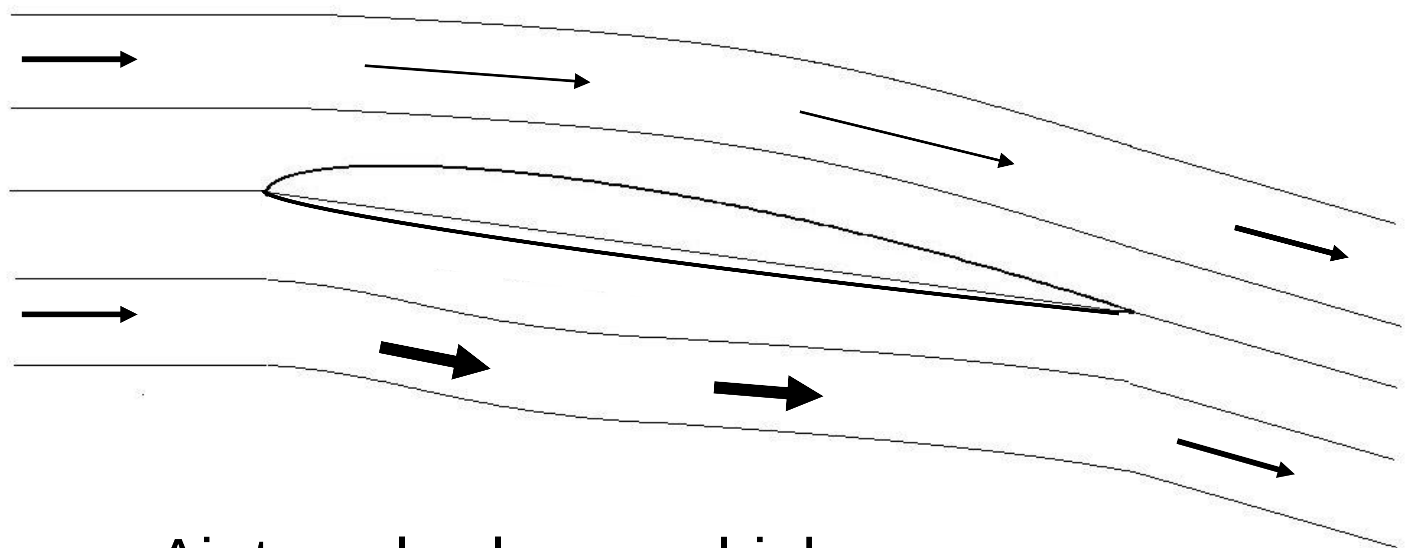


Chord line = straight line joining leading and trailing edges

A cambered wing is better

What keeps it up?

Air travels faster = low pressure



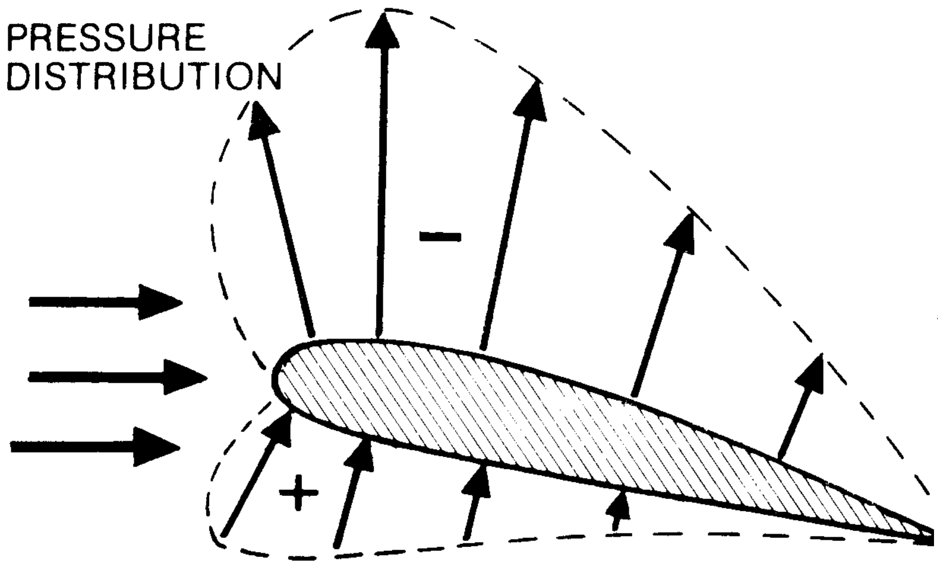
Air travels slower = high pressure

(Bernoulii's explanation)

EQUIVALENT FORCE

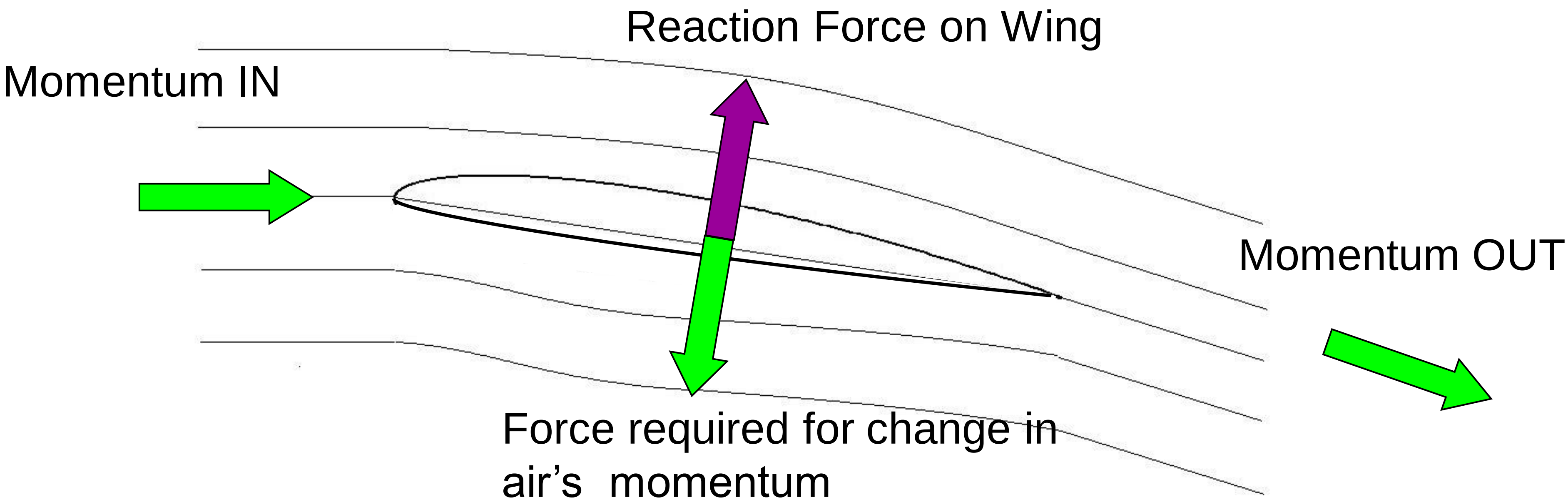
TOTAL REACTION

70% above



30% below

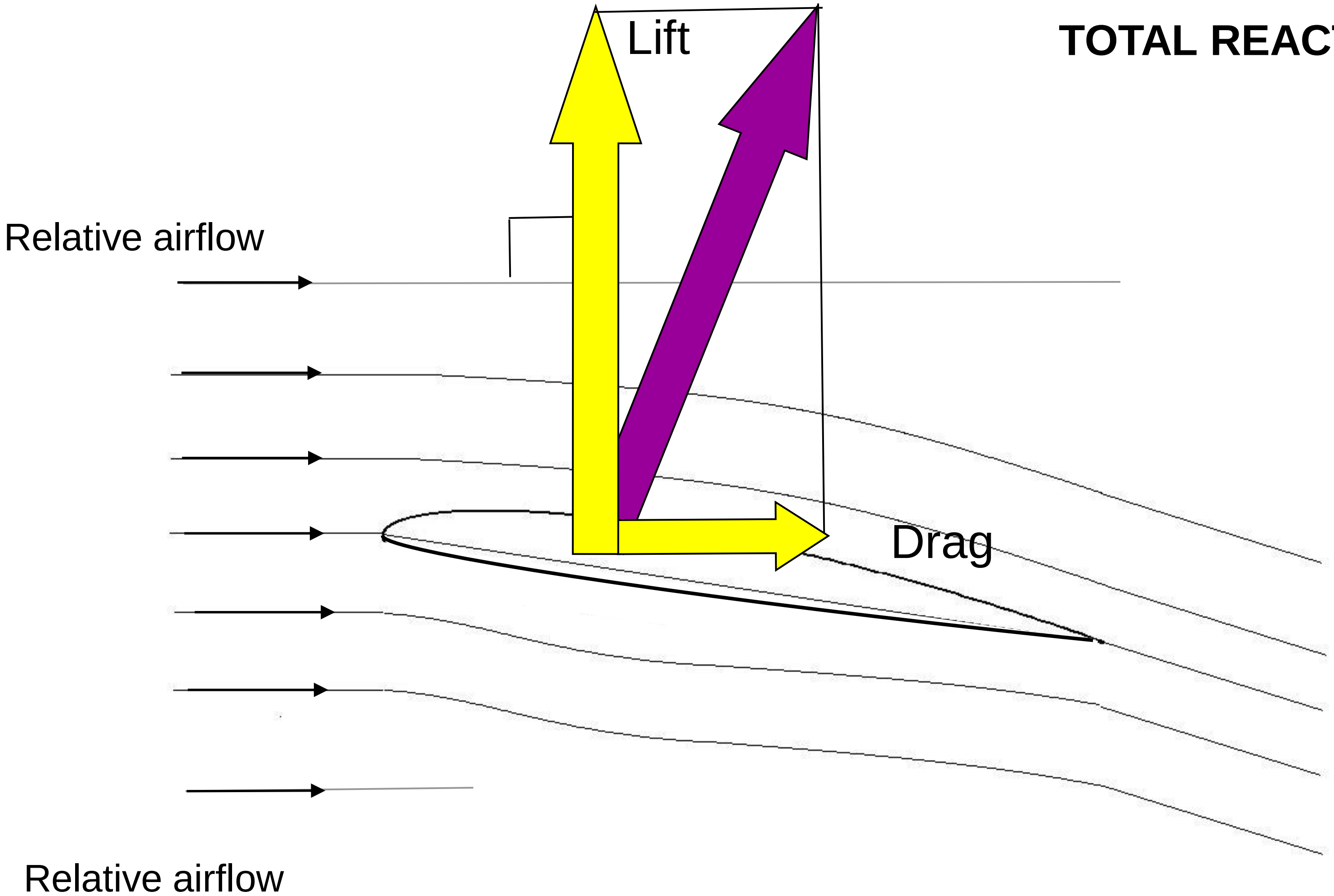
Momentum



Air is deflected downwards so wing experiences a force upwards

(Newton's explanation)

TOTAL REACTION



DEFINITIONS

LIFT

- Definition of lift v. drag
  - With respect to the relative airflow (at a distance from the wing)
- *Terminology: In some books ‘Lift’ is sometimes conflated with ‘Total Reaction’*
- Contribution to lift from above (70%) and below (30%) the wing (approx)

- LIFT INCREASES AS THE SQUARE OF THE SPEED (IAS)

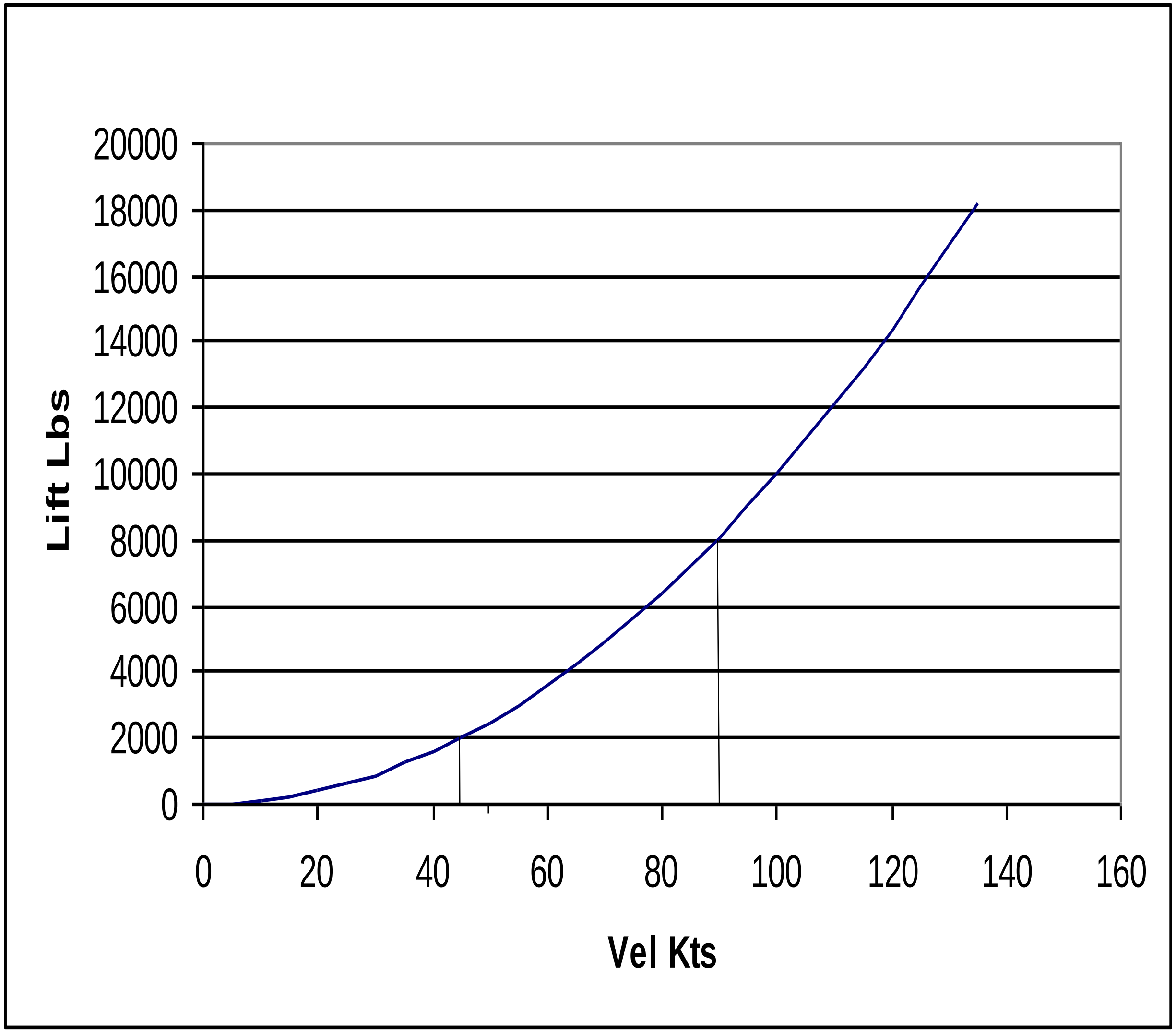
(if other things are equal !!!)

- IF YOU GO <u>TWICE</u> AS FAST YOU GET <u>FOUR</u> TIMES AS MUCH LIFT
- IF YOU GO <u>THREE</u> TIMES AS FAST YOU GET <u>NINE</u> TIMES AS MUCH LIFT
- IF YOU GO <u>HALF</u> AS FAST YOU ONLY GET A <u>QUARTER</u> OF THE LIFT

(If the angle of attack doesn't change)

(See below)

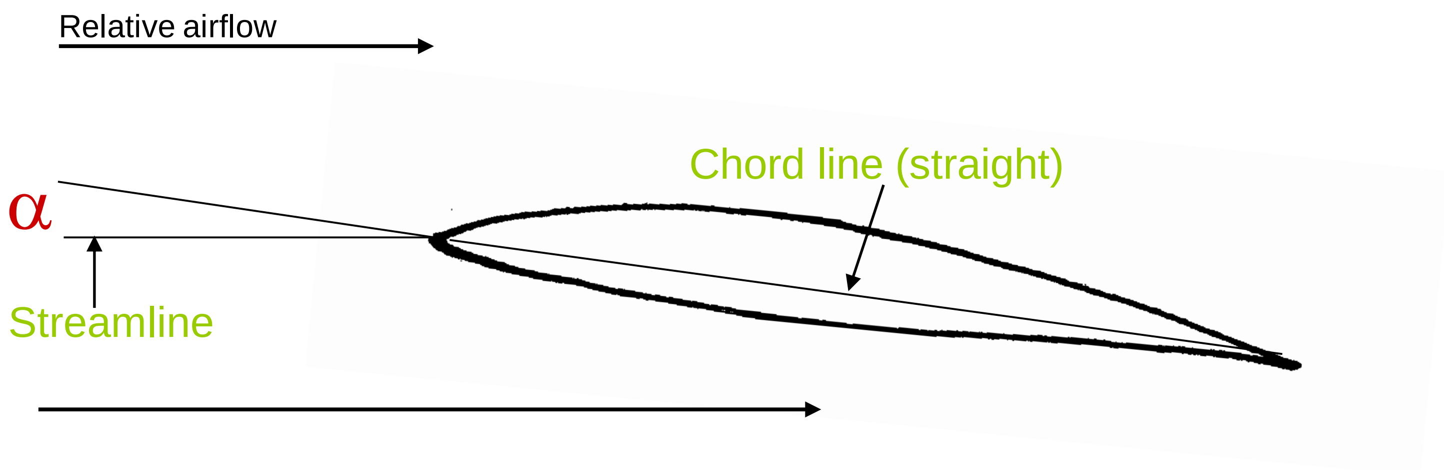
Lift v Speed


Lift Lbs
20000
18000
16000
14000
12000
10000
8000
6000
4000
2000
0
0
20
40
60
80
100
120
140
160
Vel Kts

ANGLE OF ATTACK (AoA)

- <u>Defined</u> as angle between chord line and airflow

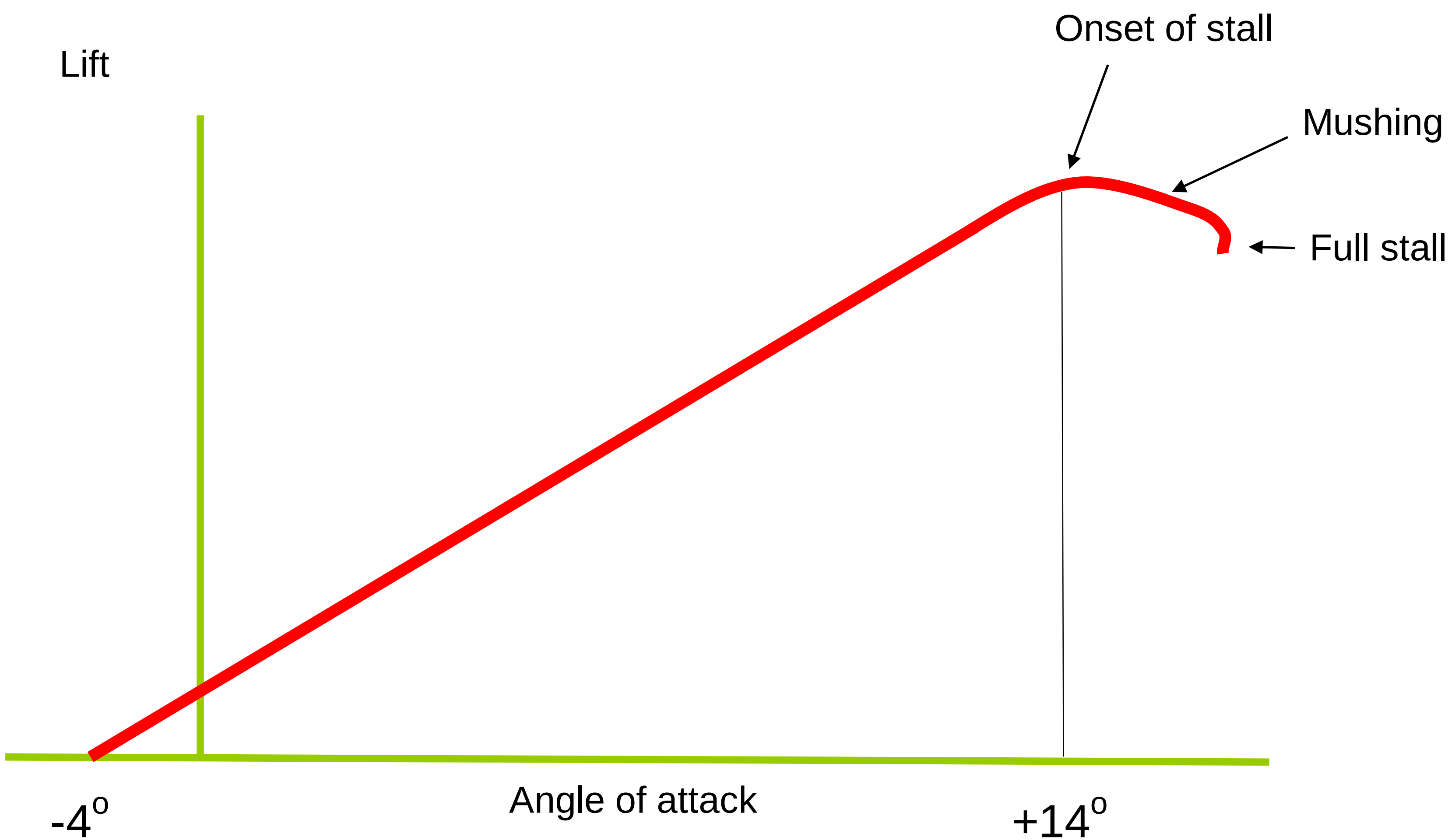
ANGLE OF ATTACK α



ANGLE OF ATTACK (AoA)

- Defined as angle between chord line and airflow
- Lift increases
  - from zero at approx -4^{o} (linearly)
  - to maximum at approx $+14^{o}$

Lift v AoA



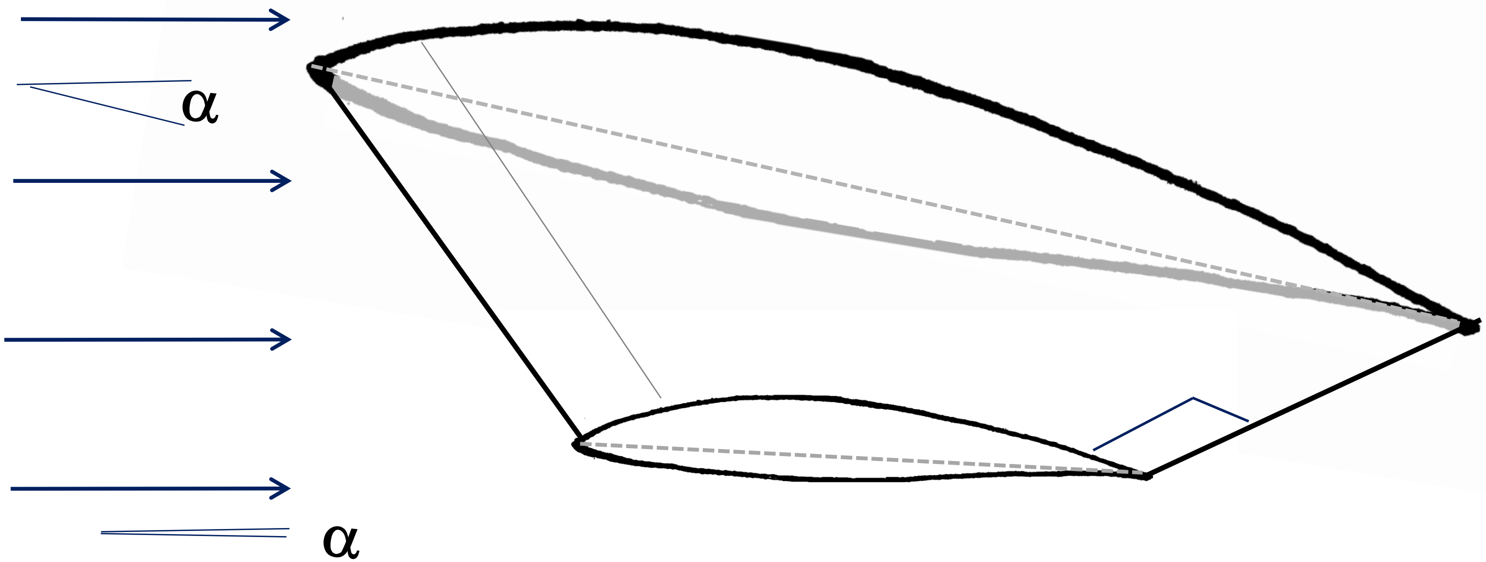
At constant speed

ANGLE OF ATTACK (AoA)

- Defined as angle between chord line and airflow
- Lift increases
  - from zero at approx -4^{o}
  - to maximum at approx $+14^{o}$
- Stall angle is at around $+14^{o}$
    - NOT speed
- Washout
    - Twist down/forwards towards tip
    - Roots stall before tips

- (Angle of incidence or Rigger's angle)

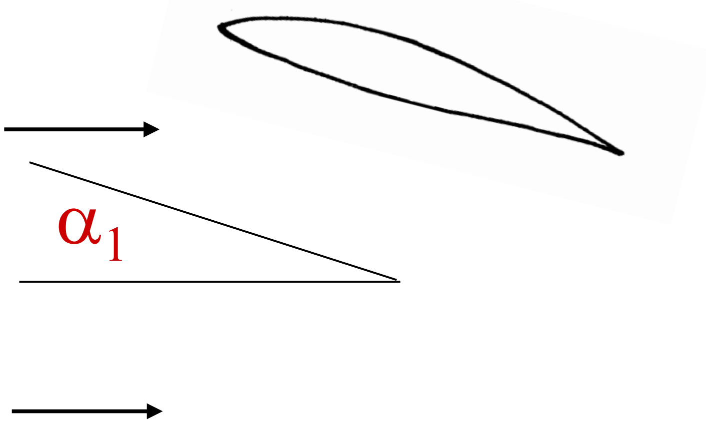
WASHOUT



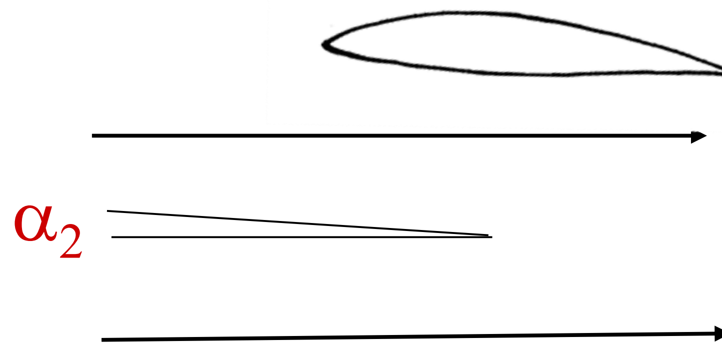
Root stalls before tip

AoA v Speed in the Glide

Lift increases with angle of attack (α)
- until the stall angle is reached



Lift also increases with the square of the airspeed



So to stop your aircraft from falling out of the sky you can either –

a. Fly slowly with a big angle of attack (mind you don't stall)

or b. fly fast with a small angle of attack (mind you don't exceed Vne)

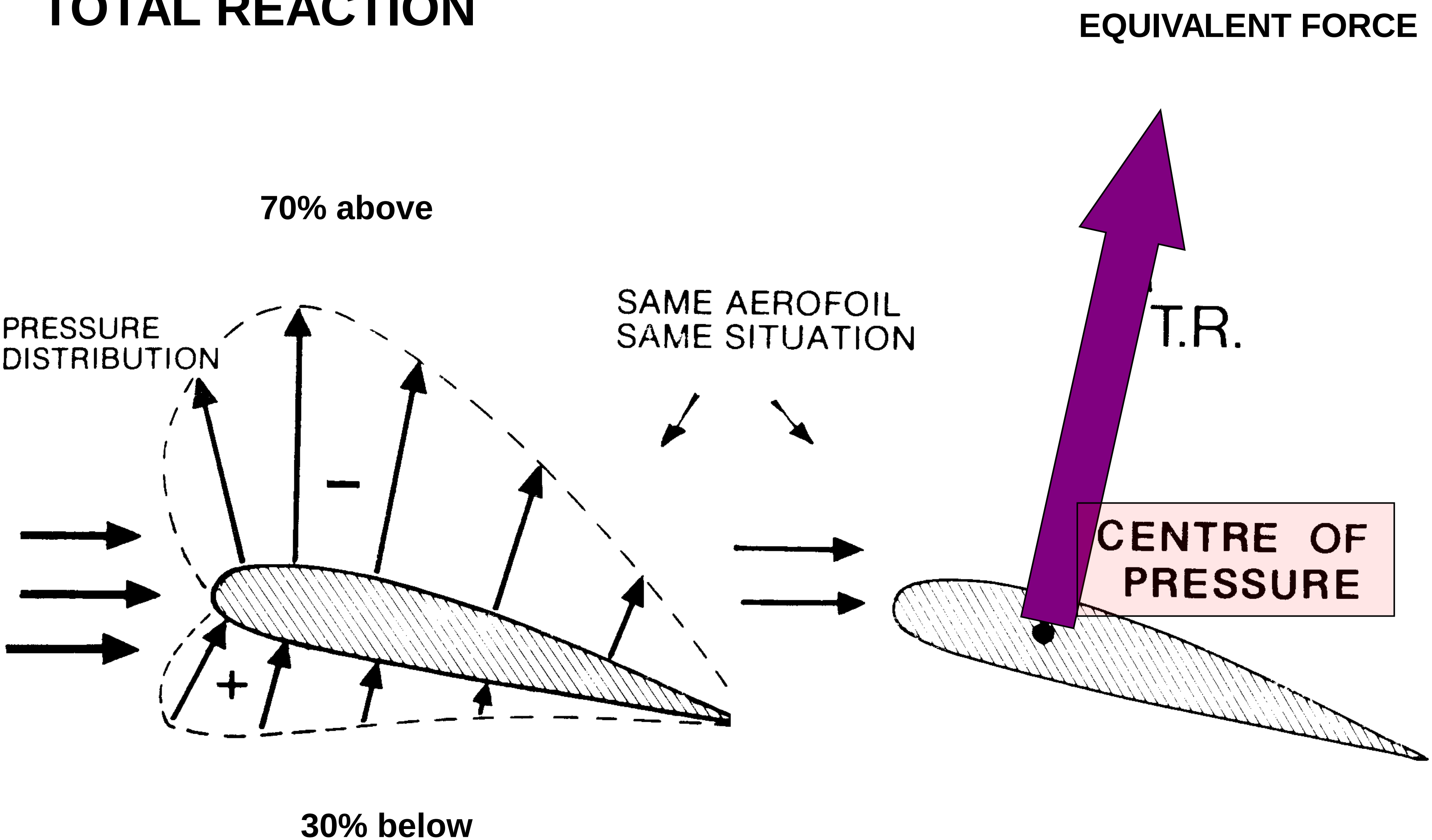
or c. anything in between

In a steady glide (in a straight line with constant speed) there is only one angle of attack for a particular speed.

however…

- The angle of attack can be changed essentially instantaneously
  - but the speed cannot
- So if you move the stick back, the angle of attack (and therefore the lift) is immediately increased but the speed takes time to reduce. So you 'zoom' up
- But if you put the stick forward, the angle of attack, and the lift, is instantly reduced whereas it takes time to increase speed. Therefore you drop – and if near the ground you will hit it!

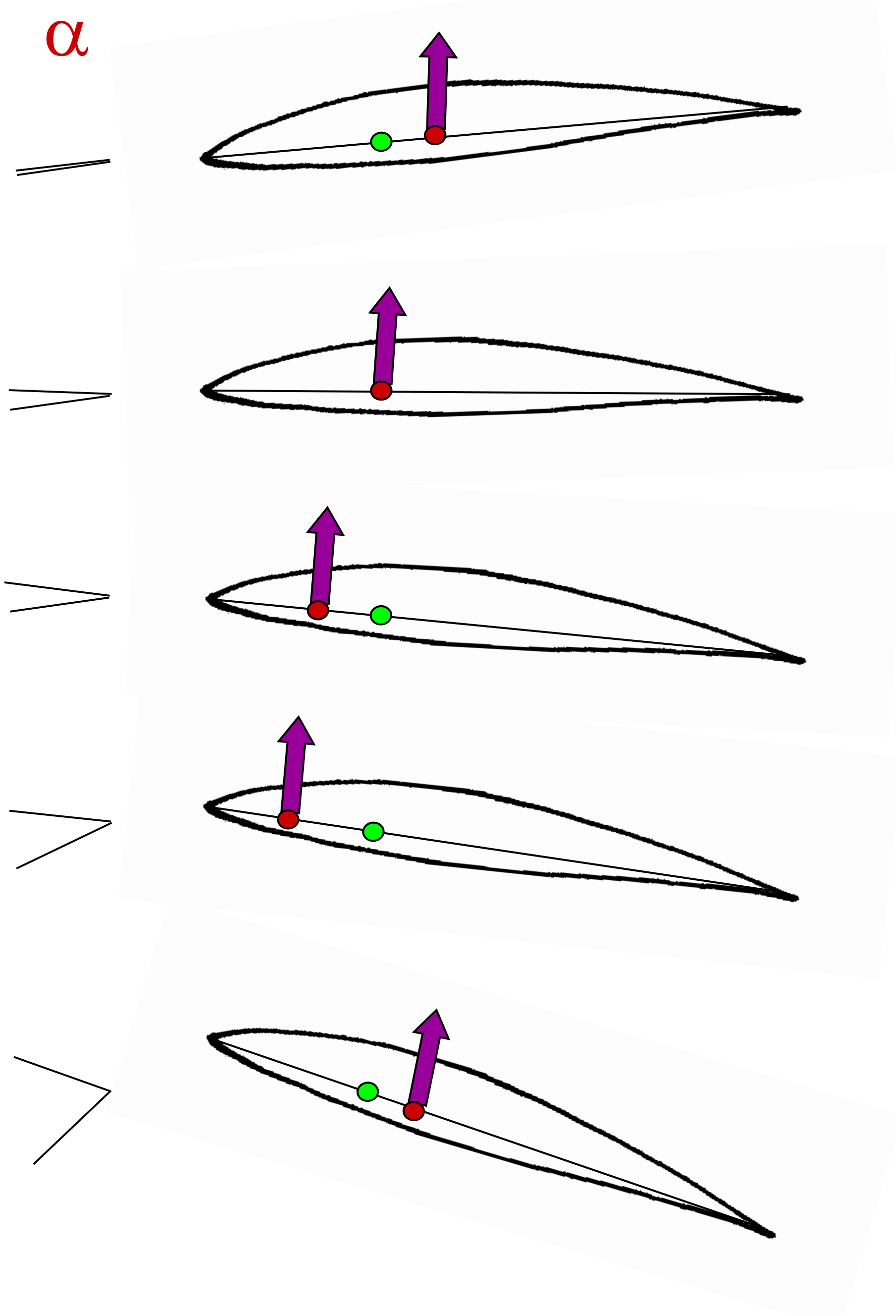
TOTAL REACTION



CENTRE OF PRESSURE (C of P)

- Point on chord line where total reaction acts
- Acts approx one third back from leading edge for normal AoA's

C of P moves …



Fast – moves back

MOVEMENT
OF C of P

Medium

Slow – Moves forward

Just above the stall – max forward

Just below the stall – moves back again

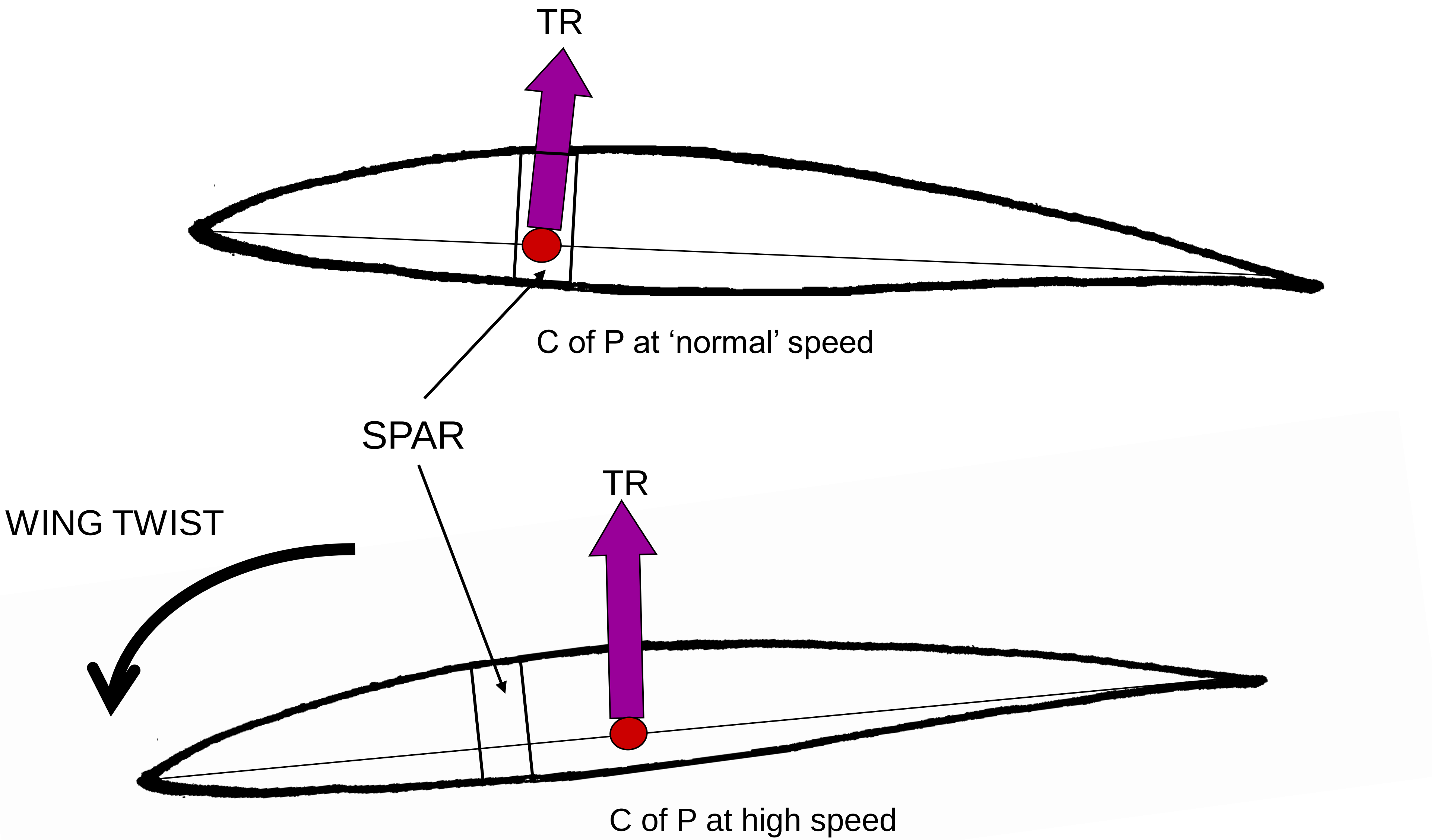
HENCE NOSE DROPS

CENTRE OF PRESSURE (C of P)

- Point on chord line where total reaction acts
- Acts approx one third back from leading edge for normal AoA's

C of P moves

- backwards as AoA decreases



Use of ailerons makes it worse

Incorrect flap setting at speed may damage the wing

CENTRE OF PRESSURE (C of P)

- Point on chord line where total reaction acts
- Acts approx one third back from leading edge for normal AoA's

C of P moves

- backwards as AoA decreases
  - hence wing twisting. Can reach torsion limit at Vne
- forward as AoA increases - reaching approx a quarter of the way back from leading edge
- up to stall angle
- then moves rapidly backwards again

Movement of C of P implies wing instability (part two)

DRAG

(Remember is defined as parallel to relative airflow)

TWO fundamental types of drag

- Non-lift related drag
  - sometimes called

    PROFILE DRAG

INCREASES

AS THE SQUARE OF THE SPEED (IAS)

- Lift related drag
  - called

    INDUCED DRAG

DECREASES

AS THE SQUARE OF THE SPEED (IAS)

NON-LIFT RELATED
(or PROFILE DRAG*)

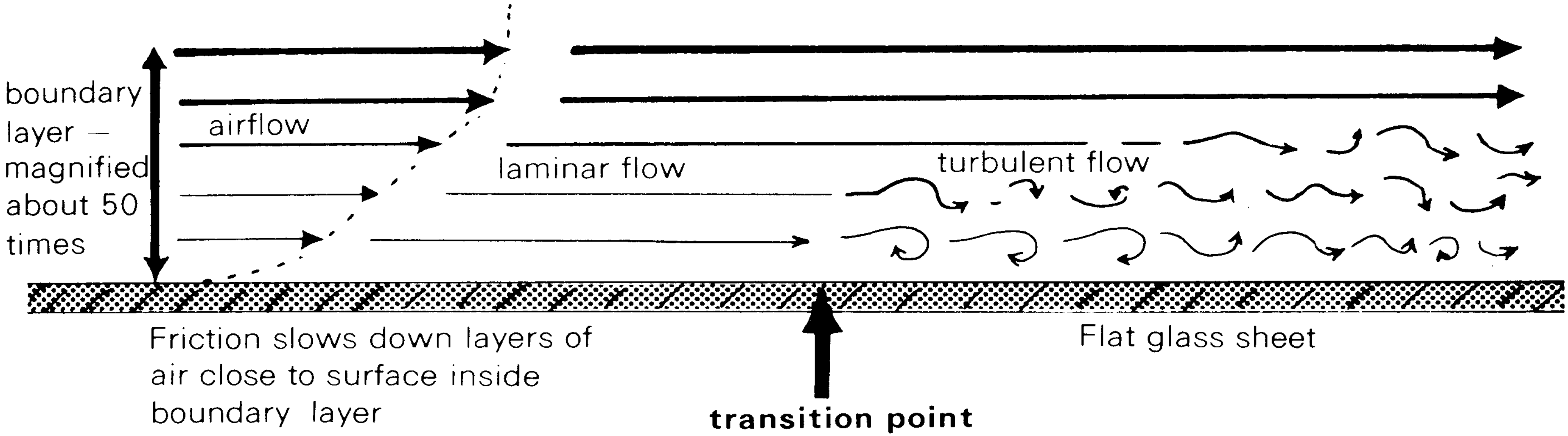
INCLUDES

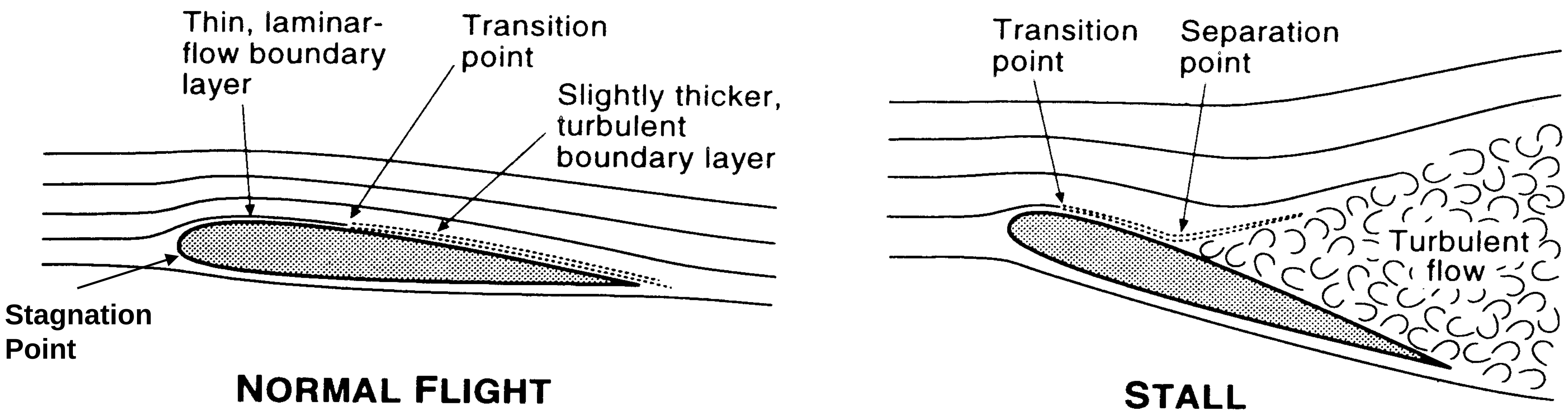
- Form drag (the aircraft has got to push air aside)
- Skin/surface friction
- Interference drag (wing tape)
- etc

* beware terminology

INCREASES WITH INCREASING IAS^2

therefore it matters at high speed

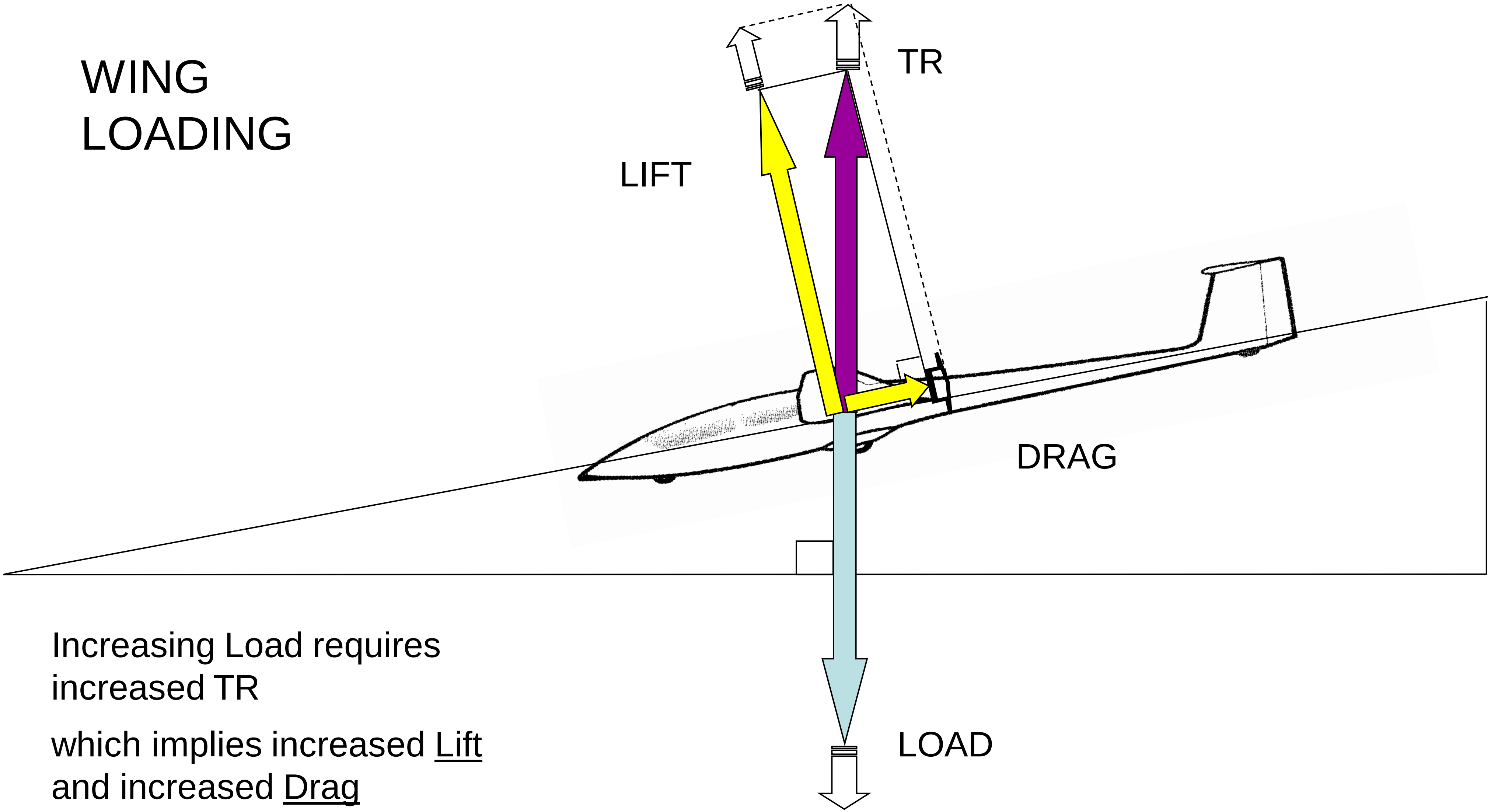

boundary
layer –
magnified
about 50
times
airflow
laminar flow
turbulent flow
Friction slows down layers of
air close to surface inside
boundary layer
transition point
Flat glass sheet


Thin, laminar-
flow boundary
layer
Transition
point
Slightly thicker,
turbulent
boundary layer
Stagnation
Point
NORMAL FLIGHT
Transition
point
Separation
point
Turbulent
flow
STALL

LIFT RELATED
(or INDUCED DRAG)

- Is lift / wing dependent
- Increases with increased wing loading

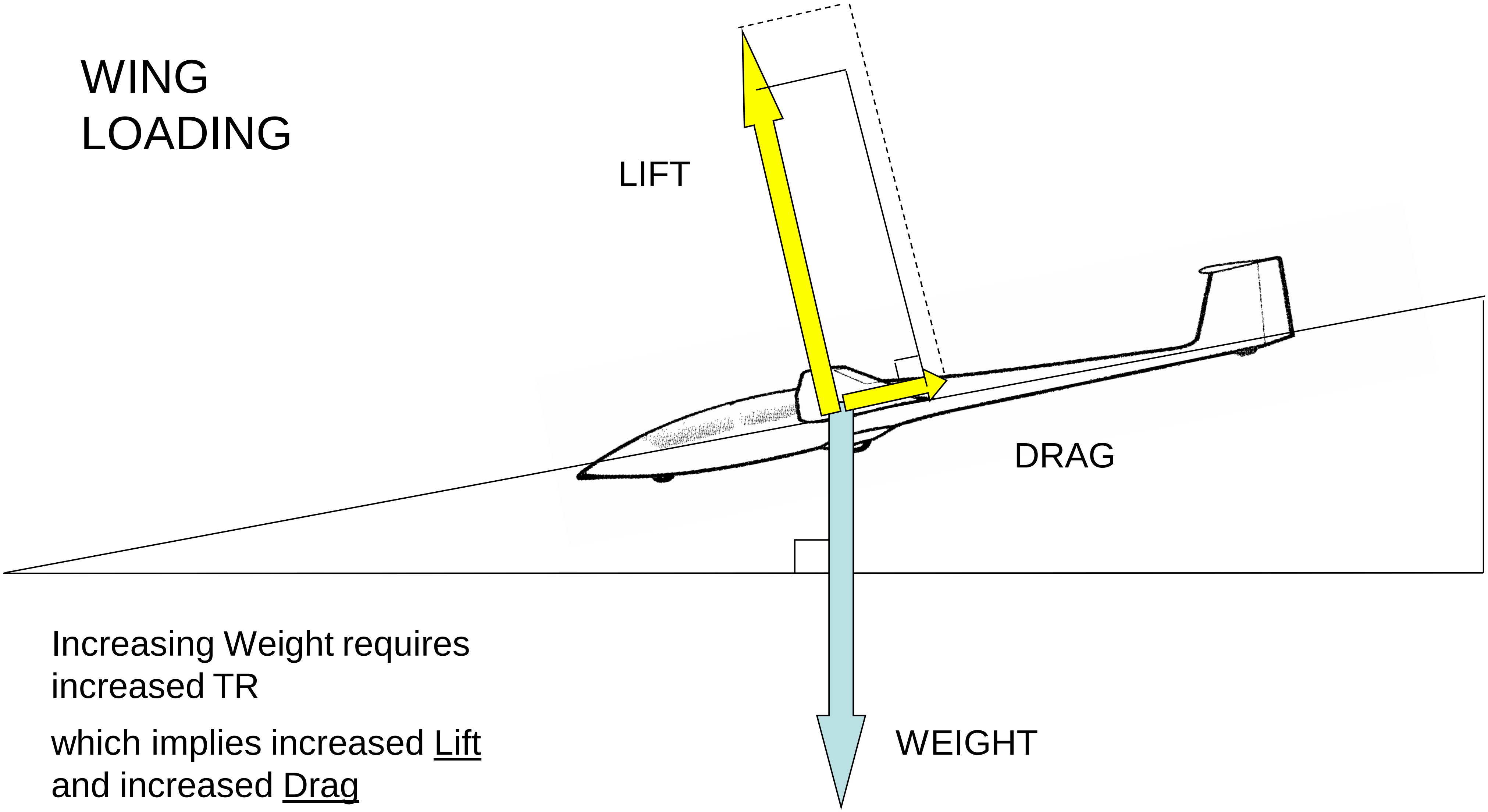
WING LOADING



Increasing Load requires increased TR

which implies increased <u>Lift</u> and increased <u>Drag</u>

WING LOADING



Increasing Weight requires increased TR

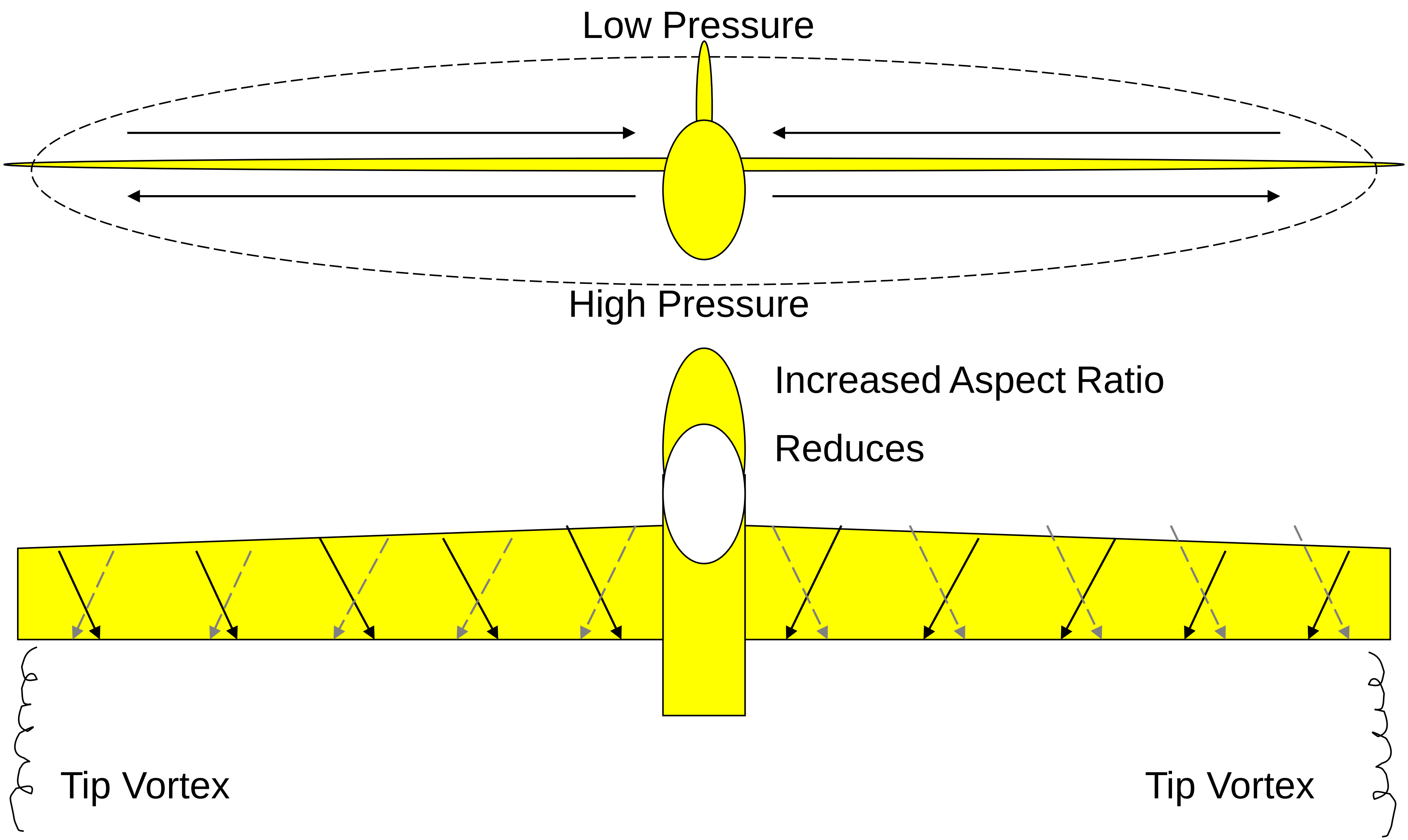
which implies increased Lift and increased Drag

The lift required is referred to as the Wing Loading

INDUCED DRAG

- Is lift / wing dependent
- Increases with increased wing loading
- Pressure differences mean span-wise flow resulting in wing tip and trailing edge vortices and a downwash

Induced Drag



INDUCED DRAG

- Is lift / wing dependent
- Increases with increased wing loading
- Pressure differences mean span-wise flow resulting in wing tip and trailing edge vortices and a downwash
    - This is what winglets are designed to reduce
- Aspect ratio = span divided by chord (? average)
  – defined as $span^2$ / area
- Induced (vortex) drag v aspect ratio
  – TINSFoS
- other things being equal (wing loading)

DECREASES WITH INCREASING IAS^2

therefore significant at low speed

DRAG

- Neither law is surprising
  - Profile drag (non-lift related)
    - The faster you go the more profile drag you get - and it is an area (frontal / skin) effect
  - Induced drag (lift related)
    - The faster you go the smaller the angle of attack (needed) and the less the induced drag you get - and it is a speed squared effect

- Total drag
  - Two combined
    - see diagram

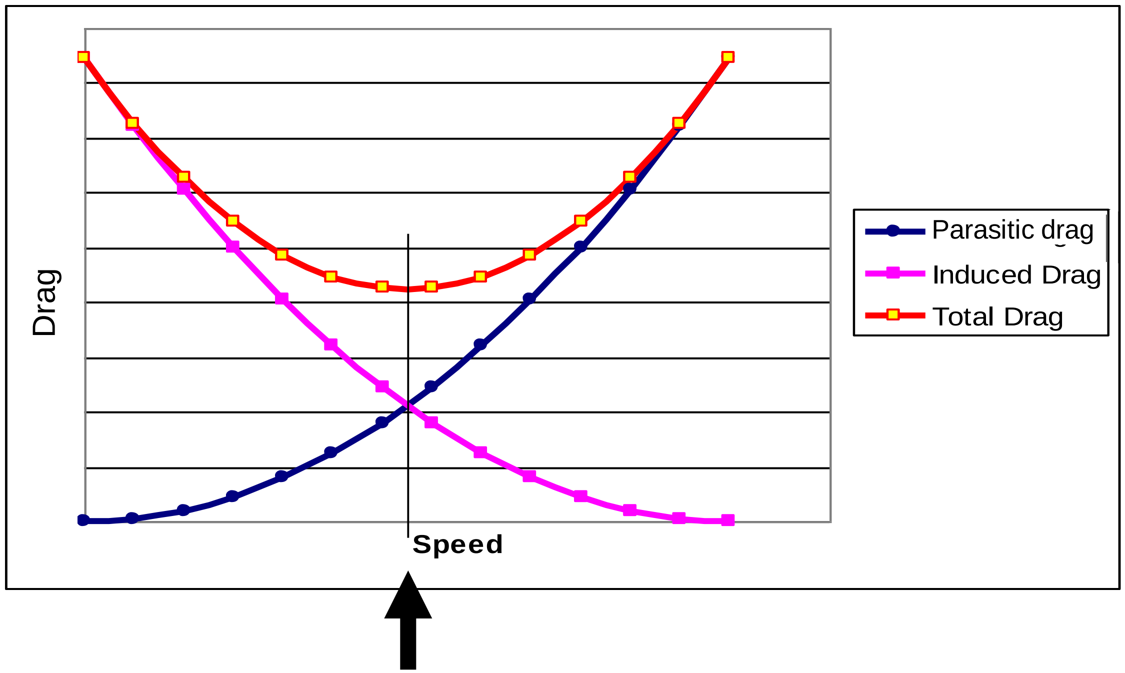
Total Drag

Induced Drag

(Lift related) decreases with speed squared

Profile drag

(Non-lift related) increases with speed squared



Minimum total drag means least loss of energy

This is Min Sink speed

DRAG

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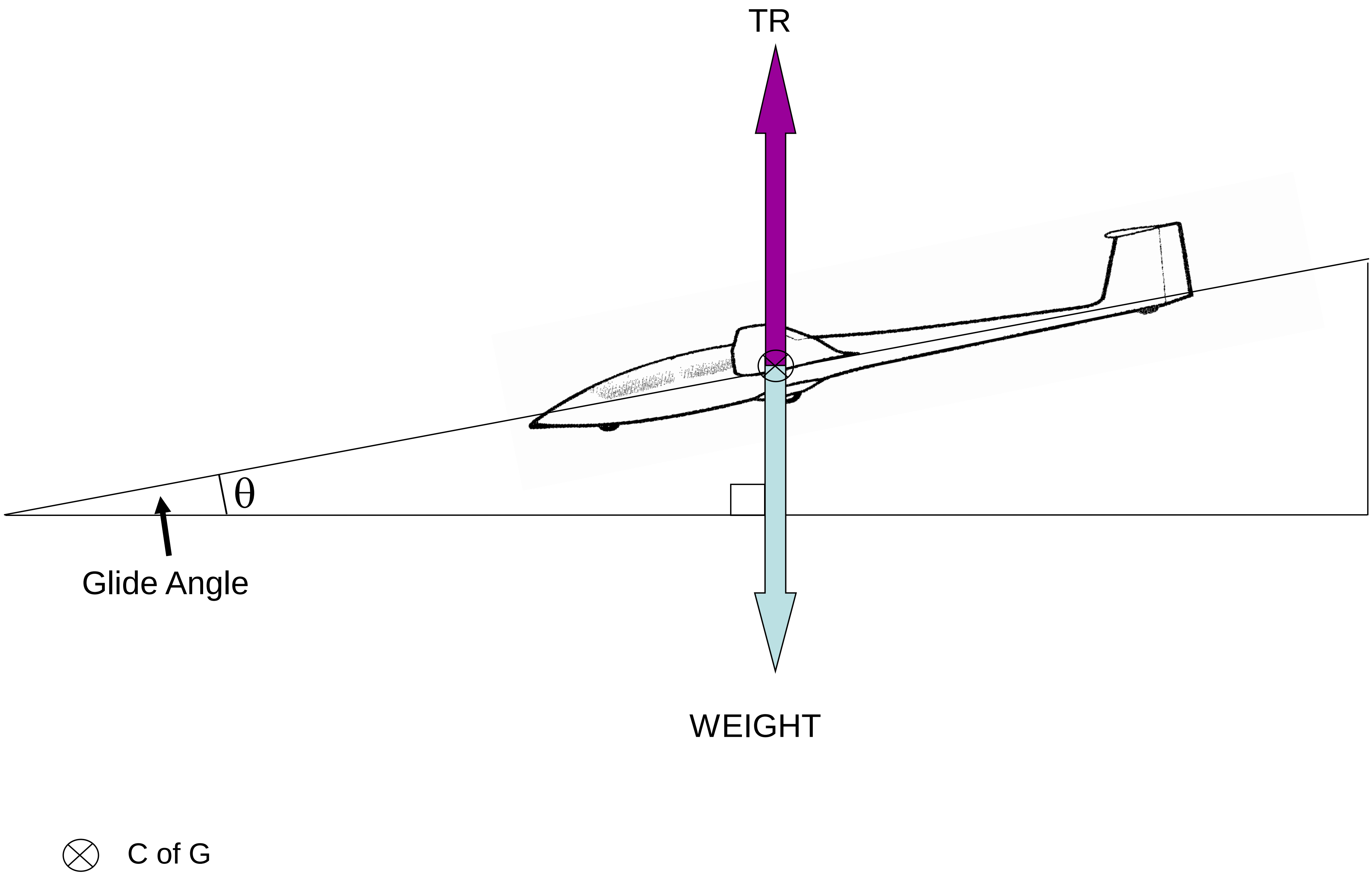
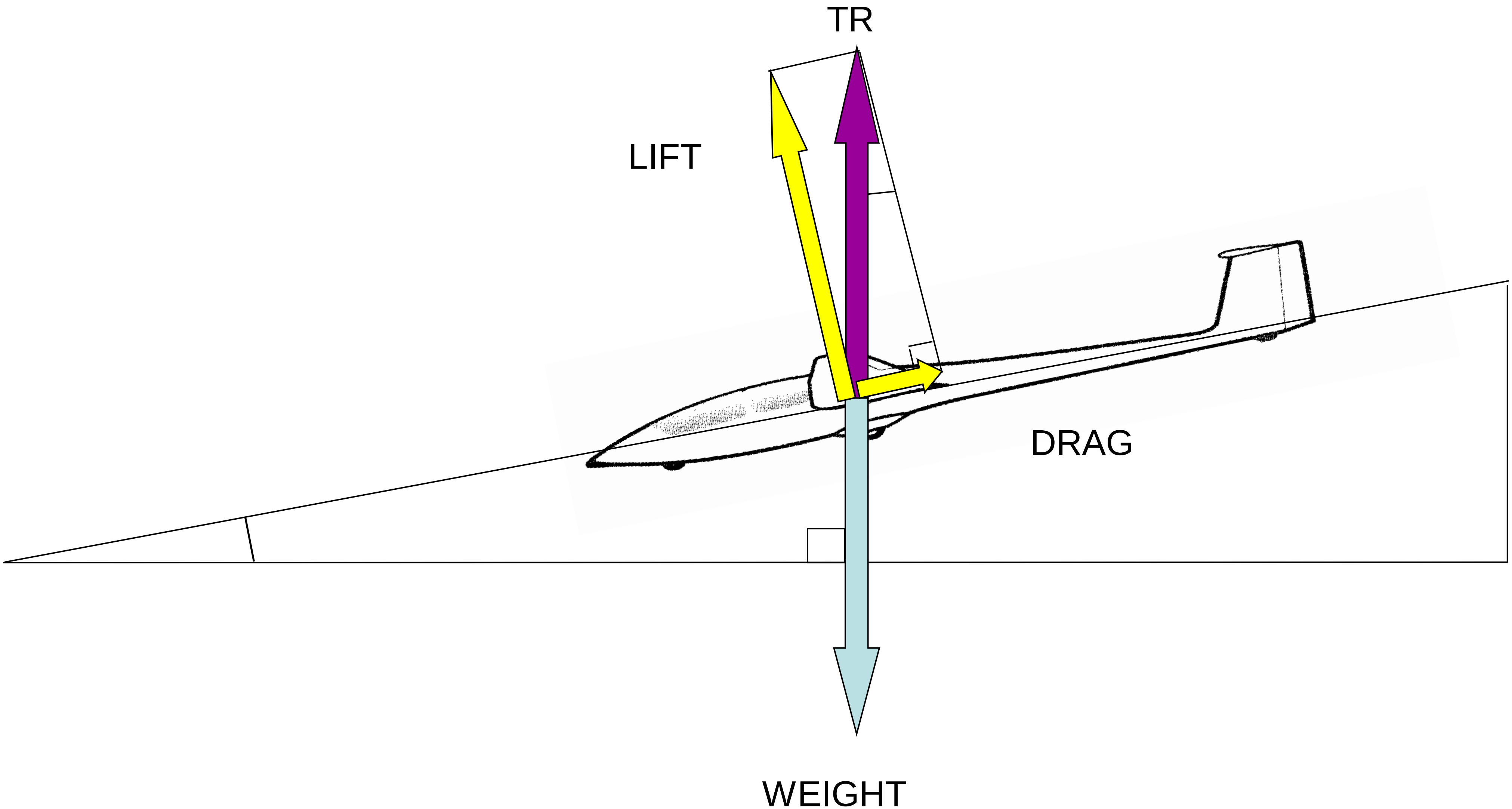
  - Profile drag
    - The faster you go the more profile drag you get - and it is an area (frontal / skin) effect
  - Induced drag
    - The faster you go the smaller the angle of attack (needed) and the less the induced drag you get - and it is a speed squared effect

- Total drag
  - Two combined
    - see diagram
  - Minimum sink
    - <u>Is NOT</u> best glide
      - » (see slides on polars)

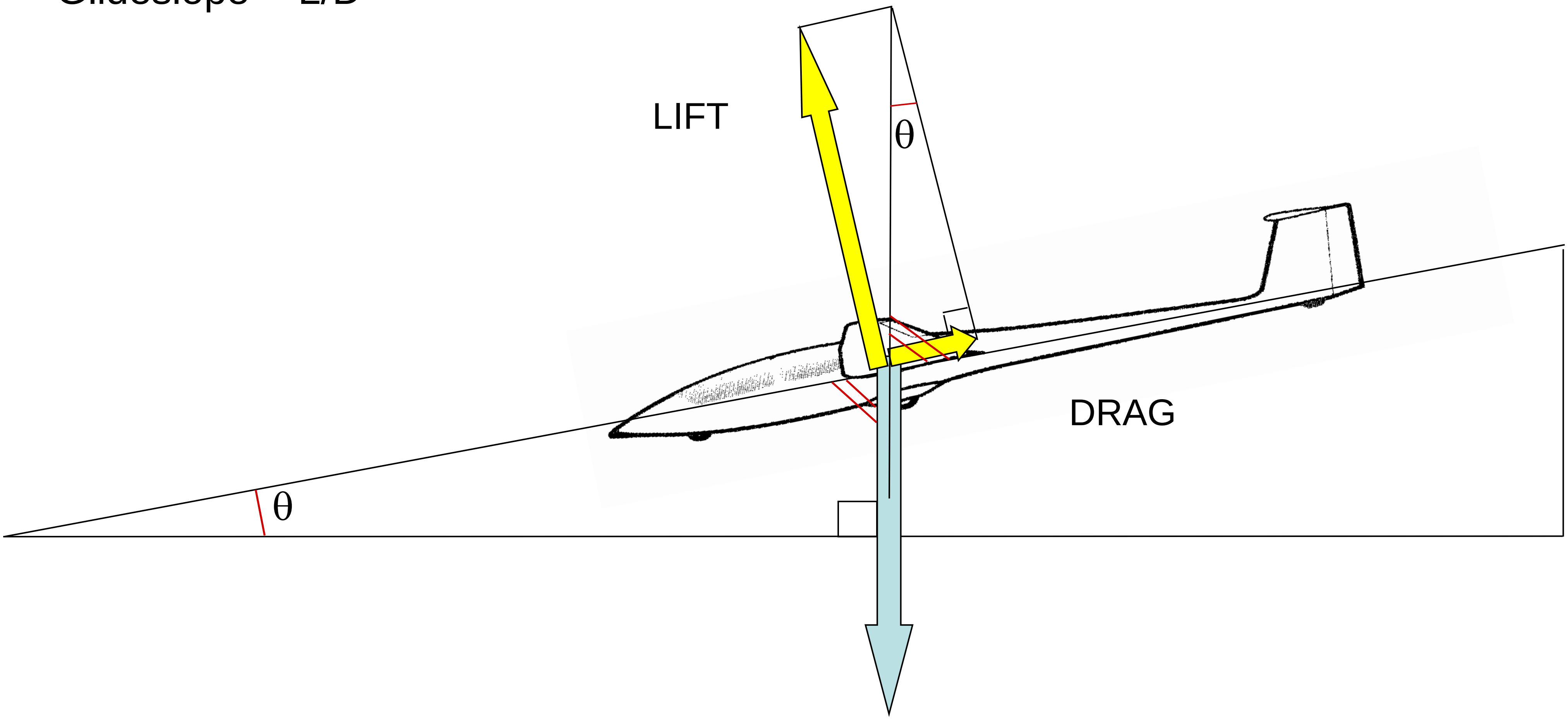
STEADY GLIDE

- i.e. at constant speed down a constant glide slope
- All forces are in equilibrium
  - in other words there is no net force
  - Newton's first law


TR
θ
Glide Angle
WEIGHT
C of G


TR
LIFT
DRAG
WEIGHT

Glideslope = L/D



(Similar triangles)

L/D = cot θ

So –

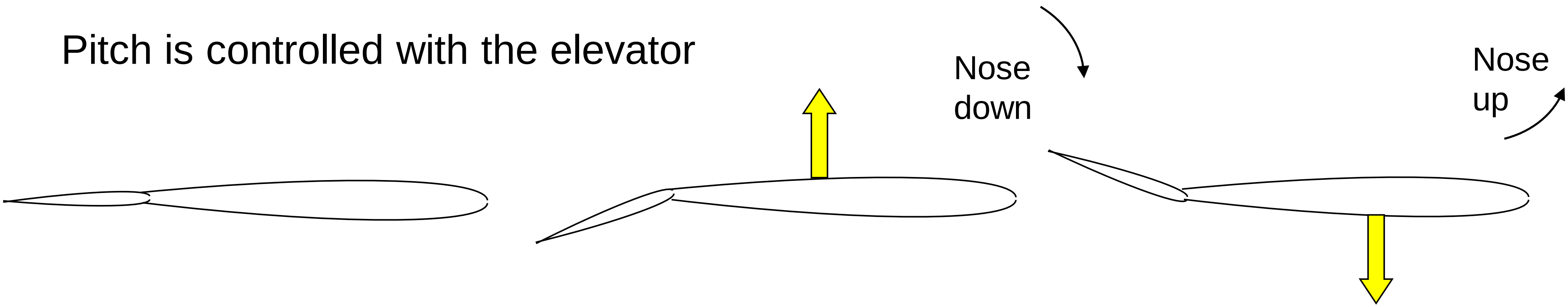
The Lift to Drag Ratio = The Glide Angle

Nothing magic !

This is a consequence of the definitions.

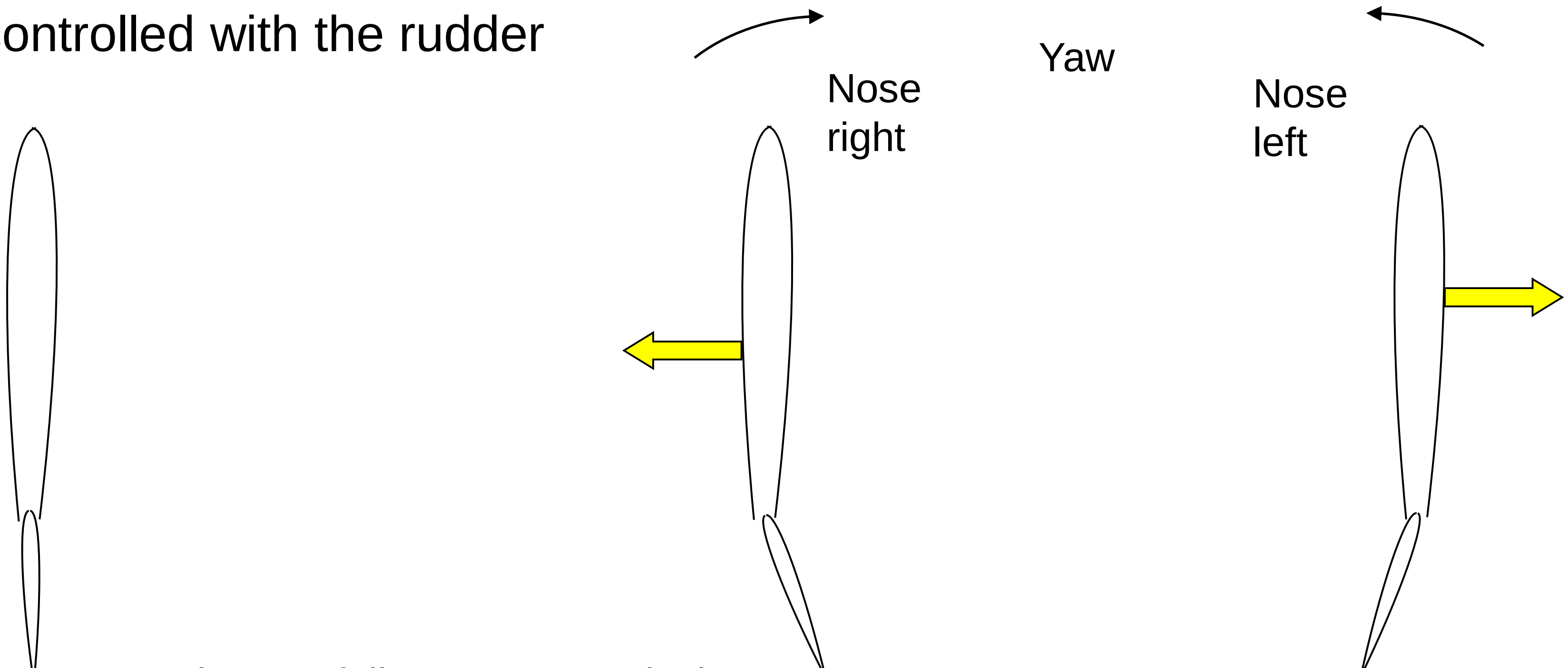
CONTROLS

Pitch is controlled with the elevator



The camber is effectively altered providing lift in the direction indicated

Yaw is controlled with the rudder

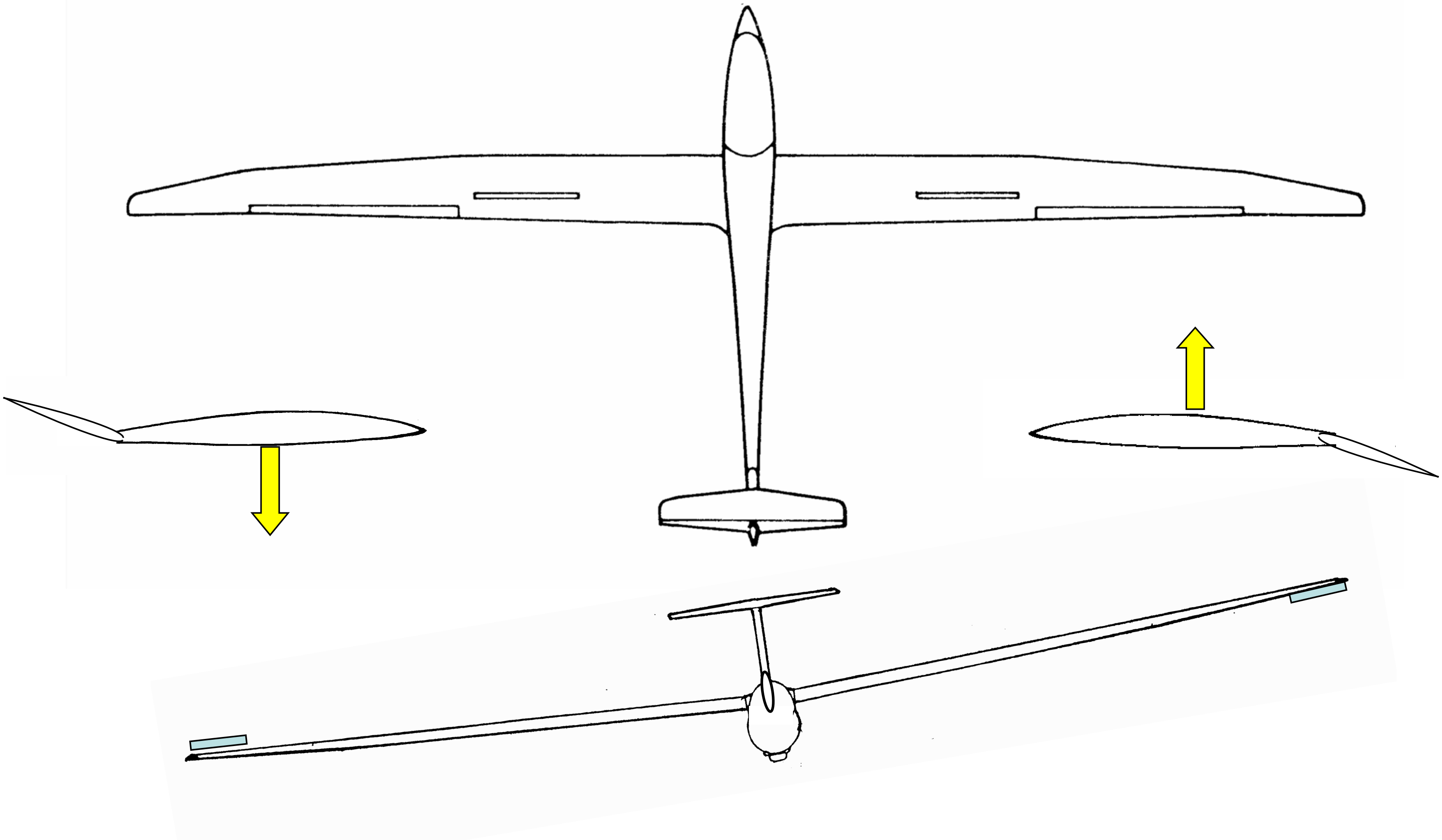


Note the aerofoils are symmetrical

CONTROLS

Roll is controlled
with the ailerons

ROLL TO THE LEFT



SECONDARY EFFECTS OF THE CONTROLS

- Rudder
  - Use of the rudder will also produce roll
    - since yaw will lead to one wing going faster than the other and therefore producing more lift
    - Hence the ability to ‘pick up the wing with the rudder’
      - » but beware doing this near the stall
- Ailerons
  - Use of ailerons will also produce (adverse) yaw
    - See discussion on turning

EFFECTS OF USING AIRBRAKES

1. Reduced lift
2. Increased drag
3. Increased roll stability

Air brakes

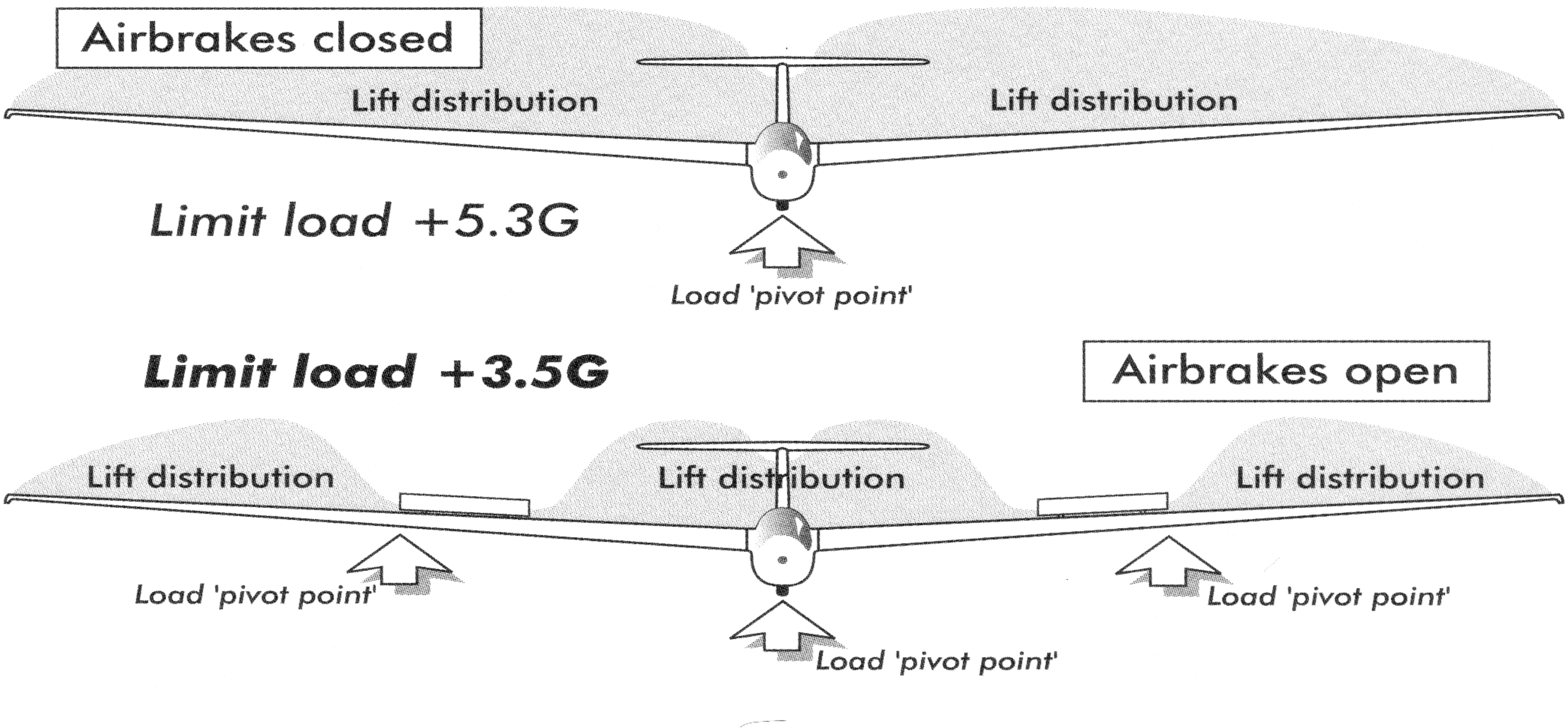
1 & 2 REDUCED LIFT AND INCREASED DRAG

- Airflow and lift on approx 20% of the wing is effectively destroyed
- Big increase in profile/form drag – large turbulent wake, may feel buffet
- Much steeper glide angle for approach
- Proportional control on glide angle (with modern a/bs)
- Some designs can change pitch attitude, flap type brakes
- Some upper & lower surface some upper surface only
- Do not exceed Dive Limit Speed (some types allow Vne but not unless open already)
- Only vintage gliders have speed limiting airbrakes
- CS (JAR) 22 requires speed to be limited only in a 30^o / *45^o dive

3 Lift distribution changes, relatively more lift outboard, more stable in roll

* If approved for cloud flying and/or aerobatics

3 INCREASED ROLL STABILITY

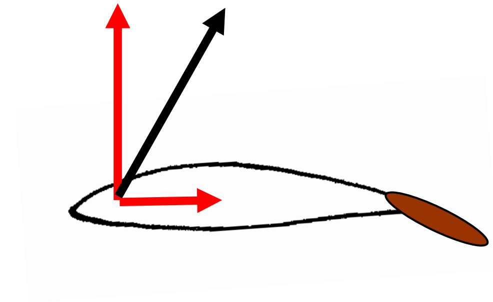


FLAPS

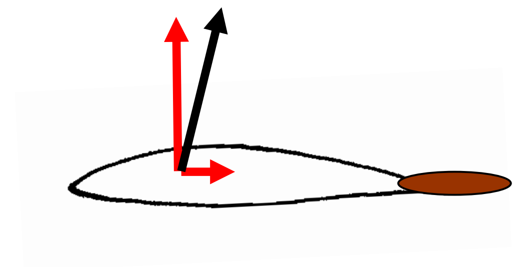
- Primary purpose is to provide better performance at different speeds in the cruise
    - See Polars in Part Two

- Also used for:-
  - Takeoff
    - Increasing aileron authority at slow speeds (flaps up-ish)
      - » in-board flaps reduce lift and leave outboard ailerons with relatively more lift
    - – (The Power Boys do it differently !!)
  - Landing
    - increasing drag and so steepening the glide angle for landing
    - lowering stall speed for landing (i.e. touchdown speed)
    - and shortening hold off and ground run

Effect of flaps



- Flaps down to increase lift and drag,
  - steeper approach angle
  - but reduced aileron authority!
  - CofP (can) move fwd (increased AOA),
    - in which case a/c tends to pitch up so you must trim forward
    - but ‘know your aircraft’ !
- Flaps up to reduce lift and drag,
  - better glide angle at high speed
  - CofP (can) move back (reduced AoA)
    - In which case a/c tends to pitch down so you must trim back
    - but ‘know you aircraft’ !
- Note limiting speeds for various flap settings
- Because of placarded speed limitations
  - To increase speed – flaps first then stick (and trim)
  - To reduce speed – stick first then flaps (and trim)
    - But don’t leave it too long !!

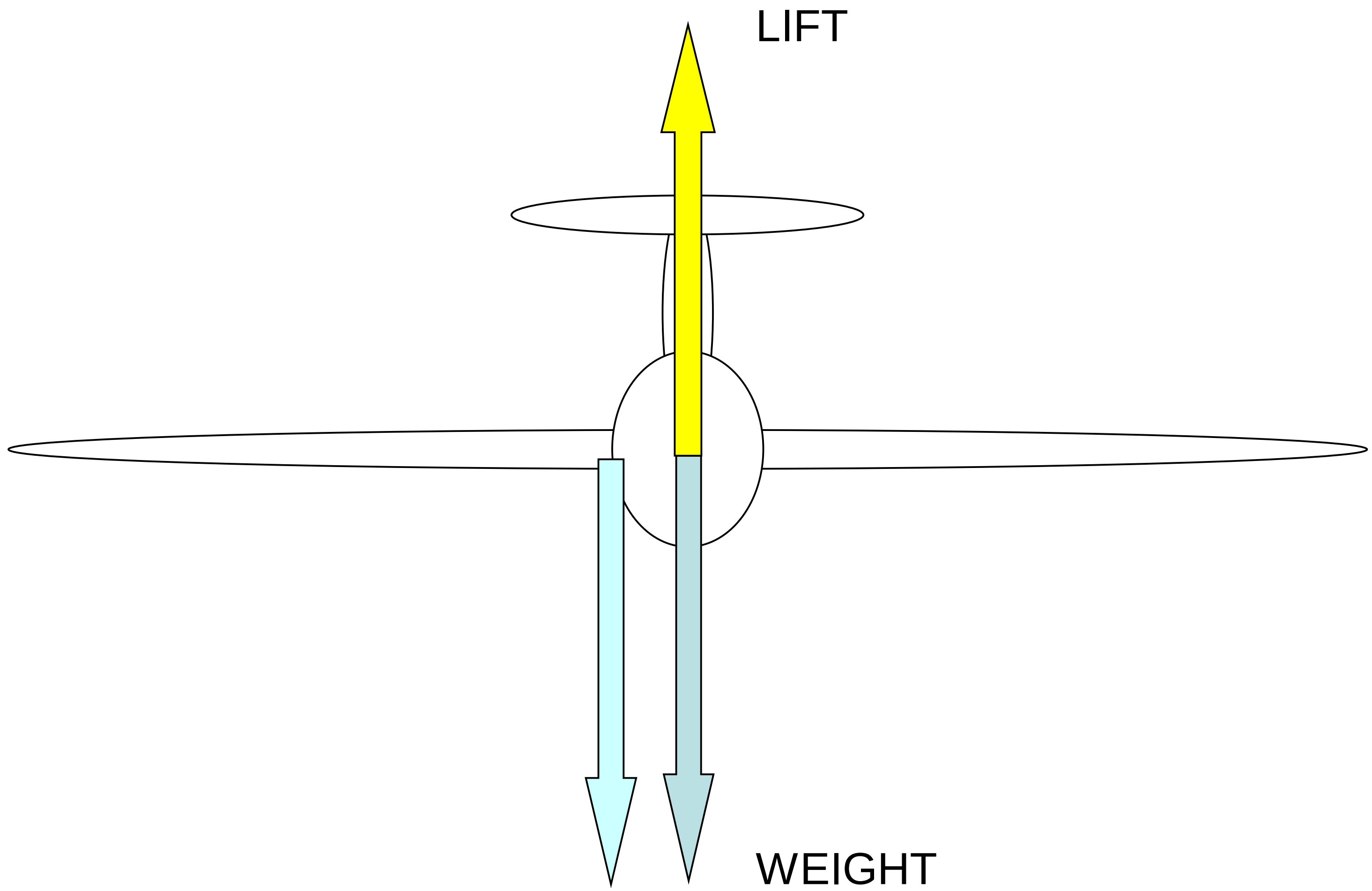


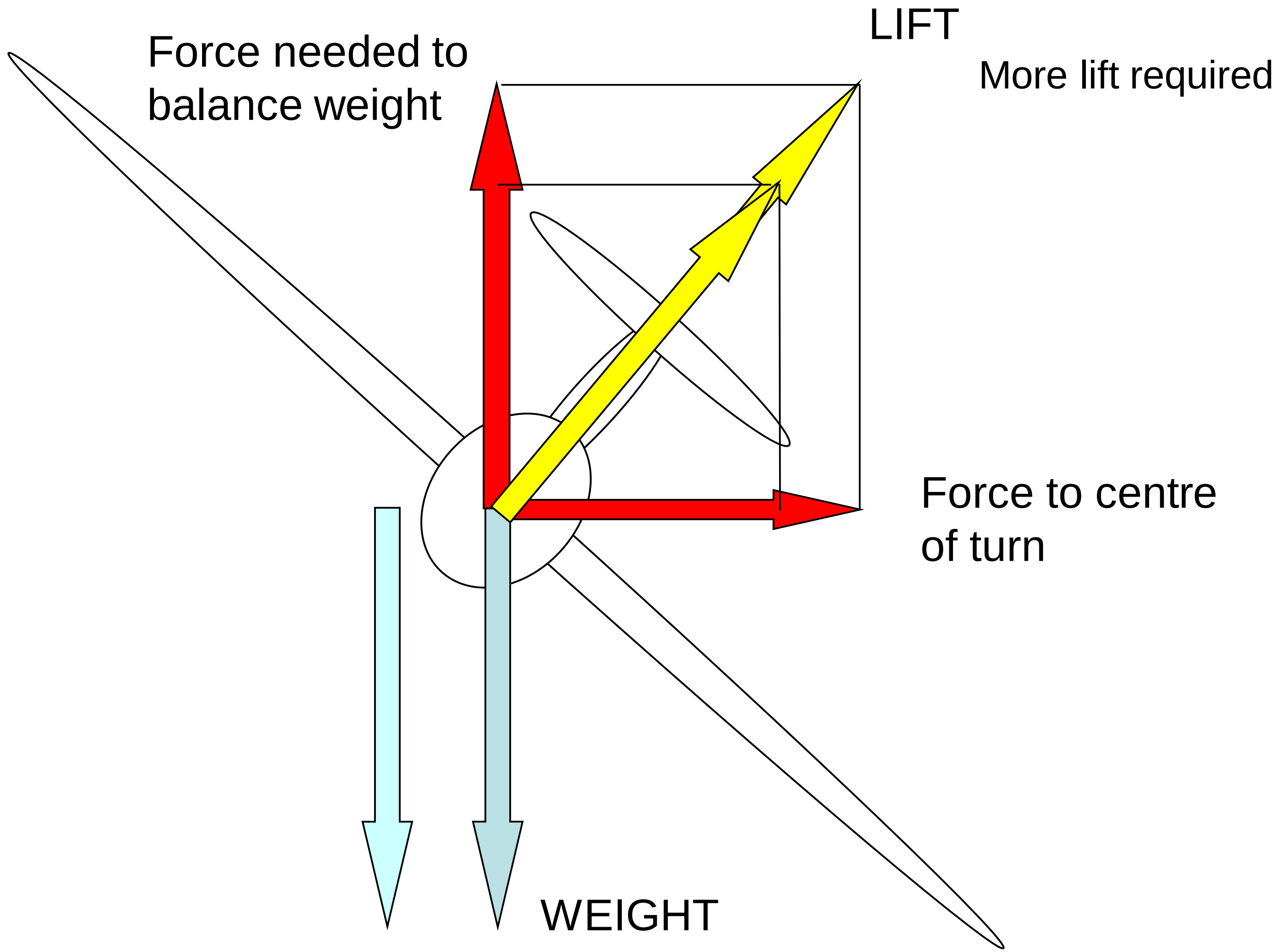
Modern designs may not show much pitch change.

TYPES OF FLAPS

- Trailing edge
- Flaperons

TURNING


LIFT
WEIGHT


LIFT
More lift required
Force needed to balance weight
Force to centre of turn
WEIGHT

TURNING

- Lift vector must be increased to provide both turning force (to centre of turn) and to support weight
- If this vector is not increased – the nose will inevitably go down (downwards acceleration)
- Two ways of increasing lift
  - more speed OR more angle of attack
- Speed cannot be increased instantaneously
- So you must increase angle of attack
  - back pressure on the stick
- Note the WING LOADING is increased in a turn

$W = L \cos b$

$\therefore$

$L = W / \cos b$

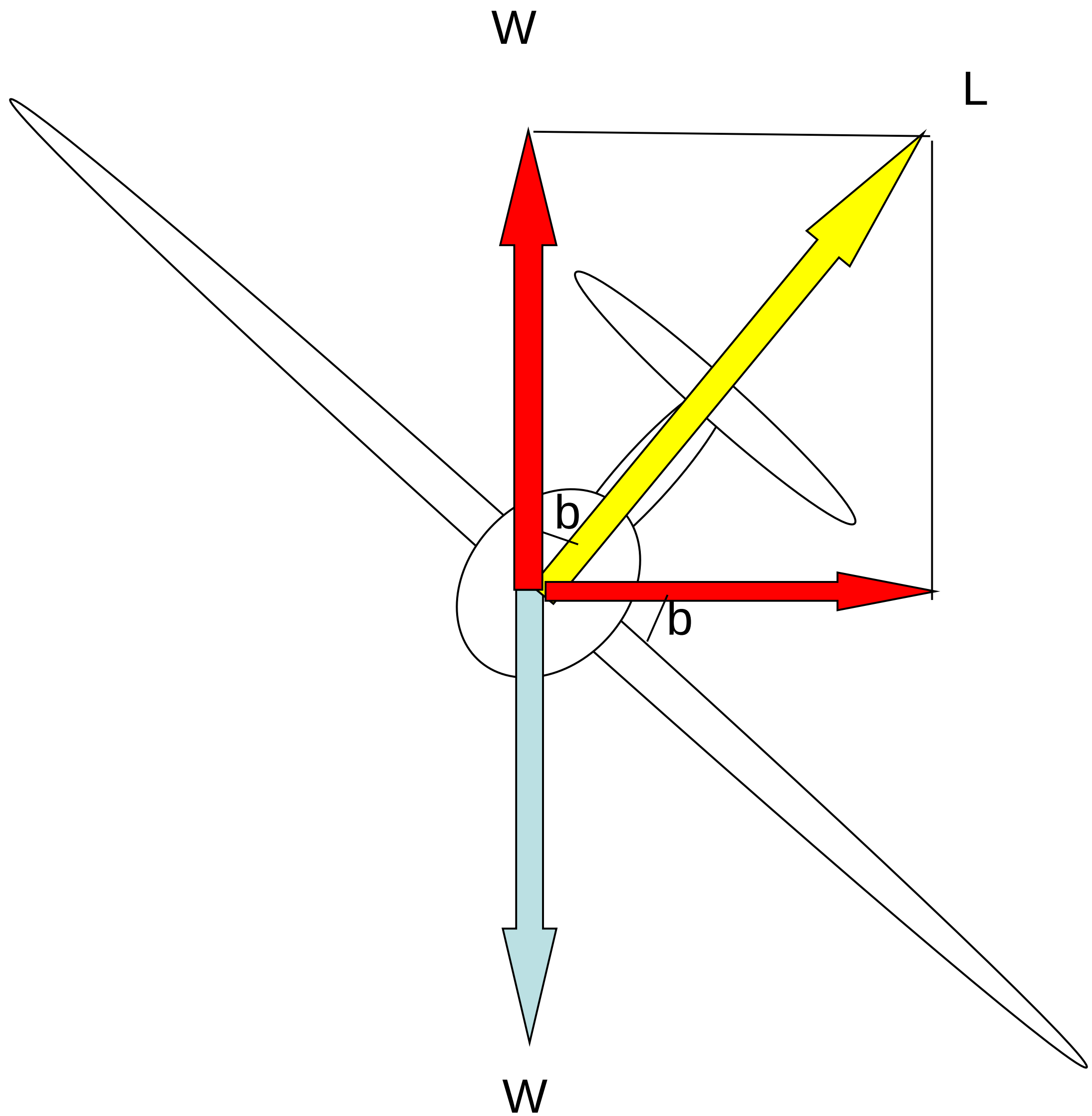
or

$L = W \sec b$

$\sec 30 = 1.154$

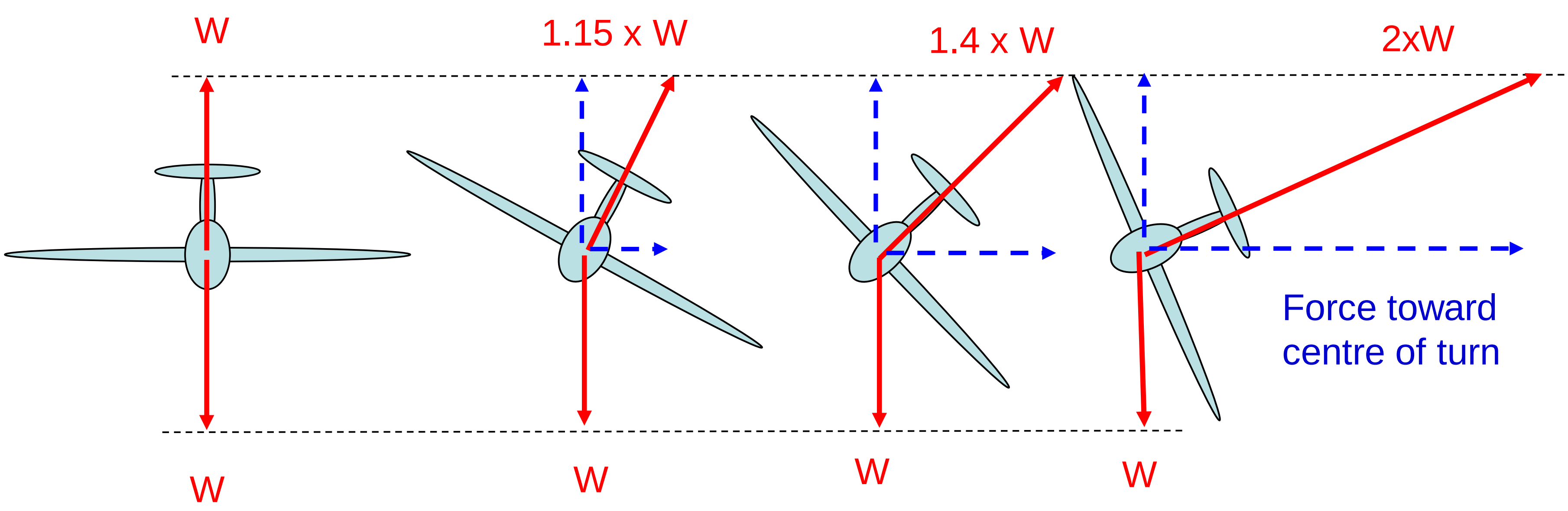
$\sec 45 = 1.414 \; (=\sqrt{2})$

$\sec 60 = 2.0$

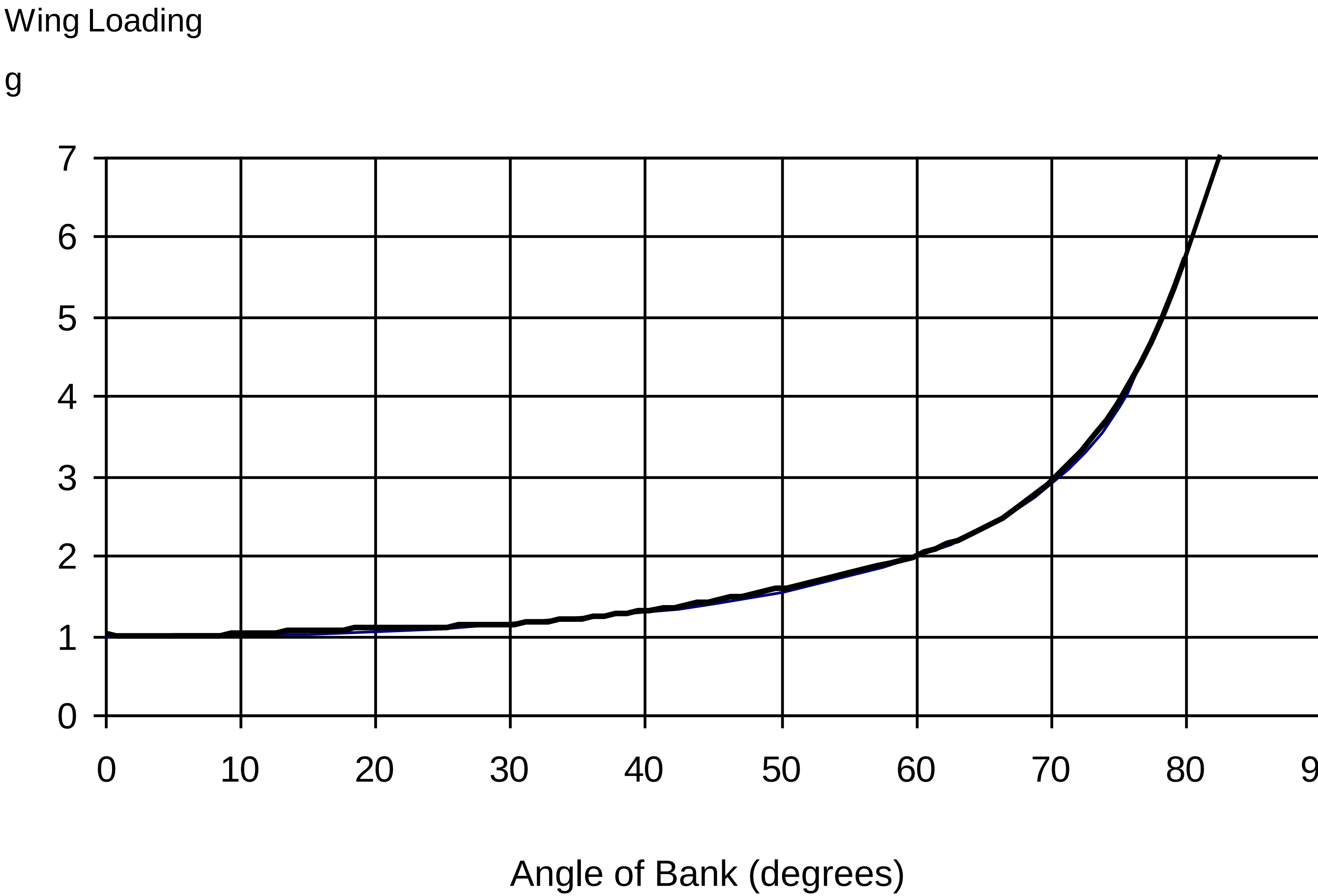


Forces acting in a turn

- The lift needed in a turn increases with angle of bank
- Only 15% at 30^0, 40% at 45^0 but 100% at 60^0
- Pull back and increase AoA to get the extra lift
- Stall Speed increases – see later slide



0^0	30^0	45^0	60^0
37kts	39kts	44kts	52kts ~ K21 stall speeds


Wing Loading
g
7
6
5
4
3
2
1
0
0
10
20
30
40
50
60
70
80
90
Angle of Bank (degrees)

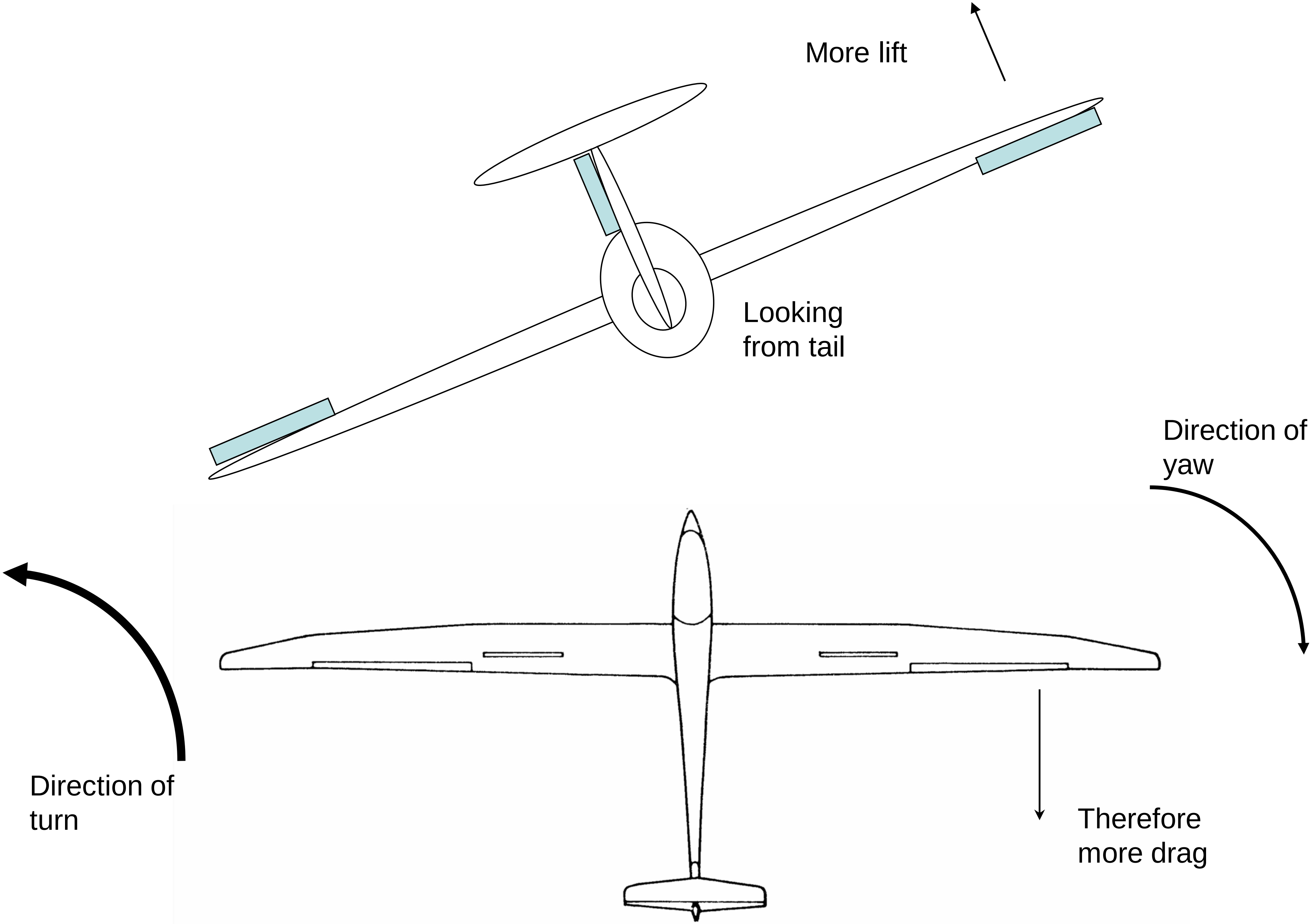
GOING IN

- To roll we put the aileron down on the opposite wing to the way we want to turn
  - Do you know which aileron goes down when we push the stick left??
- This provides extra lift on that wing because the camber/AoA is effectively increased
- More lift means more drag
  - Called ‘aileron drag’
- This leads to ‘adverse yaw’

THEREFORE

- We need in-turn rudder to counteract the adverse yaw

Differential aileron movement is normally provided to lessen this requirement.
Or might have Frise Ailerons


More lift
Looking from tail
Direction of yaw
Direction of turn
Therefore more drag

STAYING IN

- The outer wing in going faster than the inner wing
- Therefore it is generating more lift

THEREFORE

- a) there will still be some adverse yaw
  - requiring a little continued in-turn rudder

and

- b) there will be a tendency to continue to roll in-turn
  - Which will require some out-of-turn stick

STILL STAYING IN

- BUT (and ignore this if you are easily confused!)
- The outer wing has a smaller AoA than the inner wing
    - Since it is travelling further horizontally but going down the same distance vertically
- By itself this would produce a tendency to ‘roll out’ of the turn and need in-turn stick
- Practically in most gliders this just dampens the opposite effects slightly
    - Because of the long wings, good L/D and square versus linear effect (??)

STALL SPEED IN A TURN

Think of it like this:-

If you go into a turn just above the straight and level stall speed, your AoA is just on the stall angle. You need more lift but can't instantaneously speed up so you need to increase the AoA. This will immediately cause a stall. If you had gone into the turn faster you would have had a lower AoA and been able to pull back a bit and still keep flying.

- All of this applies to ANY high wing loading situation
  - e.g. a pull up, a winch launch.

STALL SPEED v. WING LOADING

At a constant angle of attack, lift is proportional to the square of the speed.

Assume we are at the stall angle.

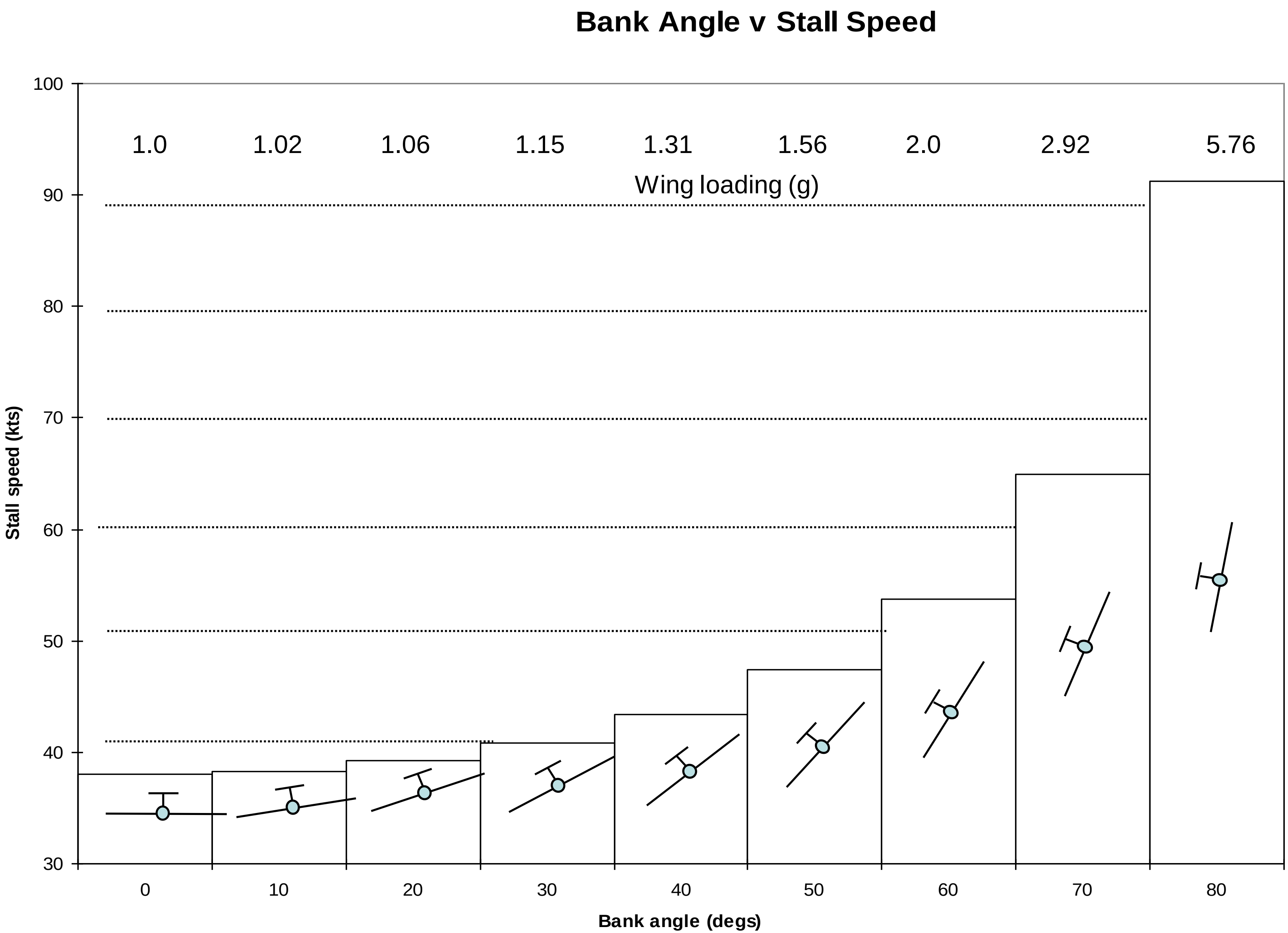
Twice the speed will provide four times the lift.

Or a wing loading of 4g will require 2 times the 1g stall speed.

Or a wing loading of 2g will require $\sqrt{2}$ times the 1g stall speed.

In general n times the wing loading will require $\sqrt{n}$ times the speed.

Or the Stall Speed goes up as the square root of the wing loading.


Bank Angle v Stall Speed
1.0
1.02
1.06
1.15
1.31
1.56
2.0
2.92
5.76
Wing loading (g)
Stall speed (kts)
100
90
80
70
60
50
40
30
0
10
20
30
40
50
60
70
80
Bank angle (degs)

STALLS

- You will stall if the AoA reaches the Stall Angle
- There will be a particular speed (IAS) at which this occurs for straight and wings level flight at a particular all up weight
- HOWEVER you may also stall at higher or lower IAS's
  - Stalls at higher IAS if wing loading is higher
    - e.g in a turn, in a pull up
  - Stalls at lower IAS if wing loading is lower
    - e.g. a push over (as in a failed winch launch)
      - What is more to the point, you may be seduced by flying slow but not stalling
- Stall symptoms ? What are they? …
- List
- The only definite symptom of the stall is that you can't raise the nose with the stick
- Stall recovery = use the stick to reduce AoA
  - i.e. push it forward (assuming you are not inverted)

High G stall

- Steeply banked turn
- Pull up from a dive

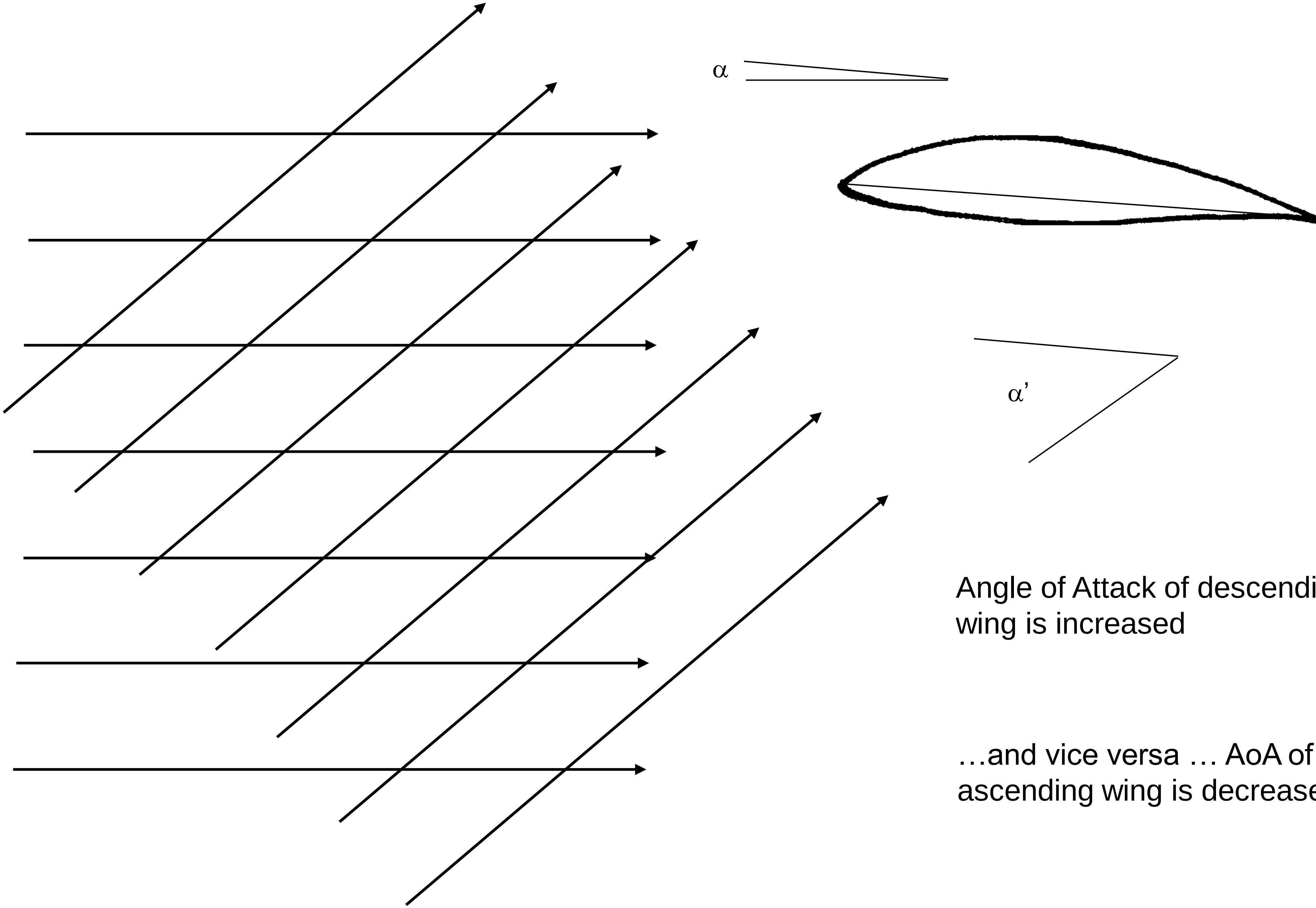
• Straight flight		1g	37kts (K21)
• 45deg bank	or	1.4g pull up	44kts (K21)
• 60deg bank	or	2g pull up	52kts (K21)

- Beware flicks when stalling with high wing loading

- WINCH LAUNCH
    - See ‘Winch Launching’ presentation.
    - See also Part Two – Flight Envelope

SPINS

- A spin is the result of a high AoA (stall) <u>with</u> yaw
- The slower going wing will have less lift and the glider will tend to roll that way
- This down going wing will now have a larger AoA and will stall more



Angle of Attack of descending wing is increased

…and vice versa … AoA of ascending wing is decreased

SPINS

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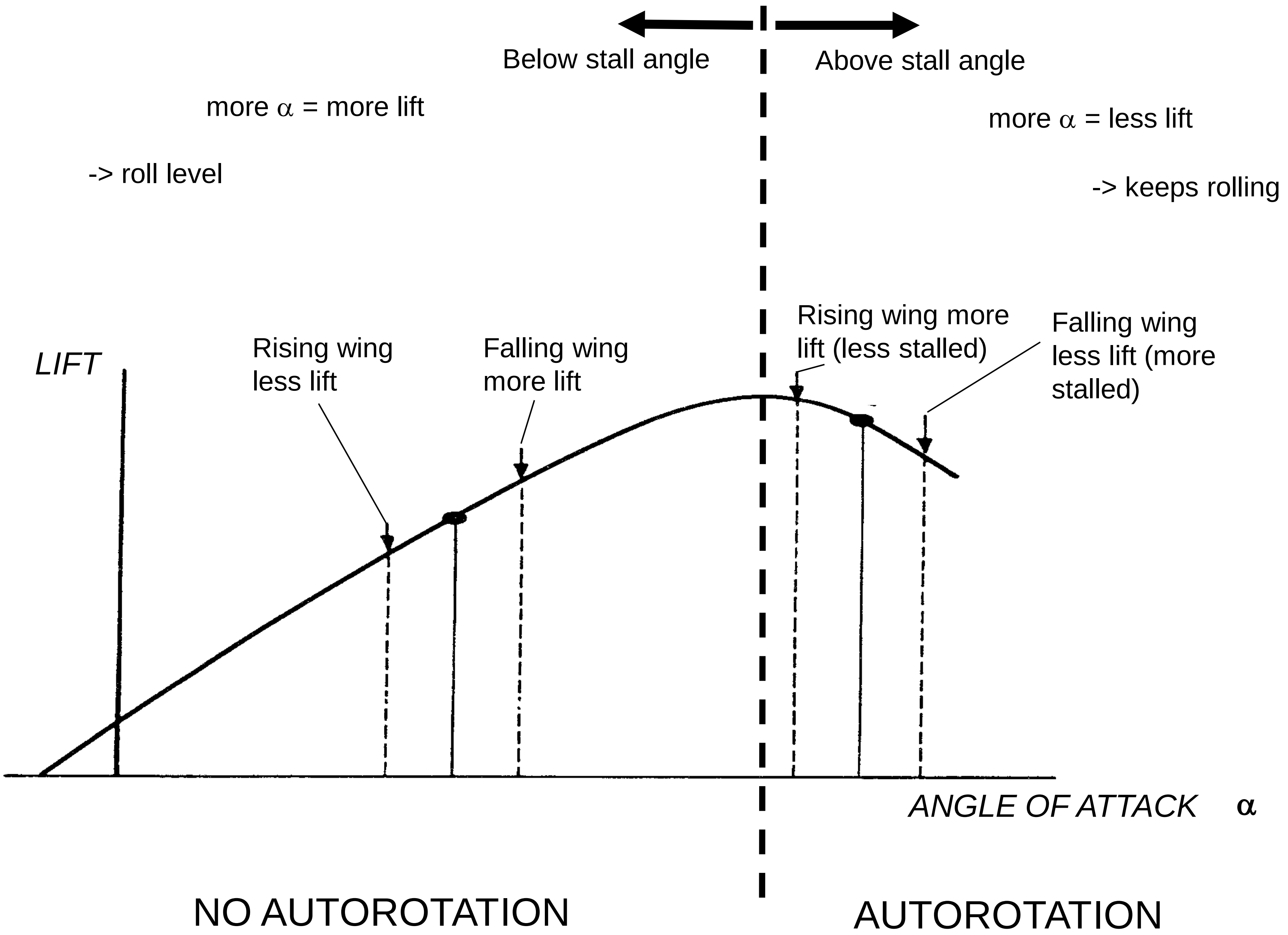
- The up going will have a smaller AoA and stall less
- HENCE AUTOROTATION

CAUSE OF AUTOROTATION



SPINS

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- The slower going wing will have less lift and the glider will tend to roll that way
- This down going wing will now have a larger AoA and will stall more
- The up going will have a smaller AoA and stall less
- HENCE AUTOROTATION
- You can recognise a spin by…
    - High rate of rotation
    - Steep nose down attitude
    - Low or fluctuating IAS
    - Absence of high g
    - Rapid loss of height

SPIN RECOVERY

CS(JAR)22

- Recover by using full opposite rudder
  - to reduce the rate of rotation and hence lower the nose
- THEN with ailerons neutral* progressively move the stick forward until the spin stops
- THEN immediately centralise the rudder*
- AND recover from the dive
  - without causing a high speed stall or exceeding Vne
  - **OR** getting close to Va with more than one control deflected †
  - !!!!!!!!

    which is difficult – so observe * above.

† see rolling limit in Flight Envelope

SPINNING

Spin characteristics of different aircraft:-

- K21 may not spin under ‘normal’ circumstances, lacks sufficient elevator, insufficient AoA
    - BUT it can be done !
    - beware if C of G is too far aft
- Aircraft with highly tapered wings + little washout are prone to spin
- HUD (K13) used to be easier to spin one way, than the other, asymmetry
- Puchacz ‘ideal’ for spinning
- Below cockpit weight limit, C of G aft of rear limit
- Some a/c (e.g. Fox) will require full recovery procedure and accurate exit
- Get a briefing
- Know you aircraft (spin yours after a briefing)

SPIN V SPIRAL DIVE

SPIN	SPIRAL DIVE
• High rate of rotation • Low or fluctuating IAS • Absence of high g In spite of pulling back • Controls ineffective • Rapid loss of height • Steep nose down attitude - No danger of exceeding Vne until after you have recovered	• Low rate of rotation • High and increasing IAS • High and Increasing g Particularly if you pull back • Controls work but are heavy • Rapid loss of height • Ever steeper nose down attitude – Danger of rapidly exceeding Vne

RECOVERY FROM SPIRAL DIVE

1. Level the wings

   with ailerons

2. Pull out of the dive

   without exceeding limits or stalling

IN THIS ORDER

OR ?

THIS IS DIFFERENT TO RECOVERING FROM A SPIN

So it is IMPORTANT to know whether you are in a spin or spiral dive

SPINNING

- See pilots' accounts in:-

Spinaccounts.doc