

GGC/RVS Soaring Ground School 2026

Theory of Flight

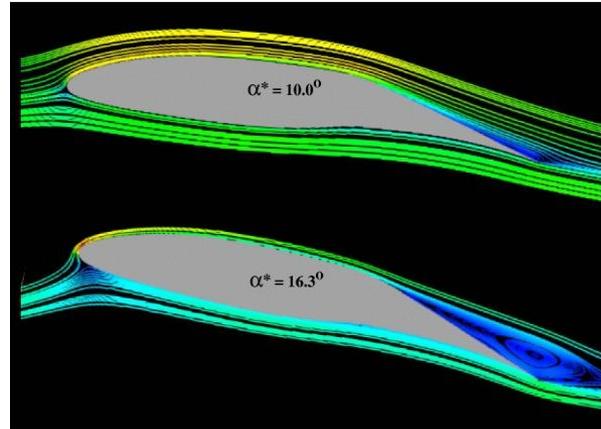


Michael Stieber
Rideau Valley Soaring

Theory of Flight: Outline

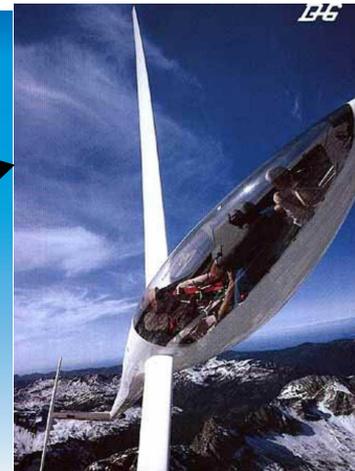
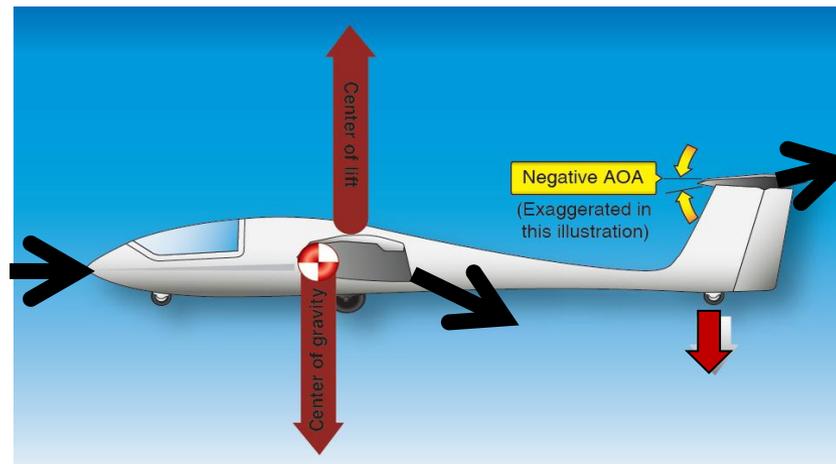
1. How do Wings work?

- Air Flow and Pressure
- Lift and Drag
- Stall and Spin



2. Glider in Flight

- Performance
- Control
- Manoeuvres



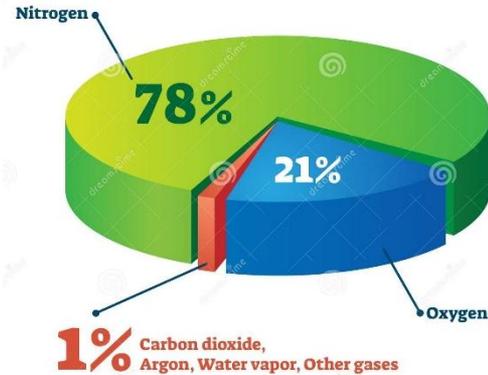
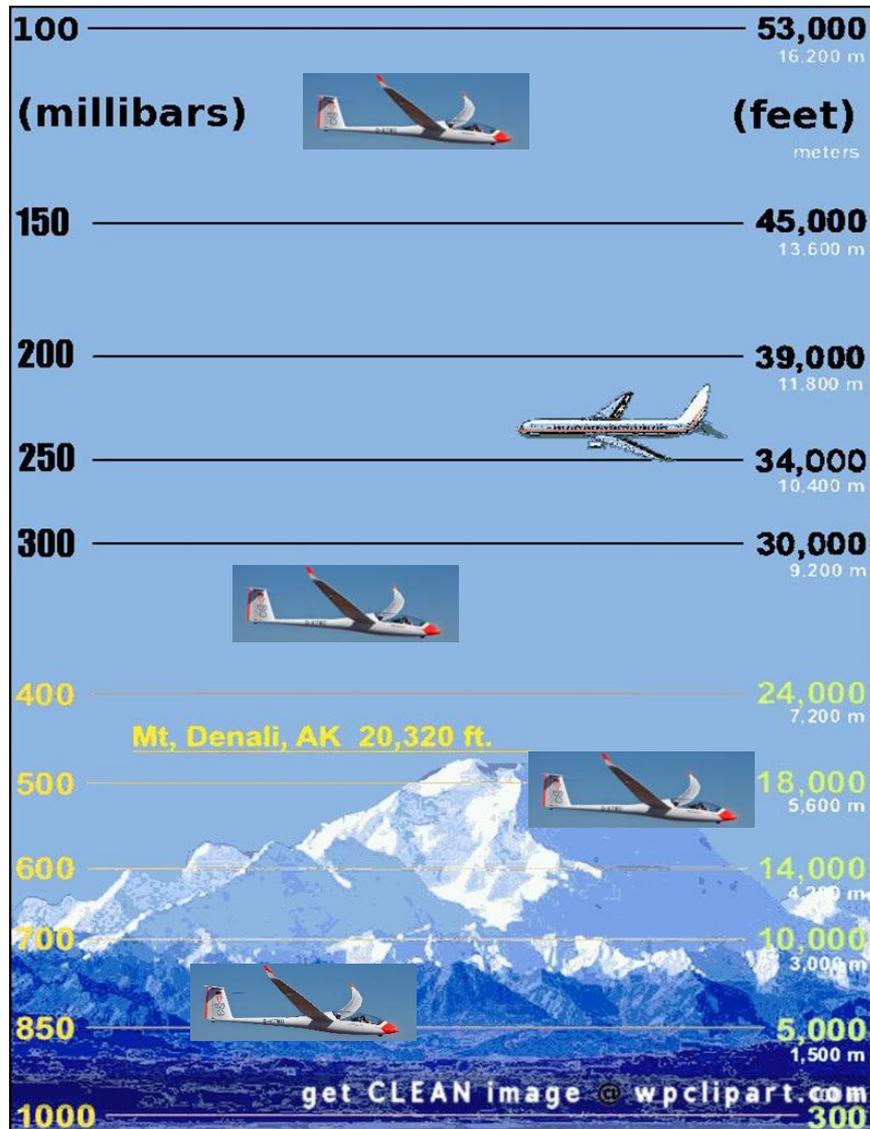
3.

**! Exam !
Question**

Atmosphere

Pressure

Altitude



At Sea Level and 15 C:

- Pressure = 1013 millibars mb
= 14 pounds/in² PSI
- Density = 1.2 kg/m³
- Air has mass!!

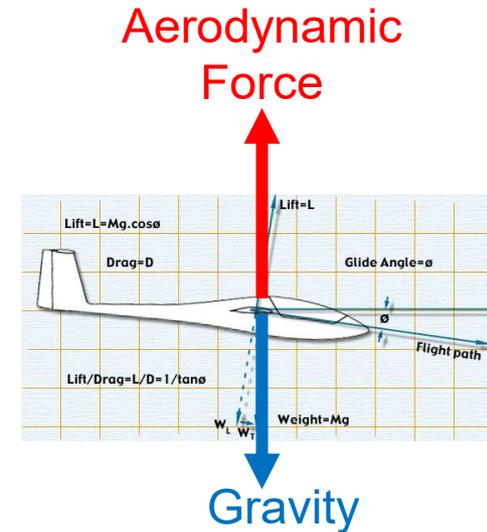
Pressure and **Density** decrease with altitude

- Decreases by half for every 18,000ft

Depiction of Forces

Forces are depicted by **arrows**

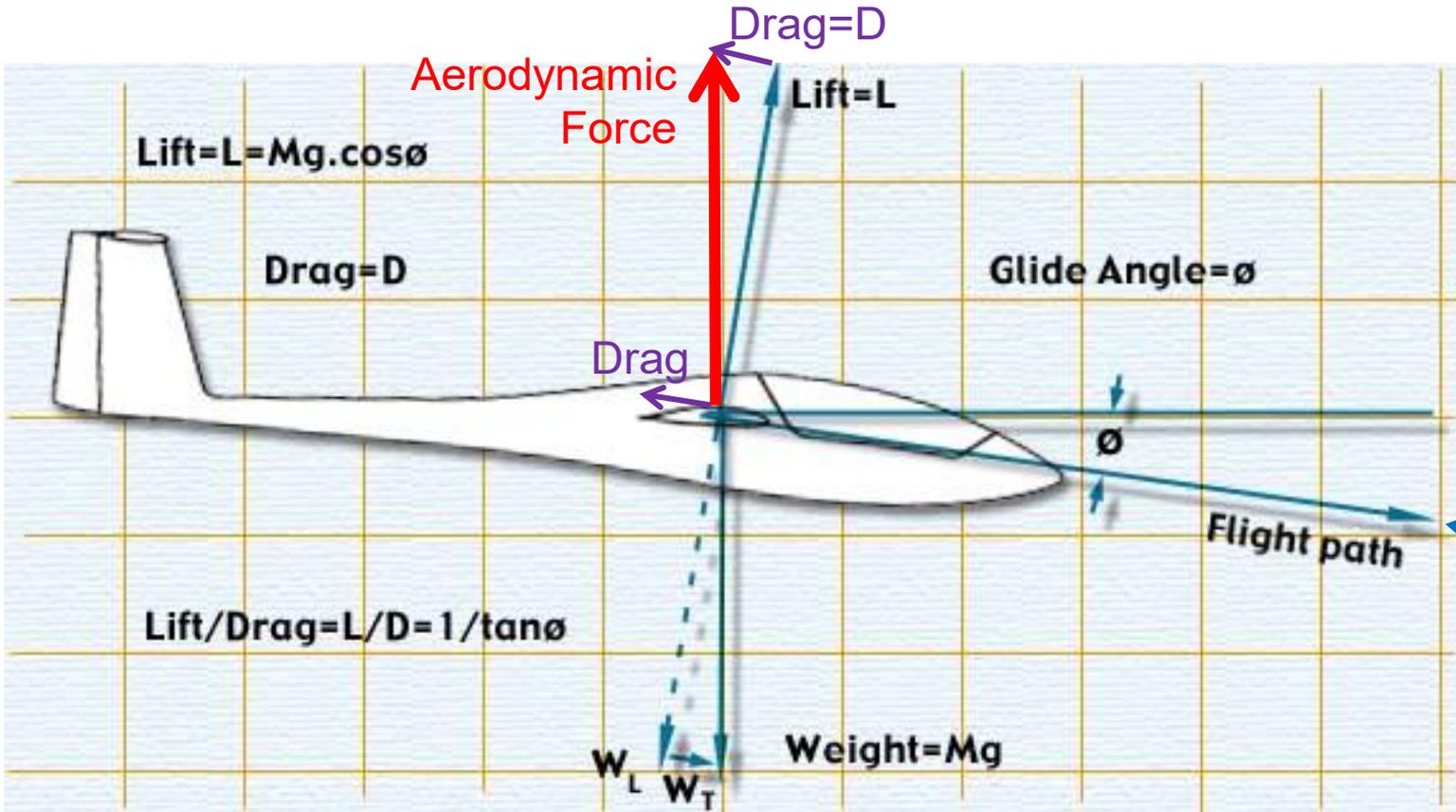
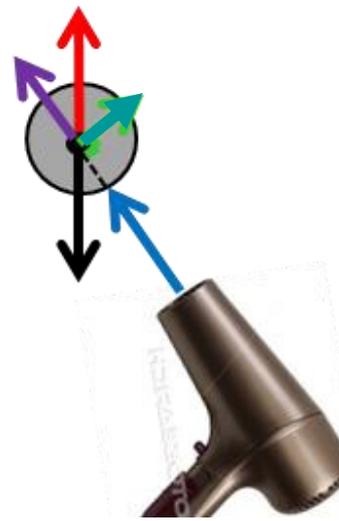
- The **length** of the arrow indicates the **strength** of the force
- The **direction** of the arrow indicates the **direction** of the force
- Mathematically speaking, **forces** are represented by **vectors**



Definition of Lift and Drag



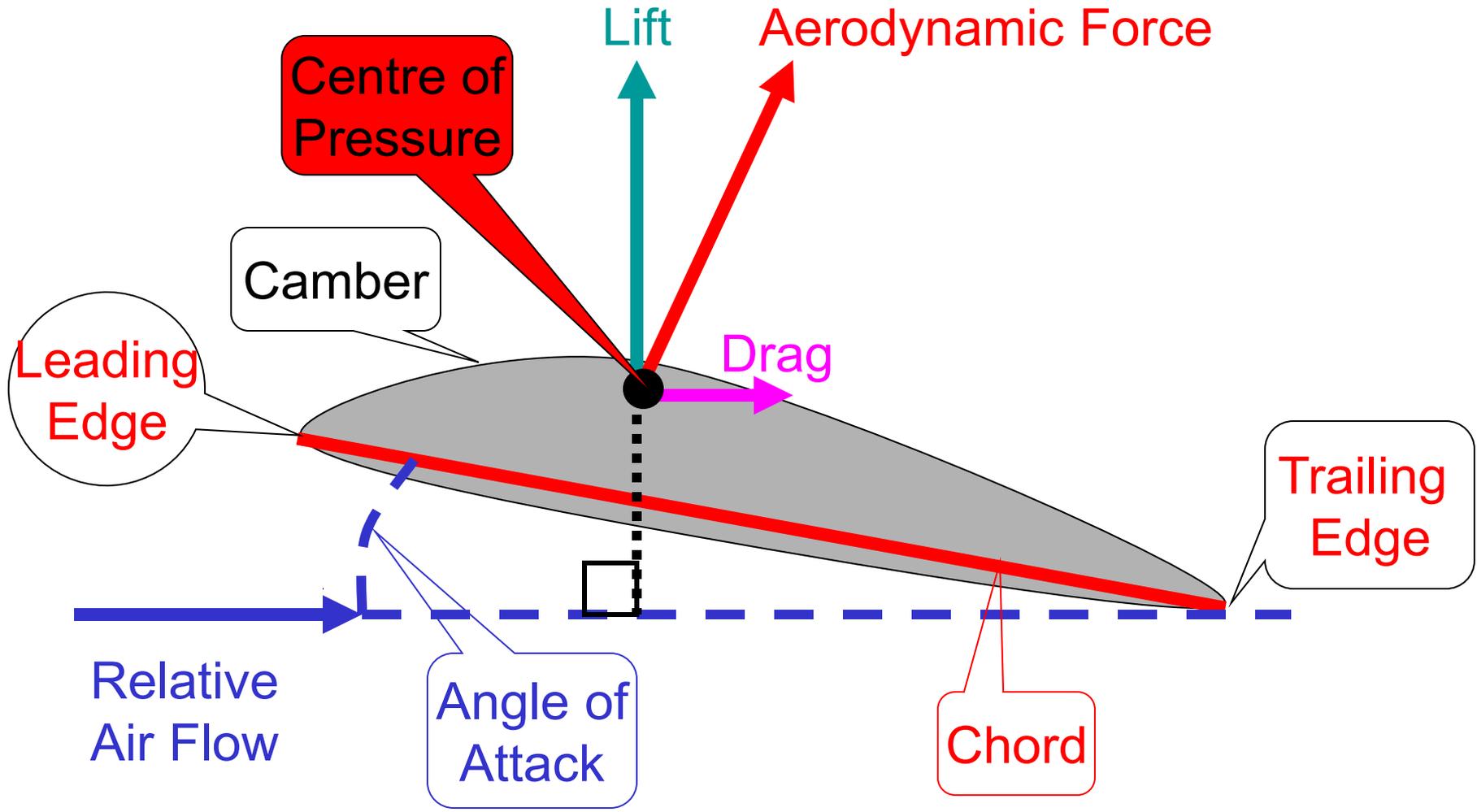
Forces on a Glider



Relative Air Flow

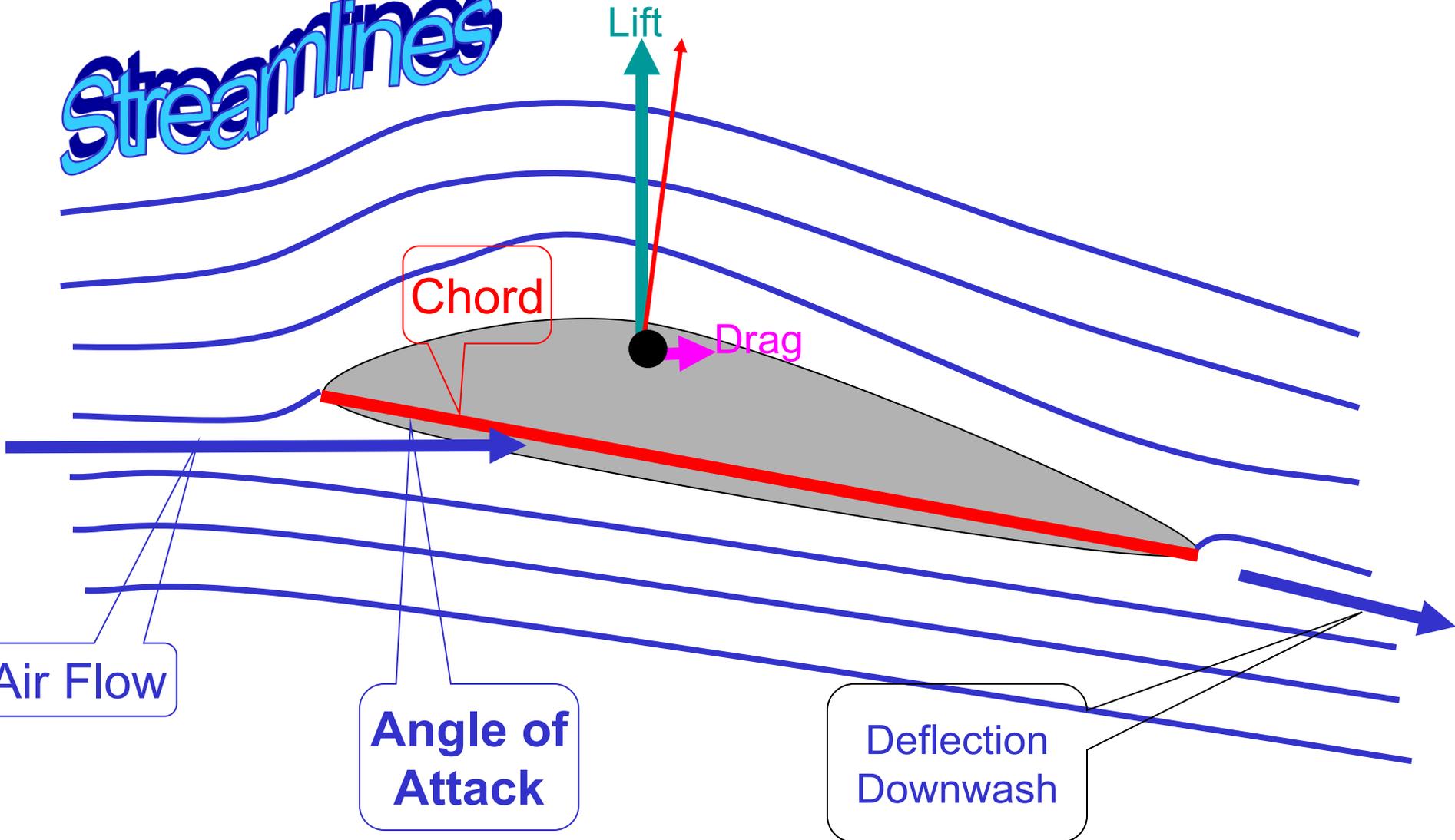
AIRFOIL DEFINITIONS

! Exam !
Question



Air Flow around Airfoil

Streamlines



Lift

Chord

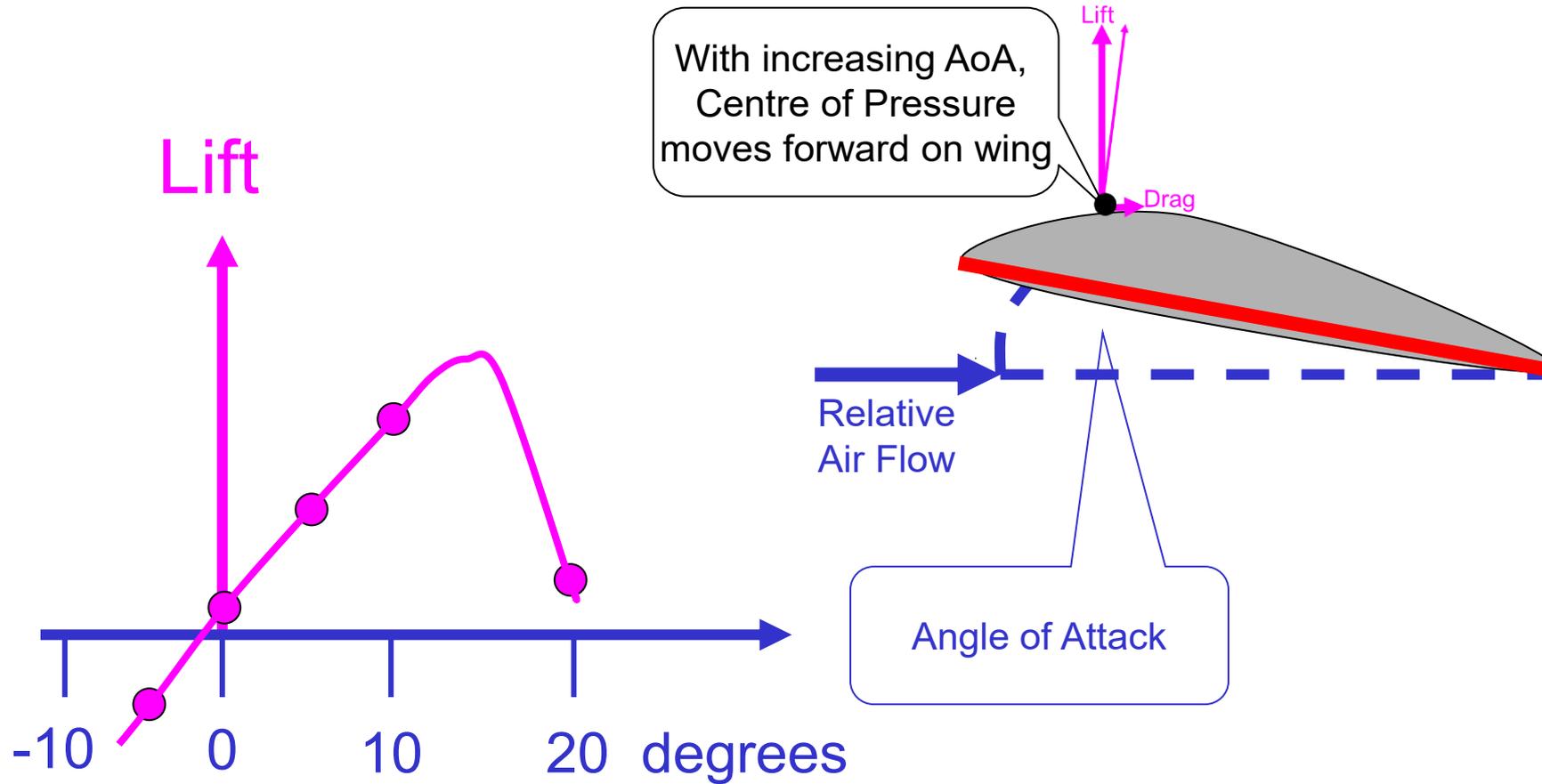
Drag

Air Flow

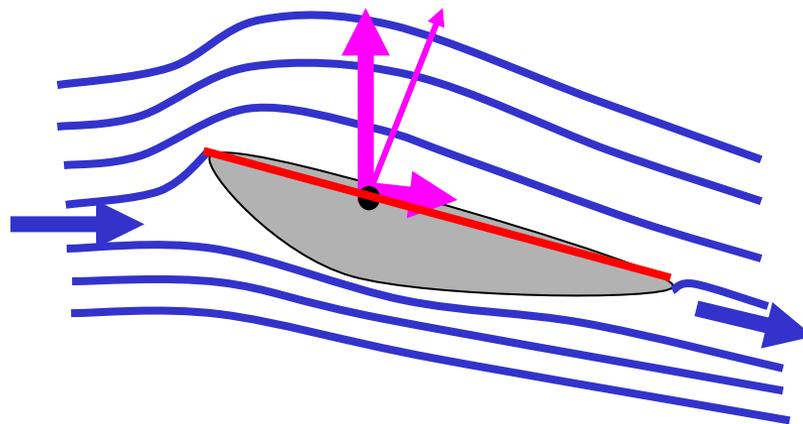
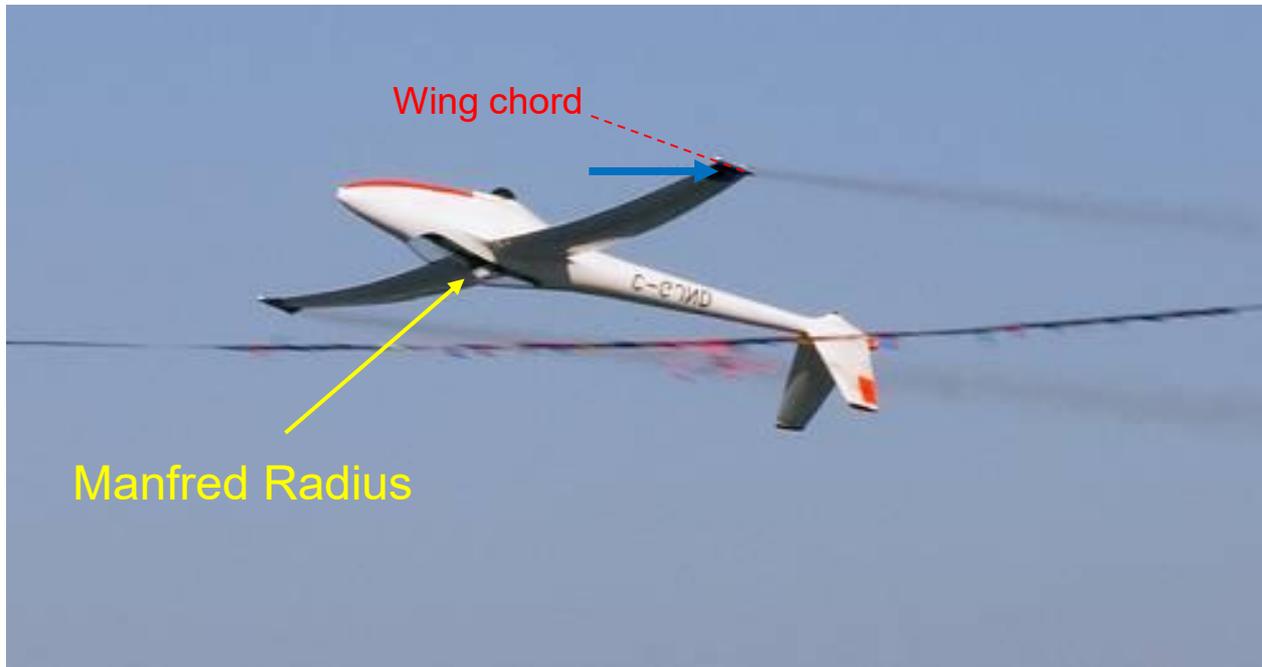
Angle of Attack

Deflection Downwash

Lift for different Angles of Attack (AoA)

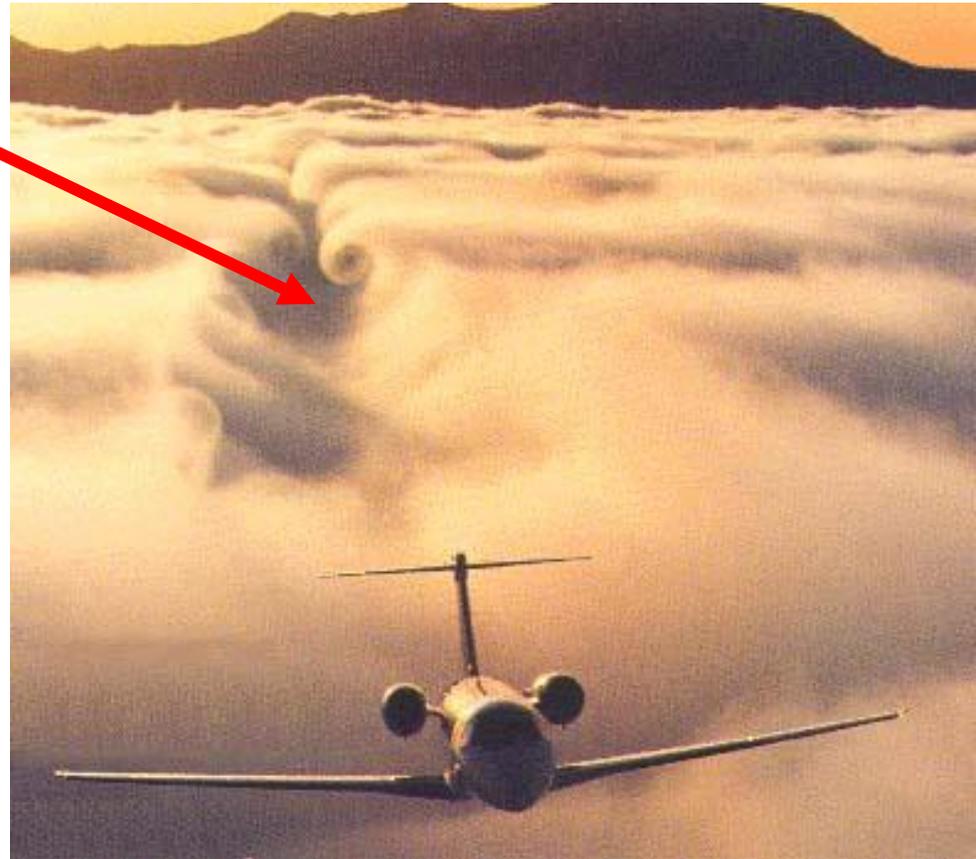


Inverted Flight

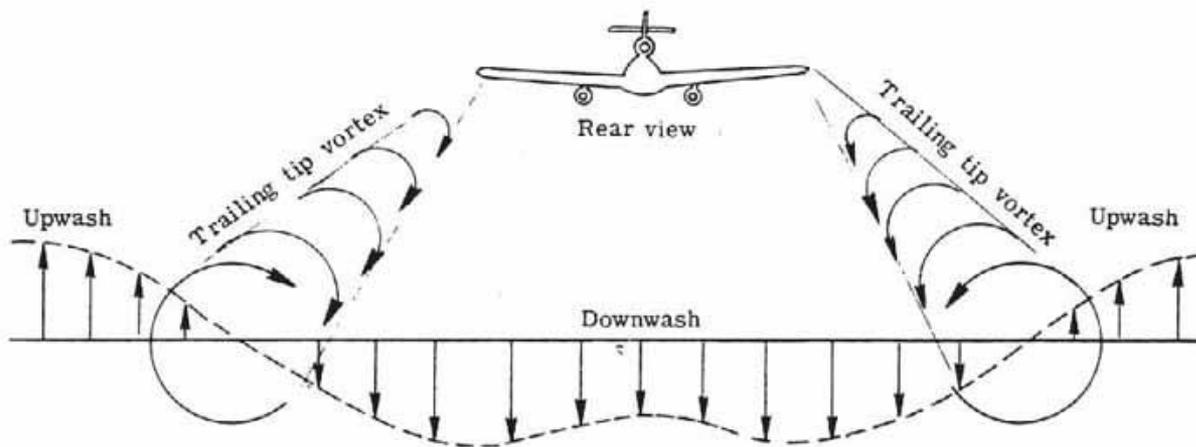


Newton's Laws "Explain" Lift

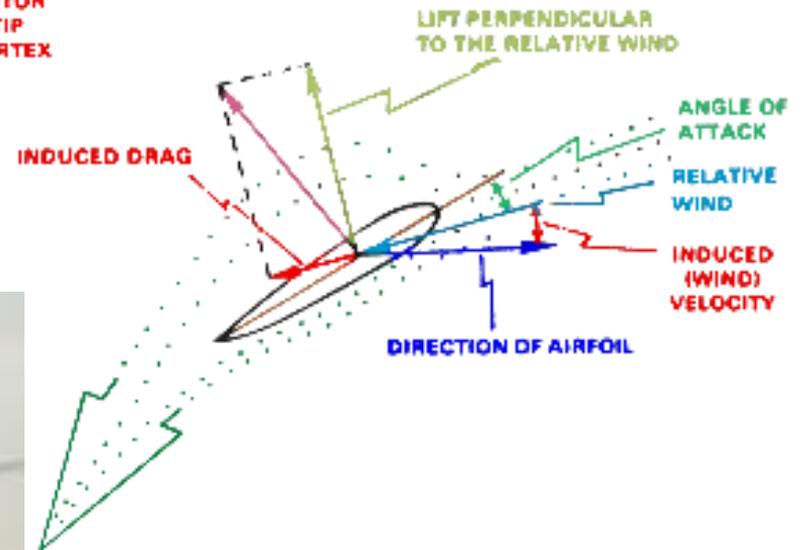
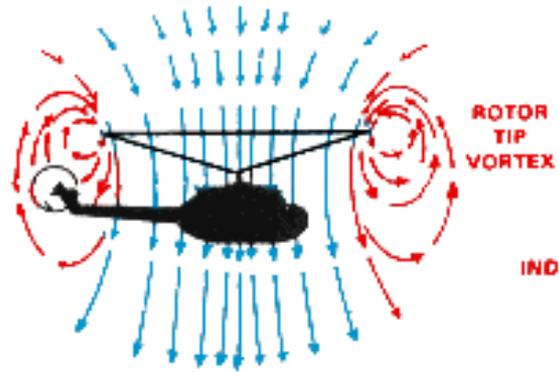
- **Downwash:** Moving wing pushes ("accelerates") air downward.
- Aerodynamic "reaction" force lifts the wing upwards.
- Note:
 - **Air has mass!!**
 - Density = 1.2 kg/m^3 at MSL & 15 C
 - Density decreases with altitude



Vortex Structure created by Aircraft



Downwash 1



Downwash 2

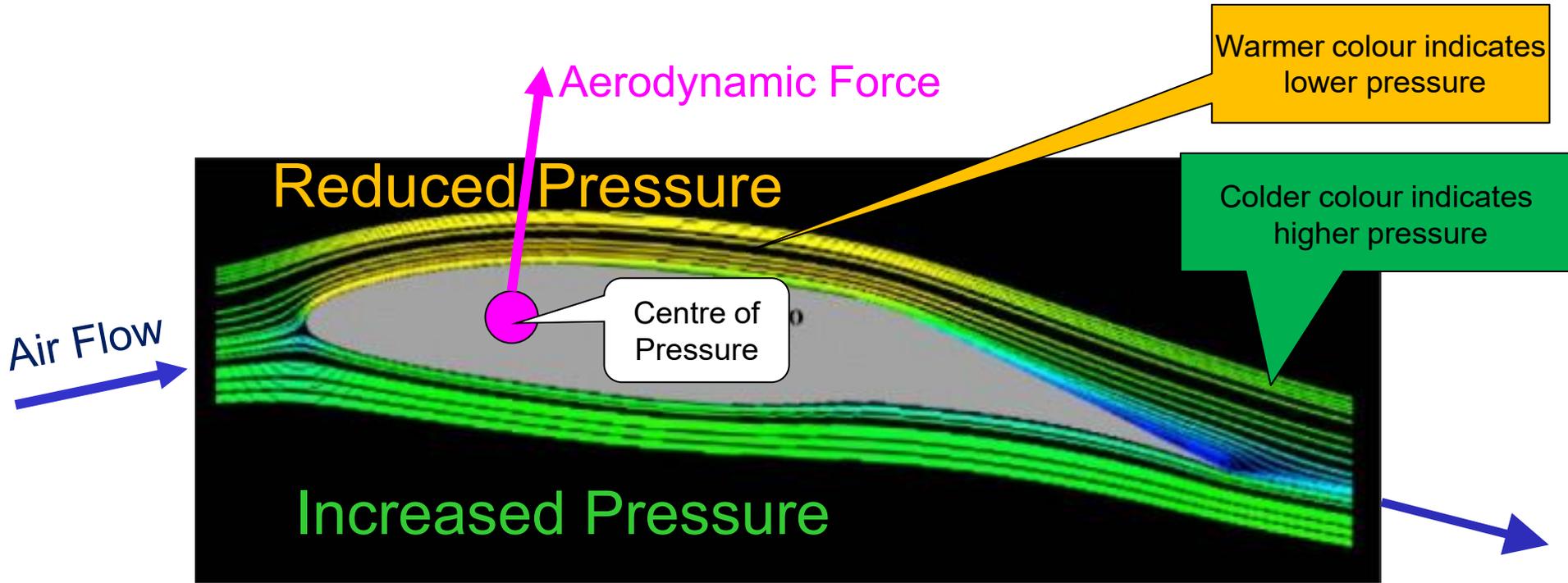


- Blades have no camber
- Blades are angled to provide Angle of Attack (AoA)
- Changing the direction of rotation changes direction of “downwash”

Reduced Pressure above Wing



Air Pressure on Wing Section



Where is the **Force** generated?

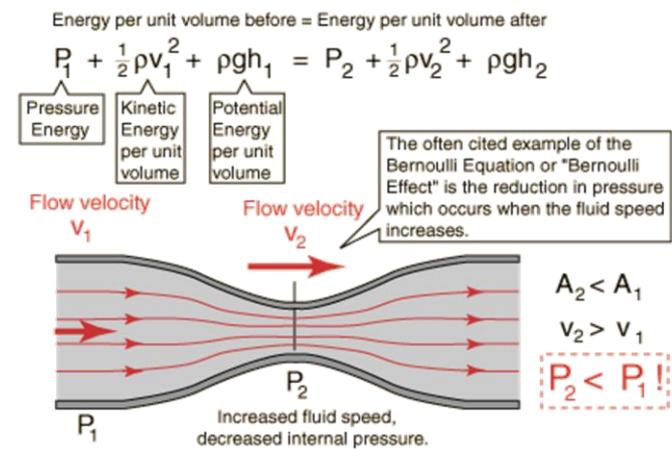
- 2/3 of lift generated over first 1/3 of wing
- 2/3 from **reduced pressure** above wing
- 1/3 from **increased pressure** below wing

For a glider at sea level:

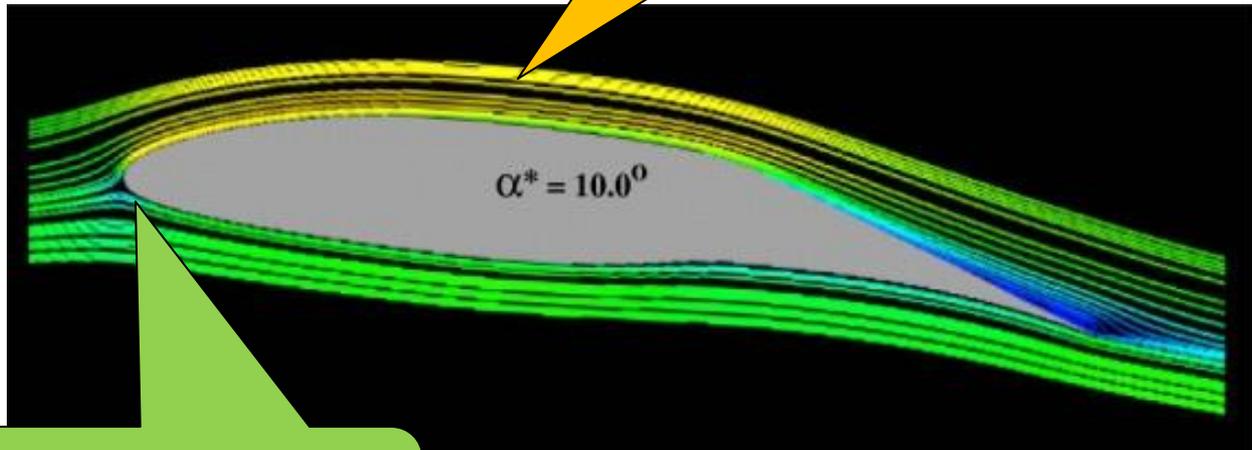
- **30 kg/m² wing loading**
- 1000 mb ambient pressure
- **Reduced P = 998 mb**
- **Increased P = 1001 mb**

Bernoulli's Principle

Pressure and **Flow Speed** have an **Inverse** Relationship

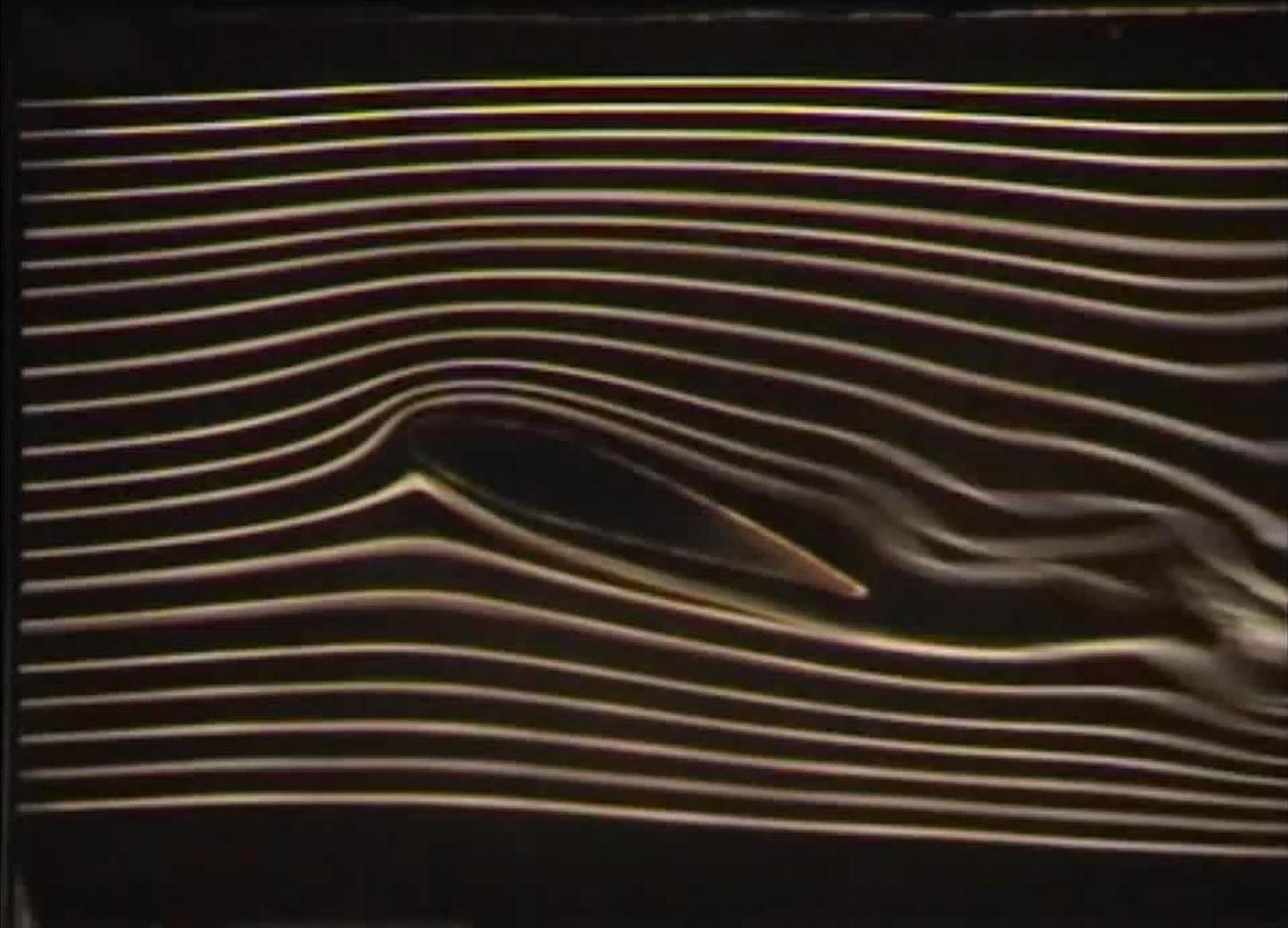


Reduced Pressure
Increased Flow Speed



Reduced Flow Speed
Increased Pressure

Air Flow across Wing (Movie)



Aerodynamic Forces Scale with Density (Pressure) of Air

- Aerodynamic Forces are proportional to Density / Pressure of the Air
 - The higher the density / pressure, the higher the force
- For every 18,000 ft in altitude
 - Density drops by half, and Aerodynamic forces drop by half (at same speed)
- **At 36,000 ft**
 - **Flying is much more efficient than at sea level**
 - Drag is $\frac{1}{4}$ Compared to Sea Level (at same speed)
 - we can fly 2x faster than at Sea Level, with same drag / fuel burn



More Speed → More Aerodynamic Force

Aerodynamic Forces have **quadratic Relationship** to Speed of Air Flow!

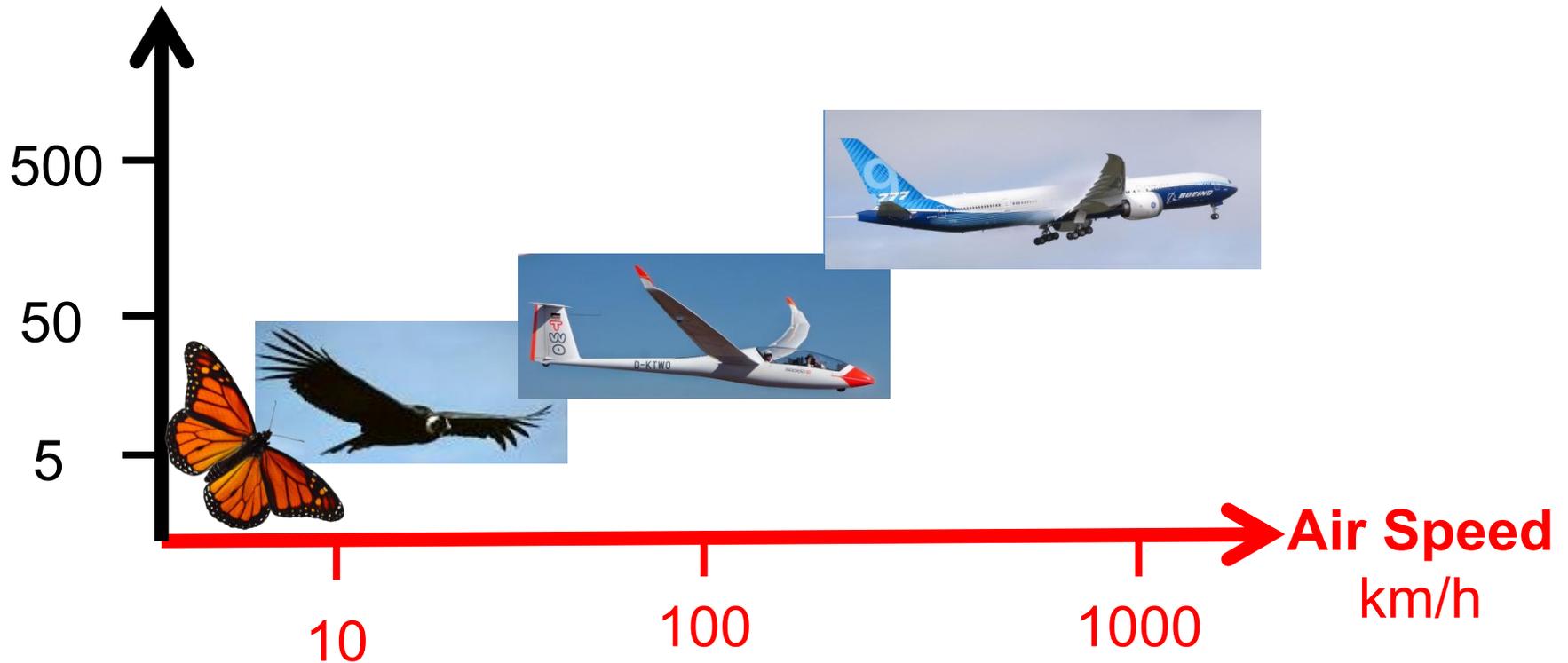
2x Speed → 4x Force

3x Speed → 9x Force

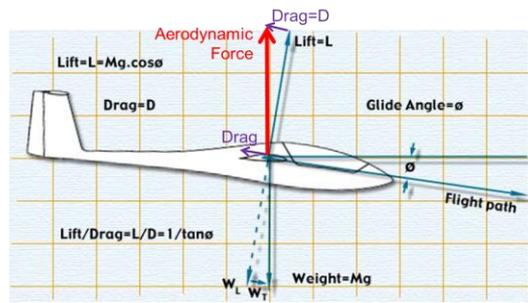
10x Speed → 100x Force

Wing Loading [kg/m²]

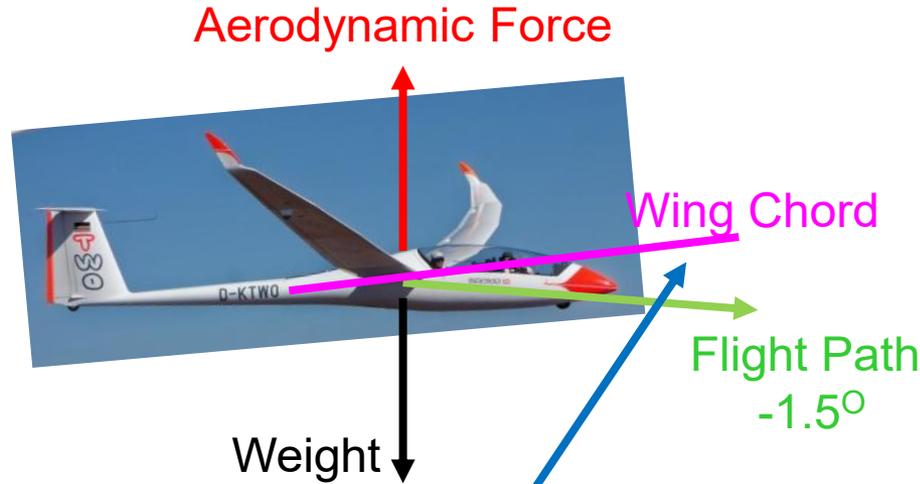
Pressure Differential above and below wing



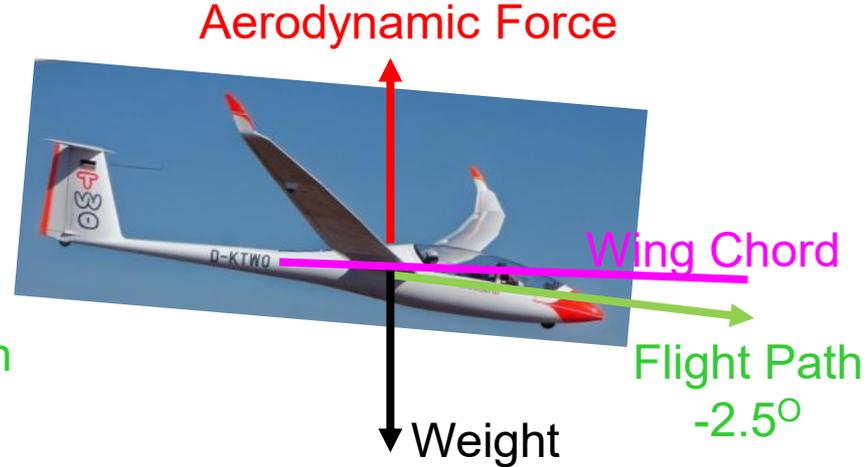
Flying slow



Flying Fast



Speed: 50kt
Angle of Attack: +12°



Speed: 100kt
Angle of Attack: +3°

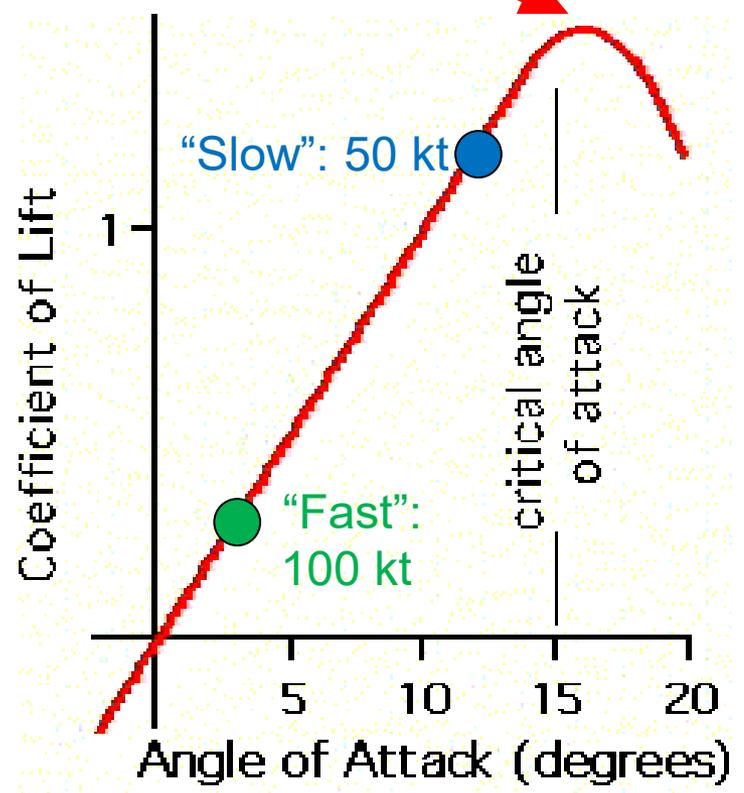
Angle between **Wing Chord** and **Flight Path**.
 Controlled by Pilot.

Aerodynamic Force
 2x Speed → 4x Force
 If everything else is same

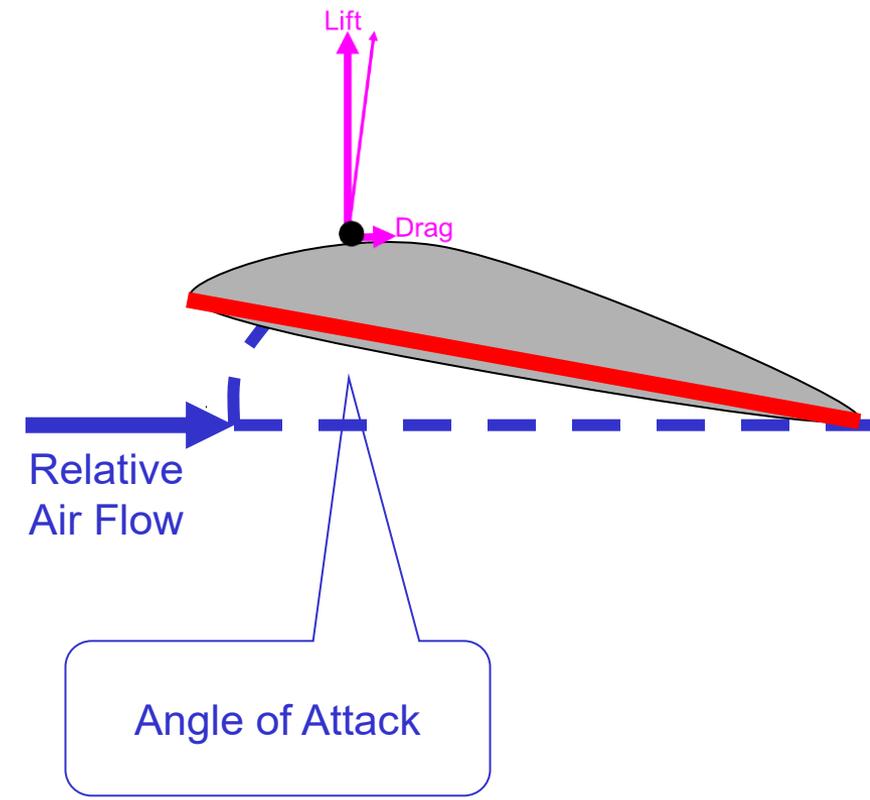
Numbers illustrate order of magnitude. They are not precise.

Lift changes with Angle of Attack (AoA)

Lift peaks when AoA is about 15°



Centre of Pressure moves forward as AoA increases



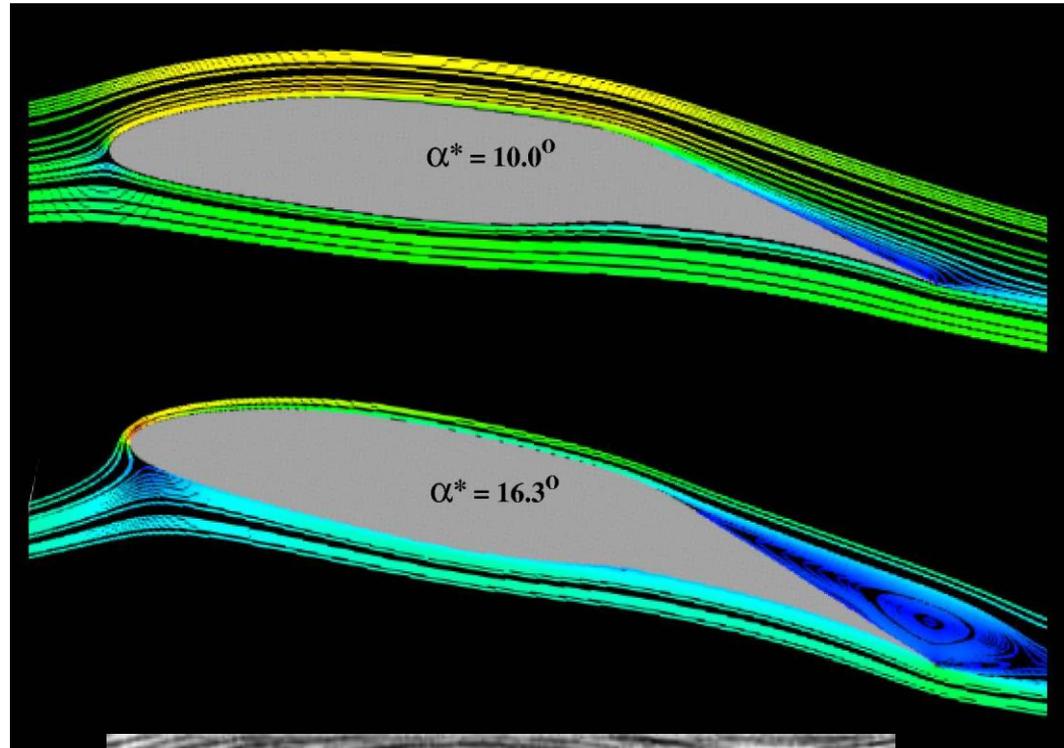
Stall and Spin



Flow at Different Angles of Attack

Angle of Attack

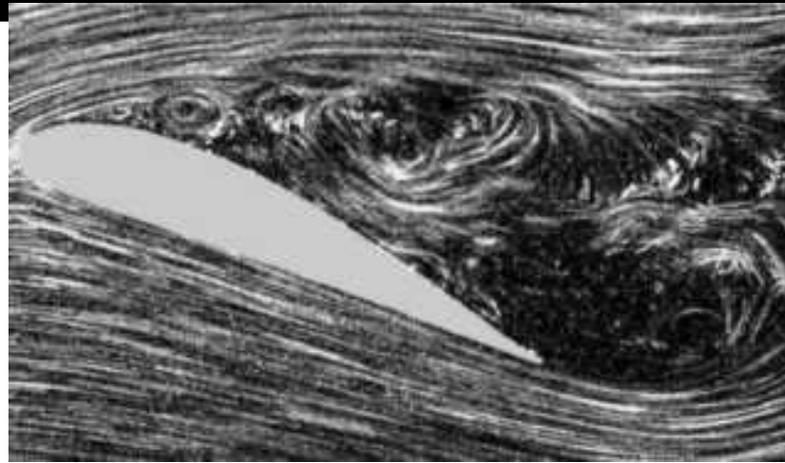
10 deg



16.3 deg

18 deg

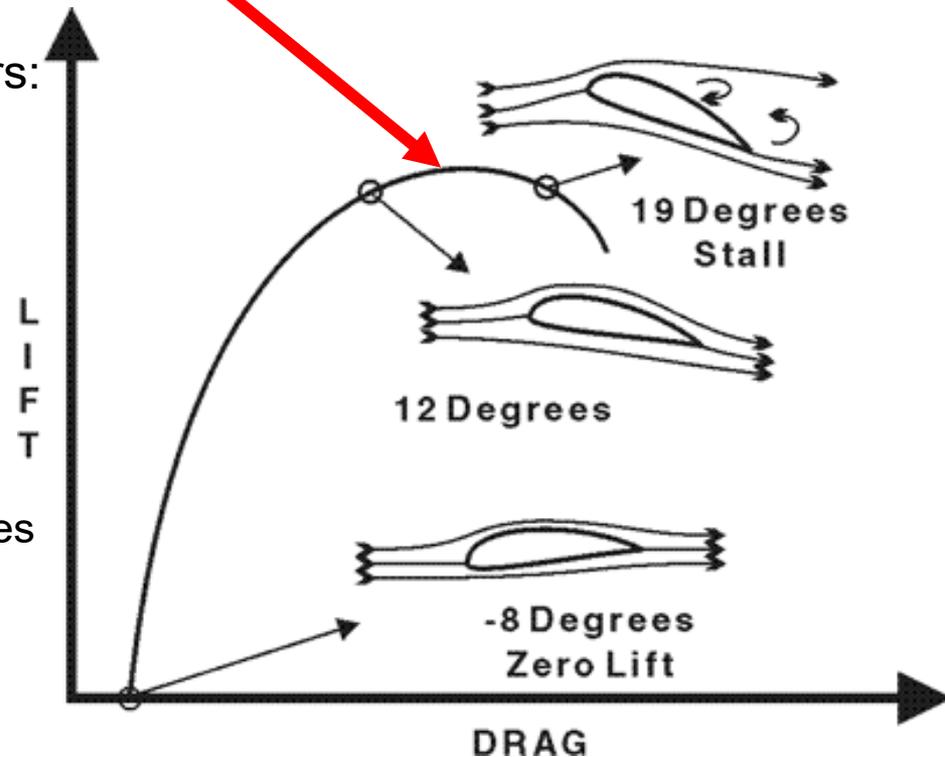
**Flow detaches from
top surface → Stall !**



Stall

! Exam !
Question

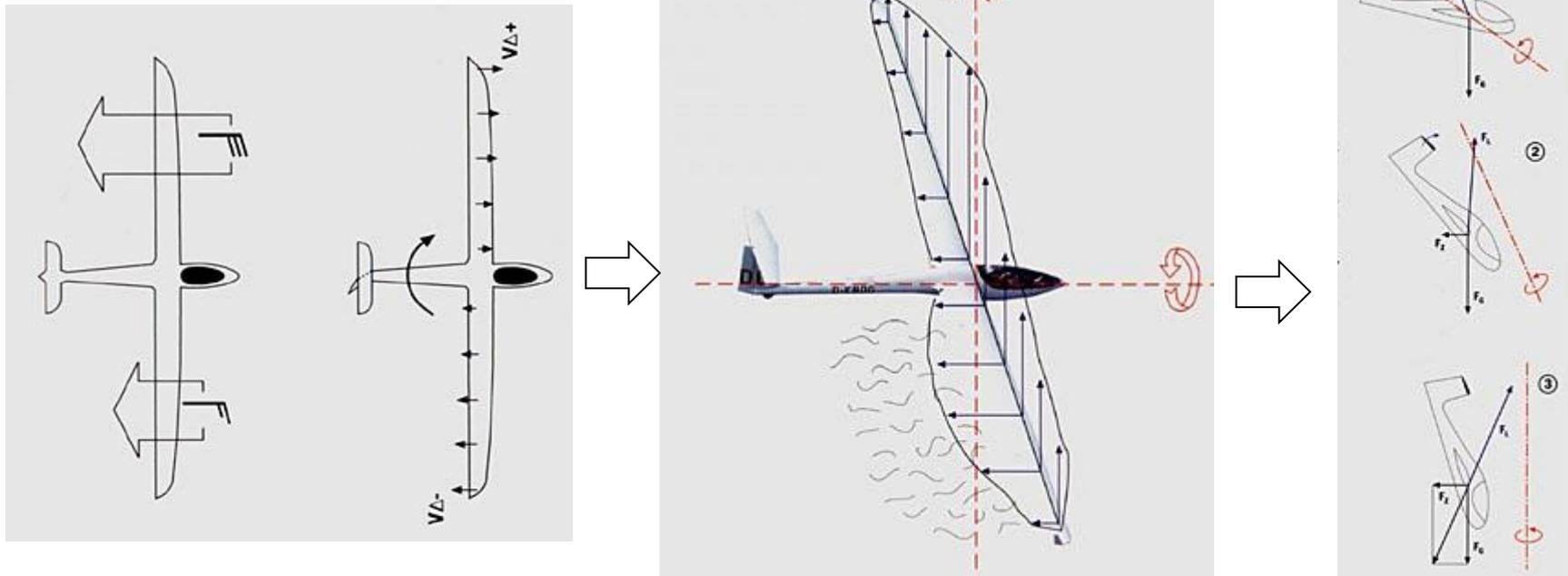
- Stall caused by **excessive angle of attack**
 - Usually, but not always, at low airspeed
 - Wing suddenly loses most of its lift
 - Drag increases
- **Warning signs** for impending stall in gliders:
 - Nose high attitude (high angle of attack)
 - Quiet cockpit (low airspeed)
 - Stick far back and shaking
 - Burbling noise caused by turbulence of separating air flow
- Recovery (glider):
 - Move stick to neutral position
 - Nose of glider drops and airspeed increases



Spin

Spin develops when **only one** wing stalls

- Asymmetry in air flow
 - gust or applying rudder in gliders
 - engine/propeller in power planes
- steep downward spiral develops quickly, possibly inverted



Spin Recovery Procedure

All certified gliders will recover from a spin, if the pilot takes the following steps:

1. Rudder: **full opposite** to rotation
2. Aileron: neutral
3. Elevator:
 1. move forward until rotation stops
 2. pull gently out of dive

Stall, Spin and Recovery (Movie)



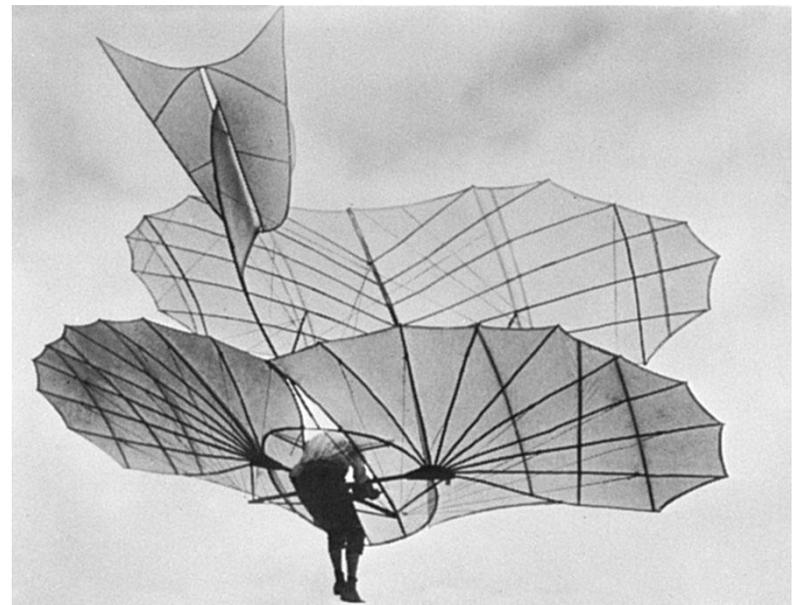
“Father of Gliding”: Otto Lilienthal

First person to fly a glider, in 1891

- Made over 2000 short flights!!
- Designed and built several gliders
- Book: “Bird Flight as the Basis for Aviation”
- Died after crash landing in 1896



1848 -1896

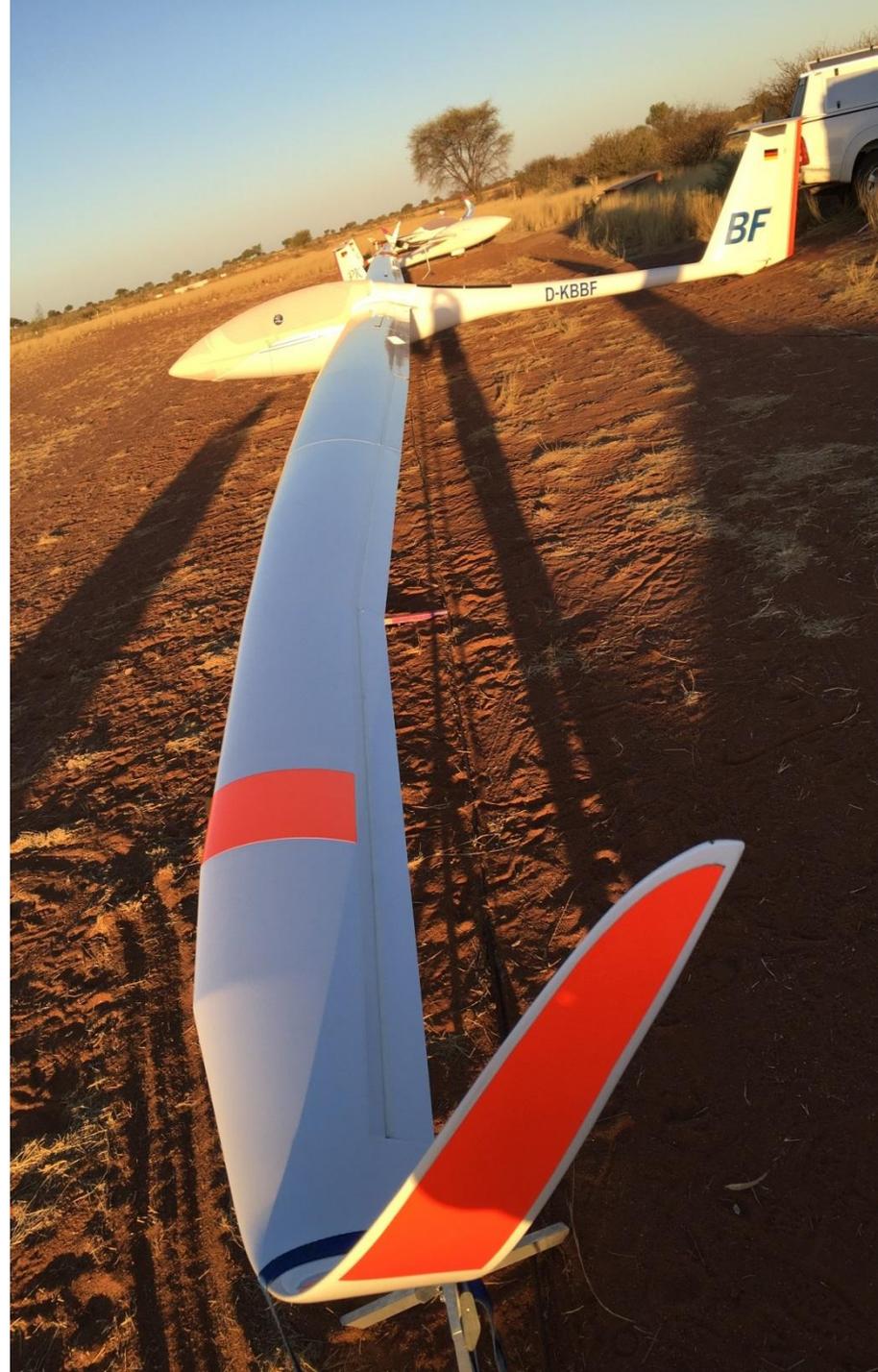


Glider in Flight

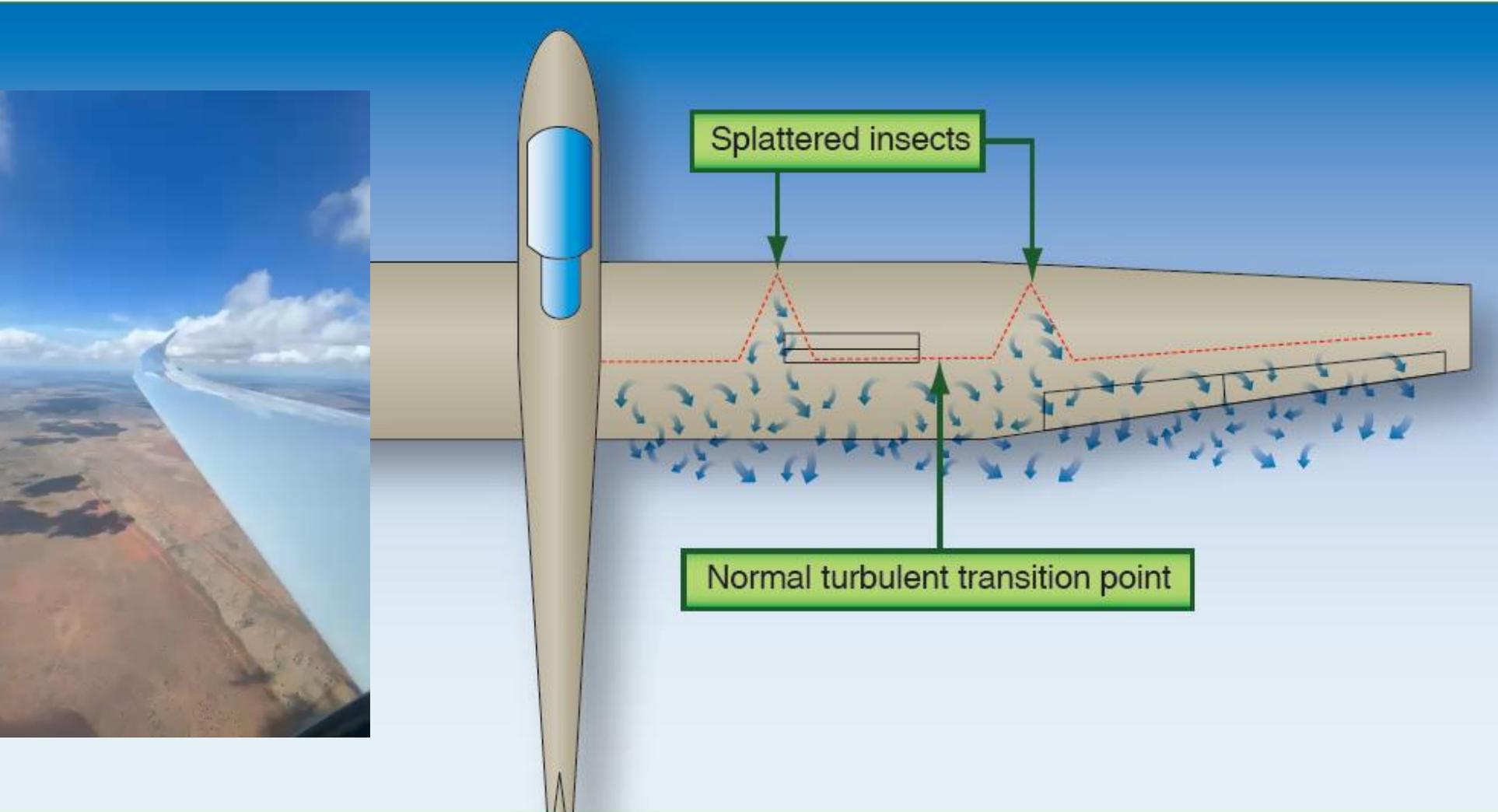
- Wings
- Performance
- Controls
- Manoeuvres



Wings



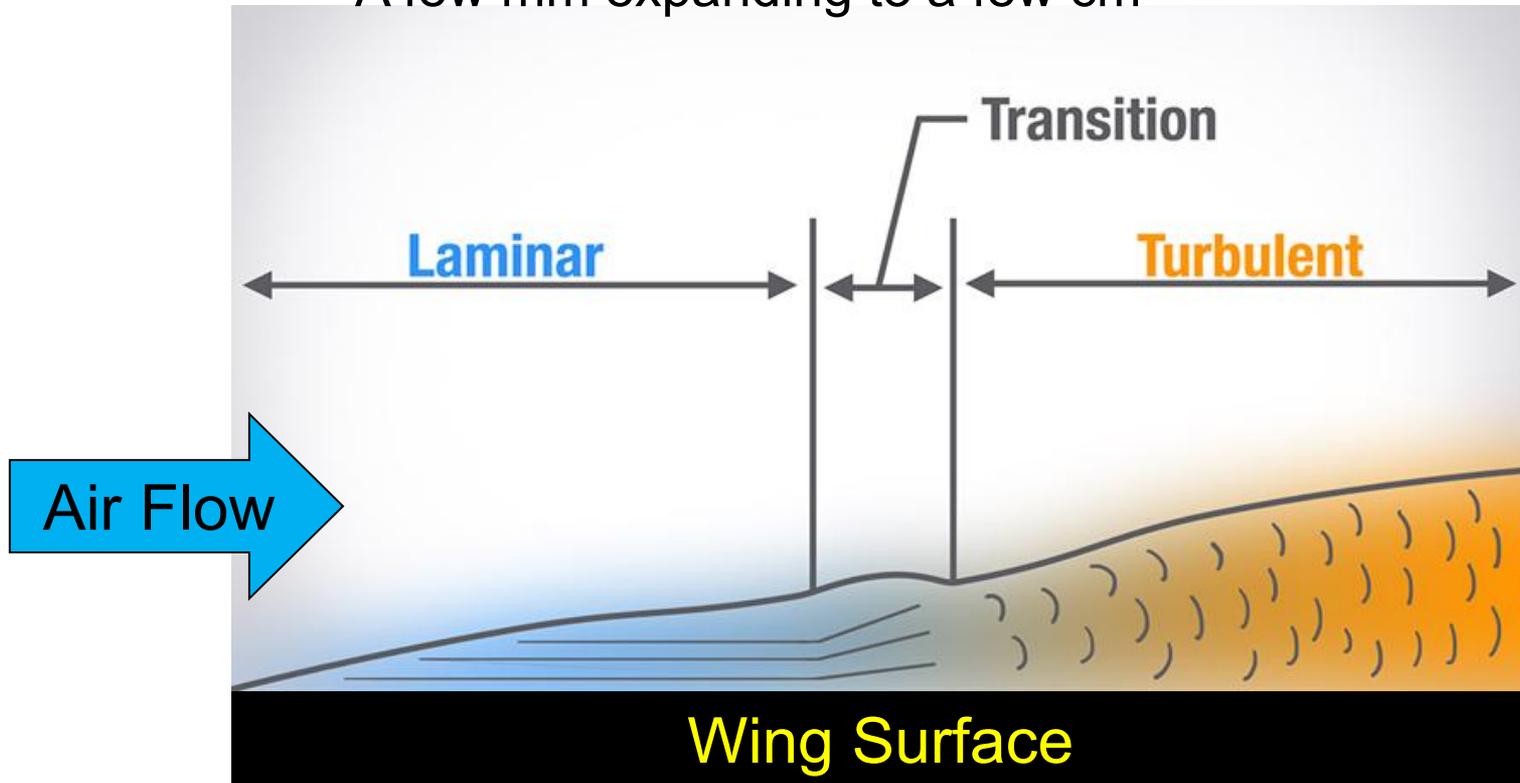
Transition from Laminar to Turbulent Flow



Boundary Layer

Thin airflow layer next to wing surface

- A few mm expanding to a few cm

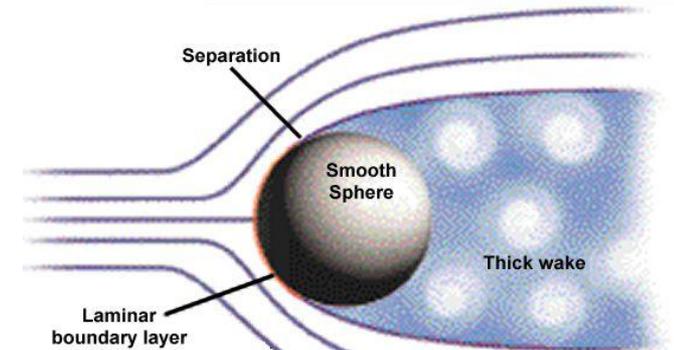
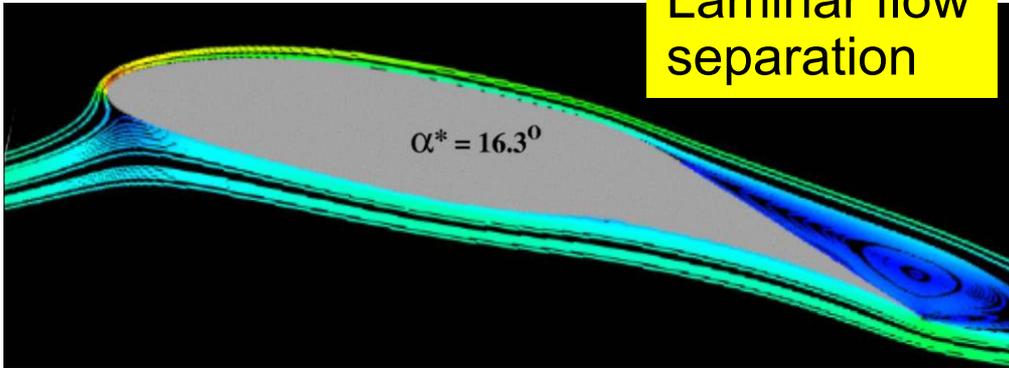


Laminar flow slows down near the wing surface

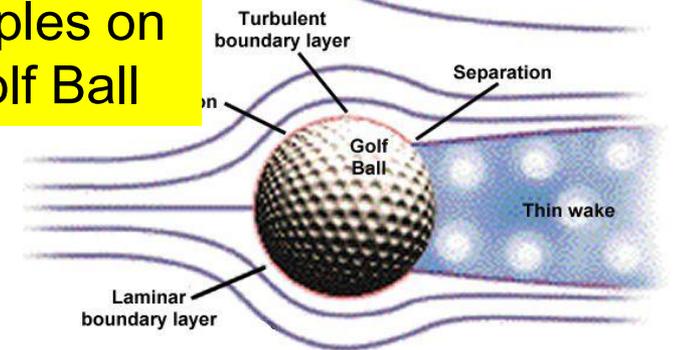
- Air Molecules “stick” to wing surface
- Transition to turbulent flow due to shear

Boundary Layer Control Devices

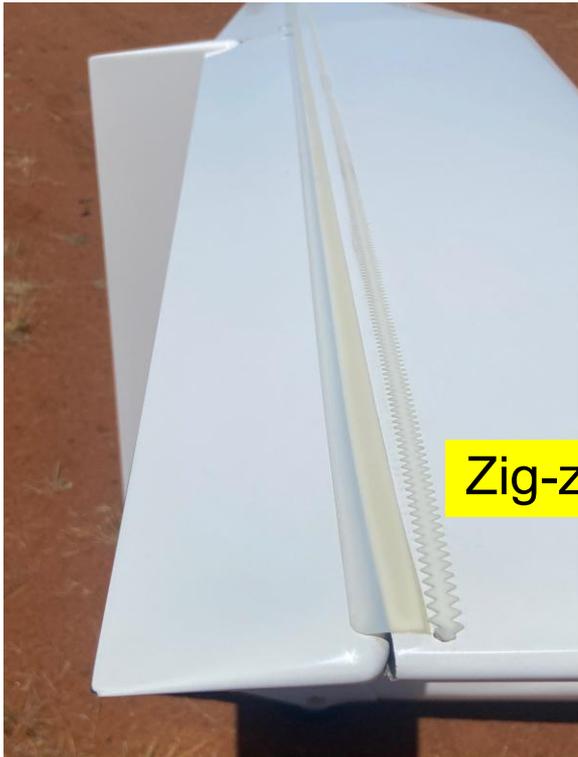
Laminar flow separation



Dimples on Golf Ball



Zig-zag Tape



Vortex Generators



Wing Aspect Ratio Comparison

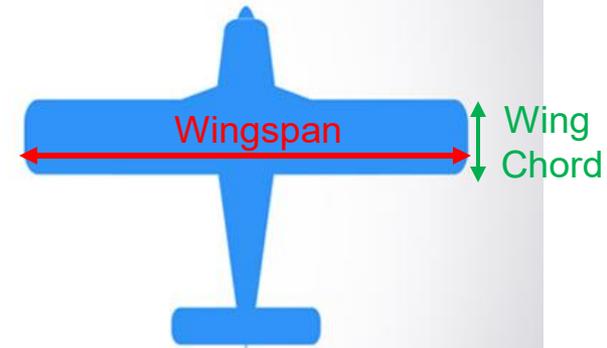
Wing Aspect Ratio =
Wingspan / Wing Chord

AR = 33.5



Schleicher ASH 31 Glider

AR = 5.6

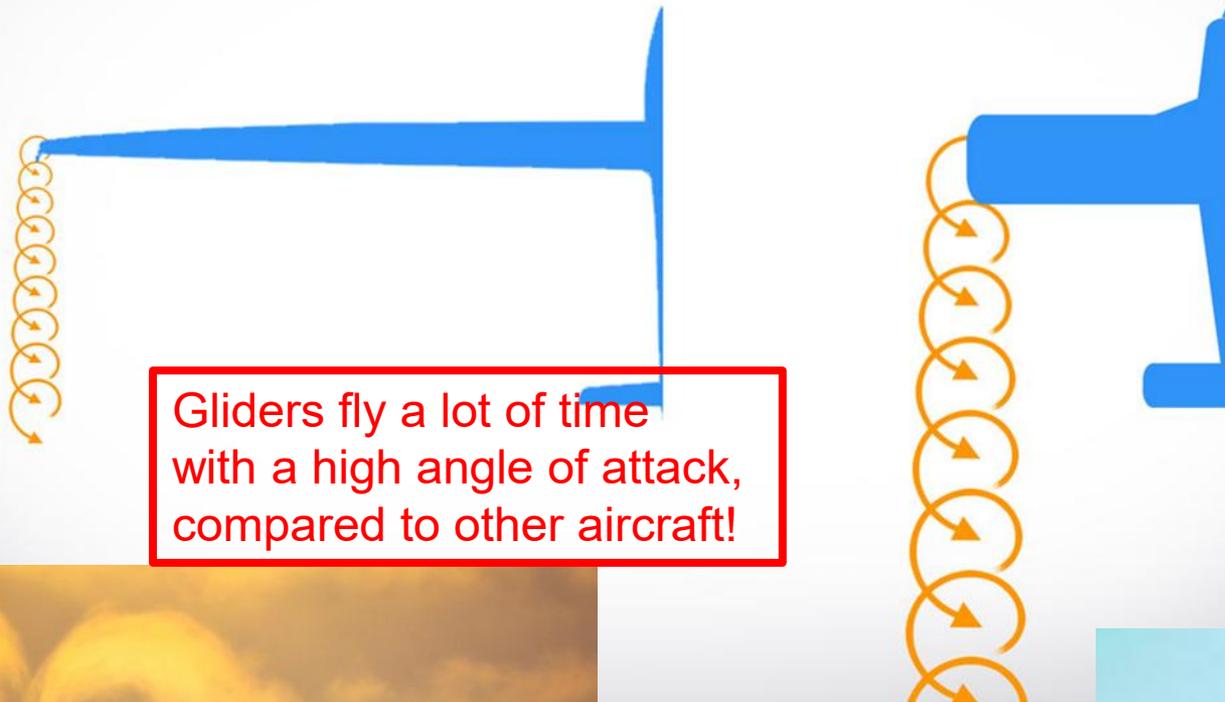


Piper Cherokee

Binder EB29
AR = 51



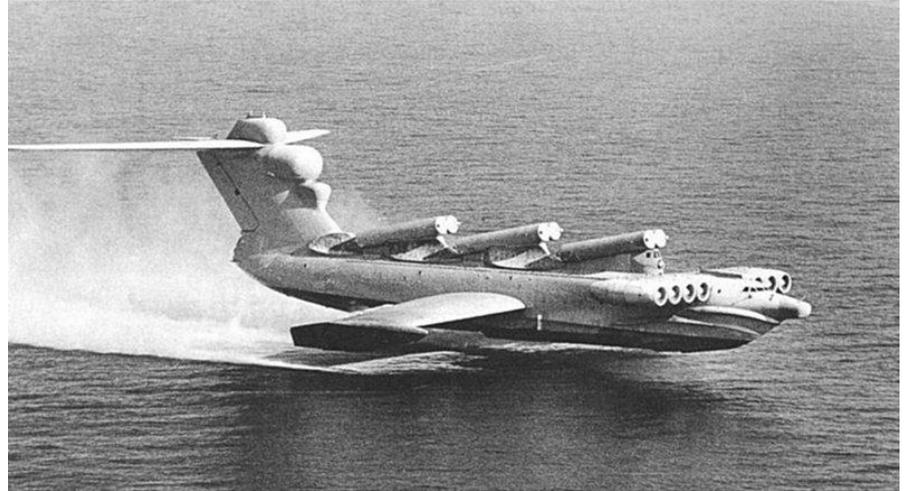
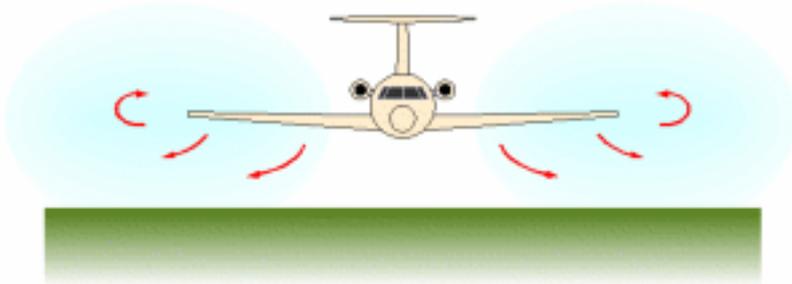
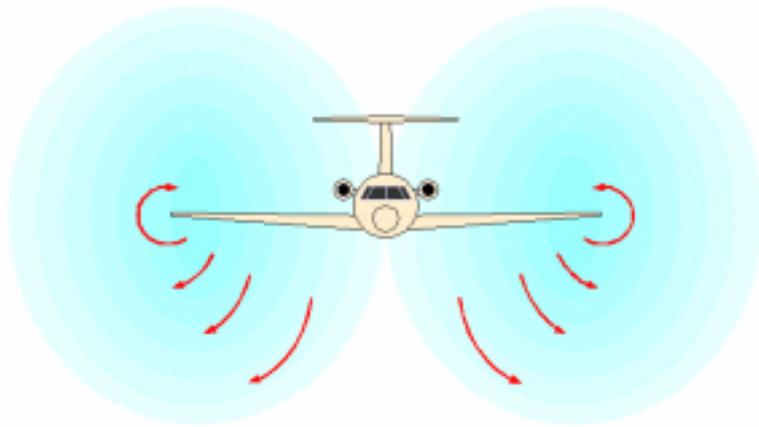
High Aspect Ratio Wings Produce Less Induced Drag



Gliders fly a lot of time with a high angle of attack, compared to other aircraft!



Ground Effect

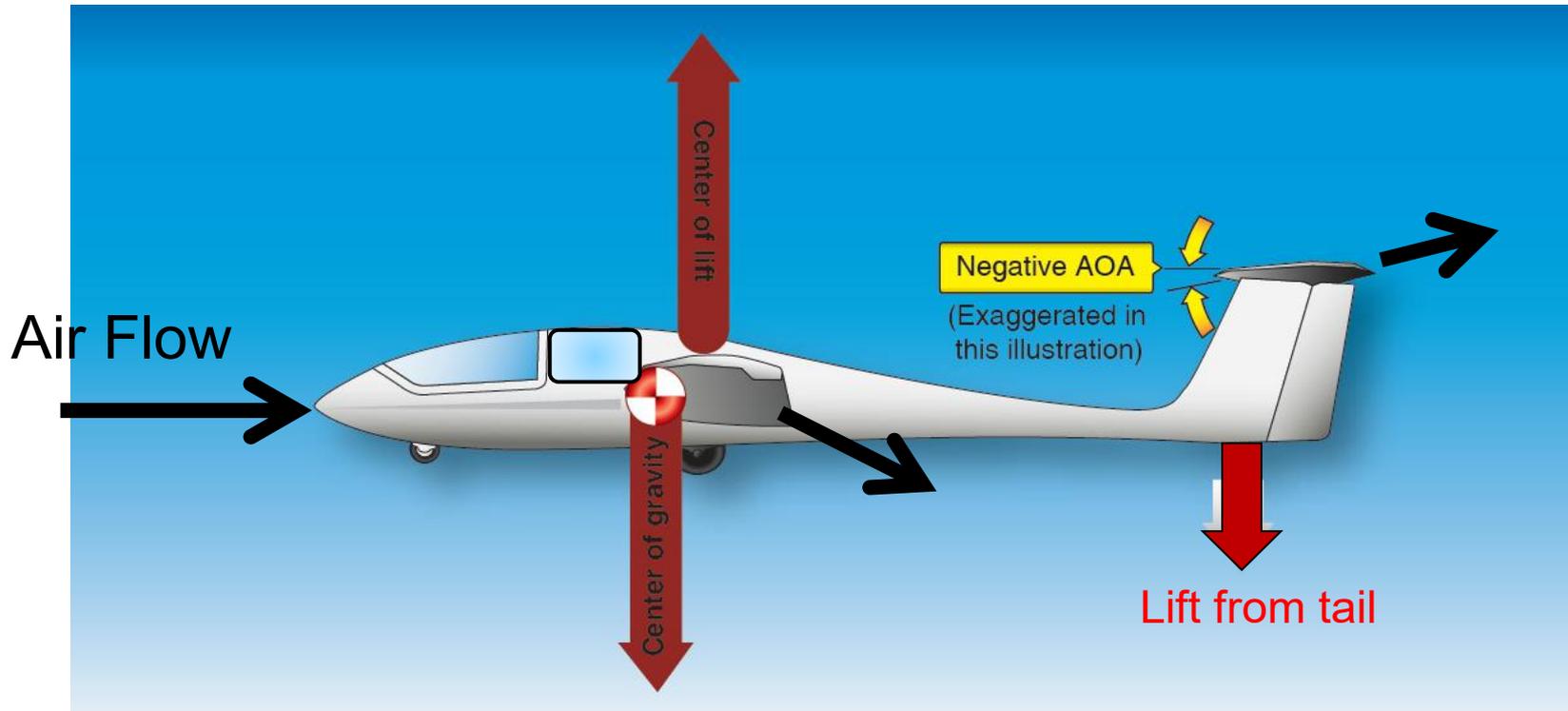


Wing “Washout” makes Stall more benign

- **What is Washout?**
 - Gradual “warping” of wing cord as you go outward on the wing so that angle of attack decreases from wing root to the wing tip
- **Makes Stall more Benign**
 - Stall first develops near the wing root
 - More benign than stalling the wing tip
 - Keeps aileron functioning at high AoA

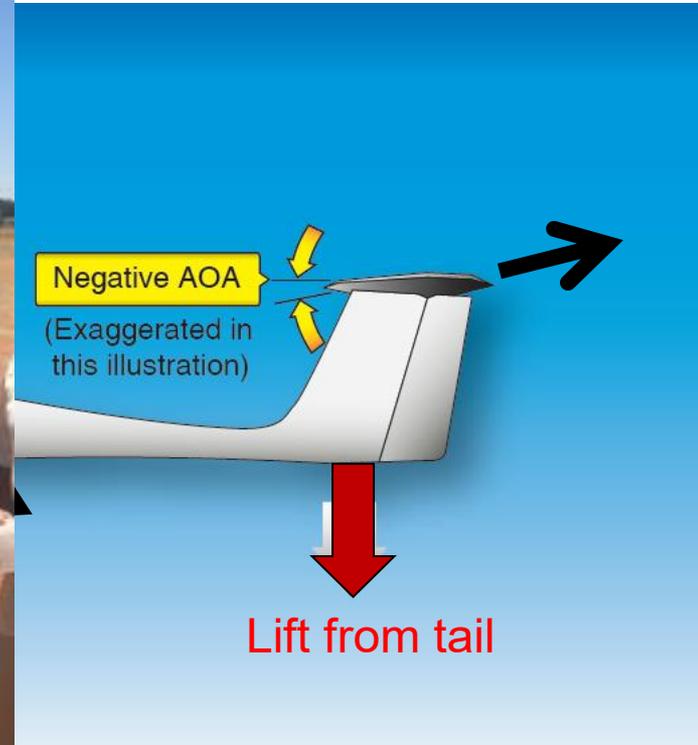


Lift Distribution and Center of Gravity (CG)



CG location must be confirmed to be in allowable range, **before every flight**

Lift Distribution and Center of Gravity (CG)



weight, and must be
nge, **before every flight**

Performance



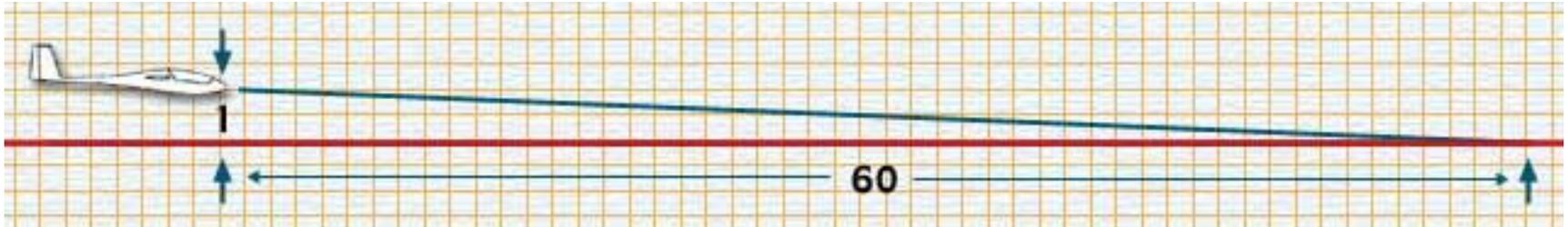
Lift-to-Drag Ratio (L/D)

- Key performance measure for gliders
- changes with airspeed
- Range for “Best L/D”: 20-70, typical 30-50



L/D	Glide Angle
20	3 deg
30	2 deg
40	1.4 deg
57	1 deg

L/D and other Ratios



These Ratios are **the same**:

1. Lift-to-Drag Ratio (L/D)
2. Distance / Height Ratio
3. Forward speed / Sink speed Ratio
4. Glide Ratio



**! Exam !
Question**

Distance Calculation



“With my current altitude, How far can I fly?”

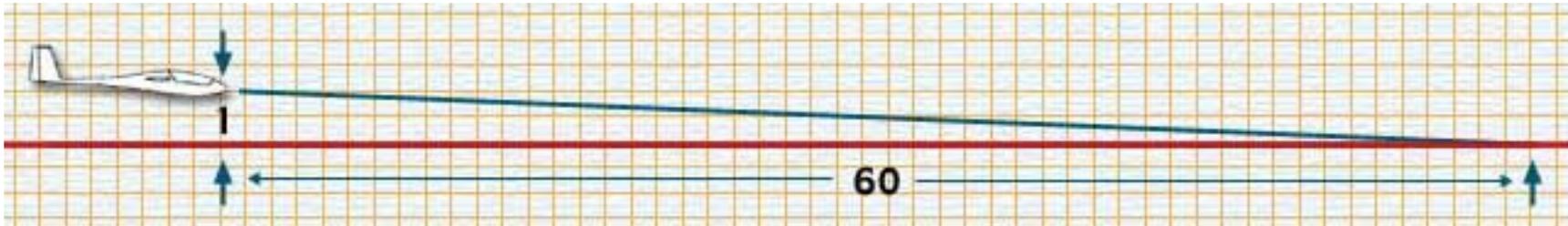
Distance Calculation in still air:

$$\text{Height} * \text{Glide ratio} = \text{Distance}$$

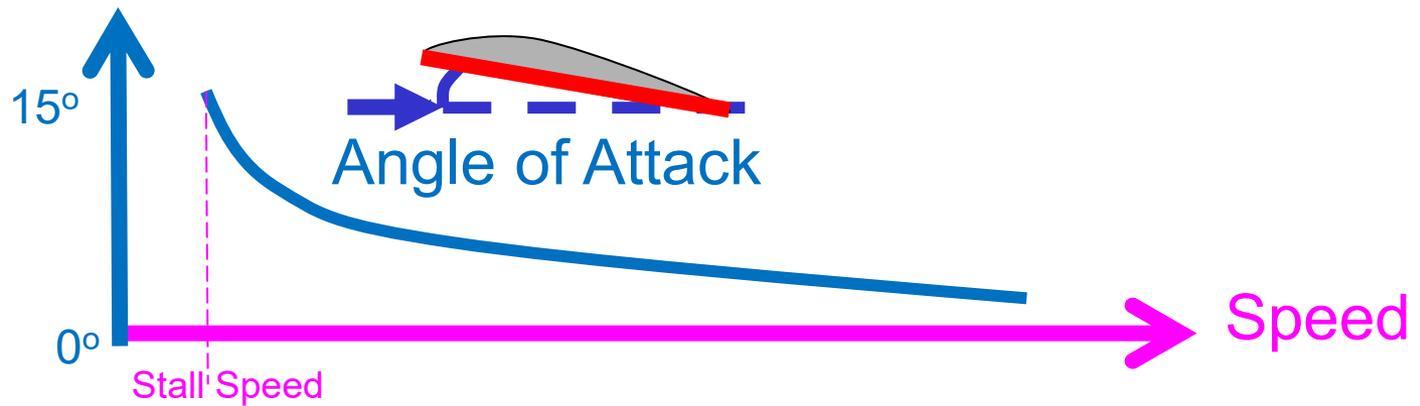
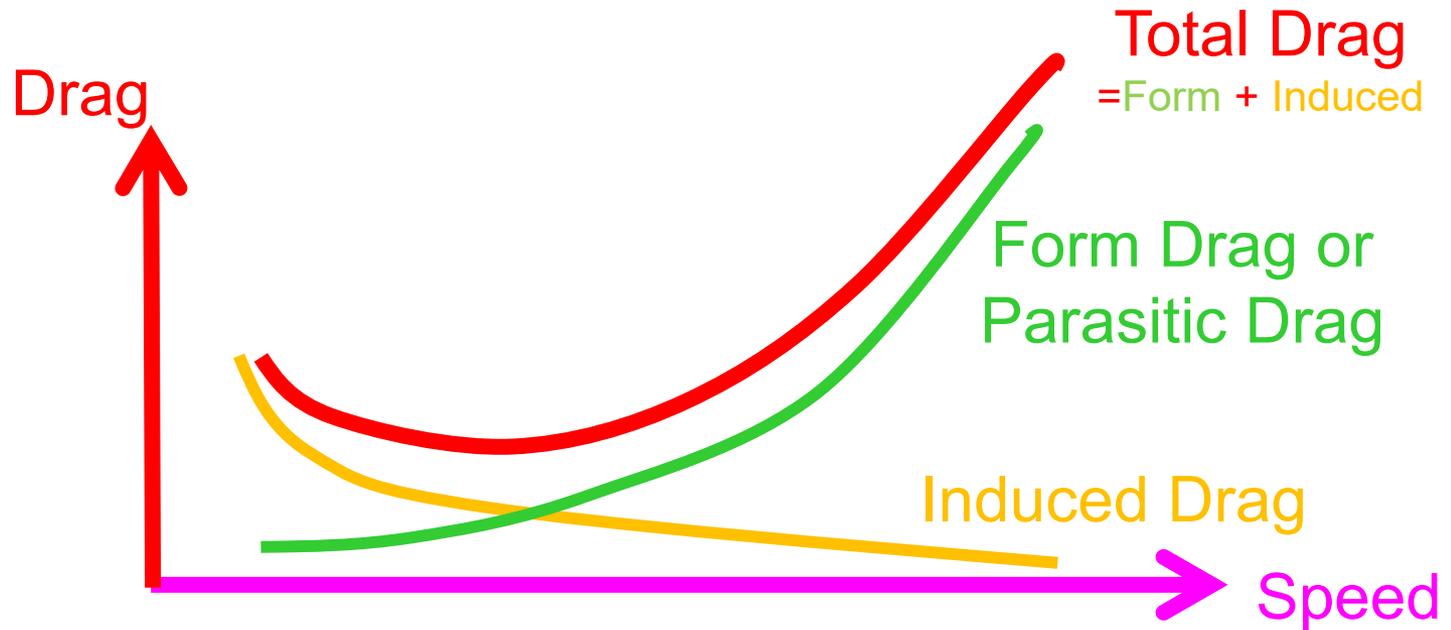
Example 1: $2000\text{m} * 60 = 2\text{km} * 60 = 120\text{km}$

Example 2: $6000\text{ ft} * 60 = 360\,000\text{ft}$

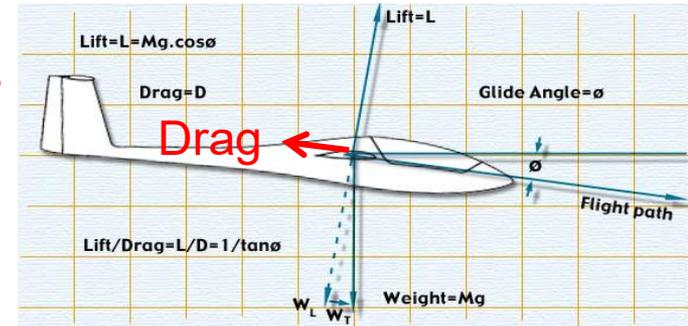
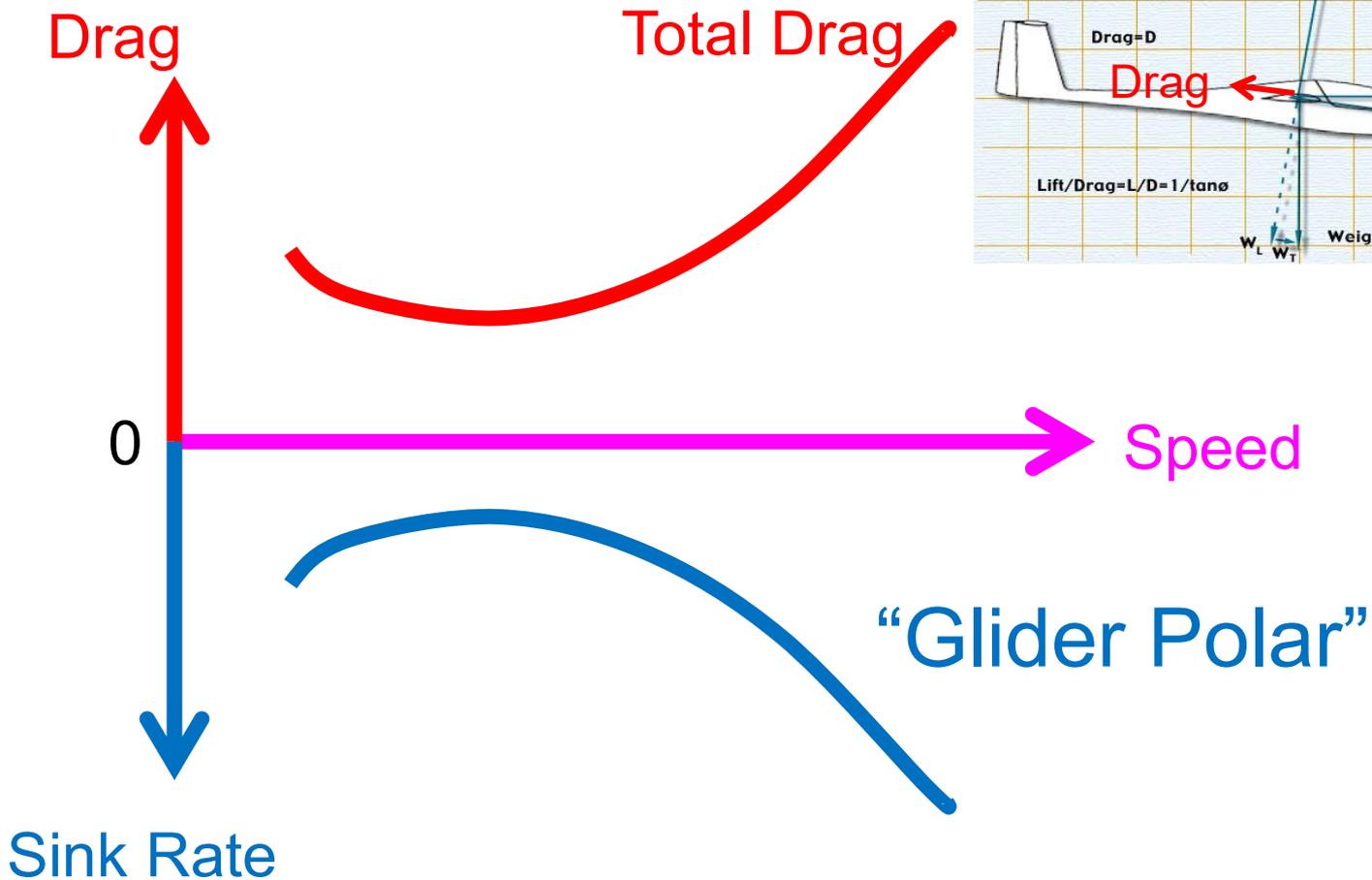
$$360\,000\text{ ft} / 6076\text{ ft/NM} = 59\text{ NM}$$



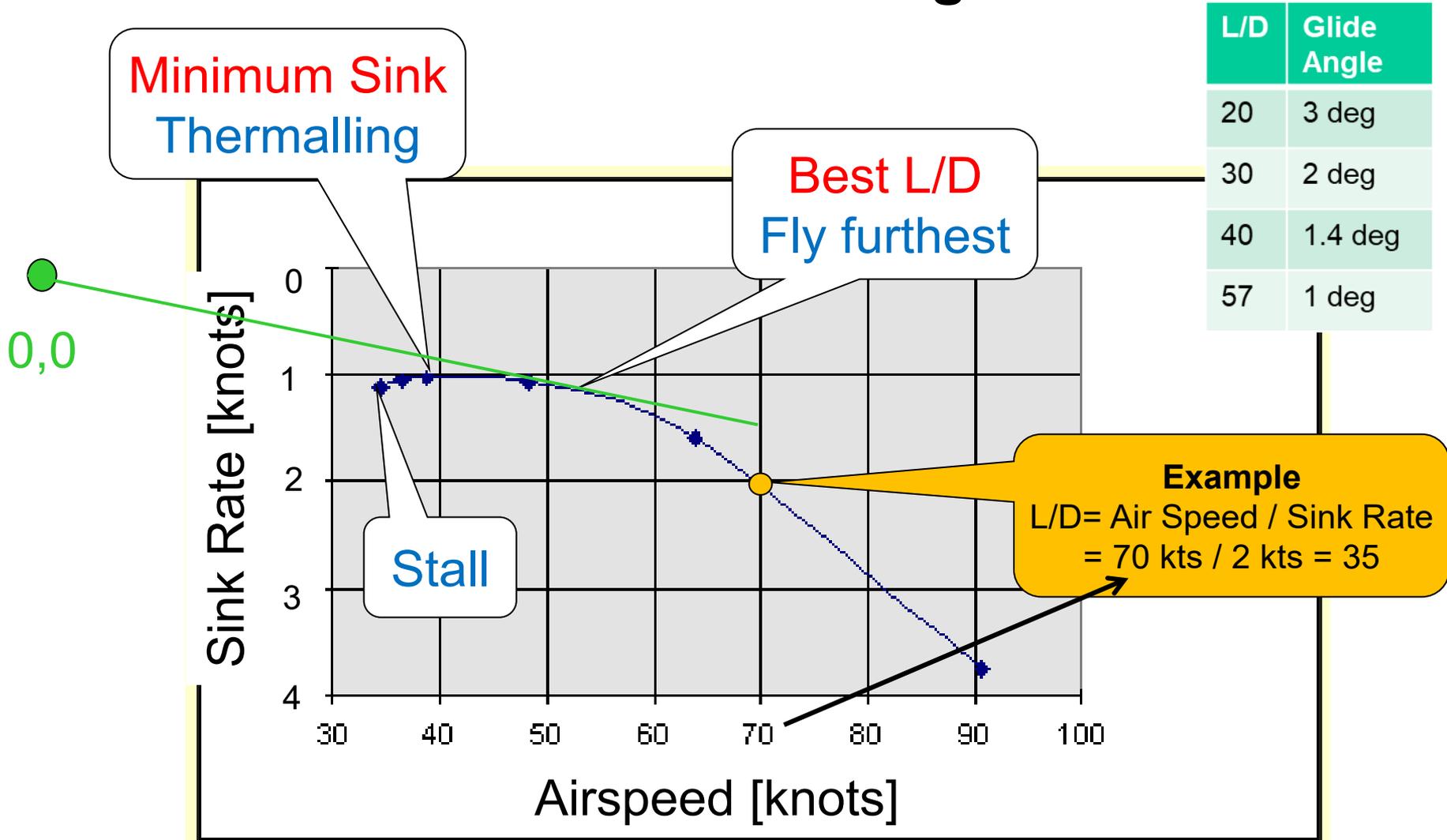
Relationship of Drag, Speed and Angle of Attack



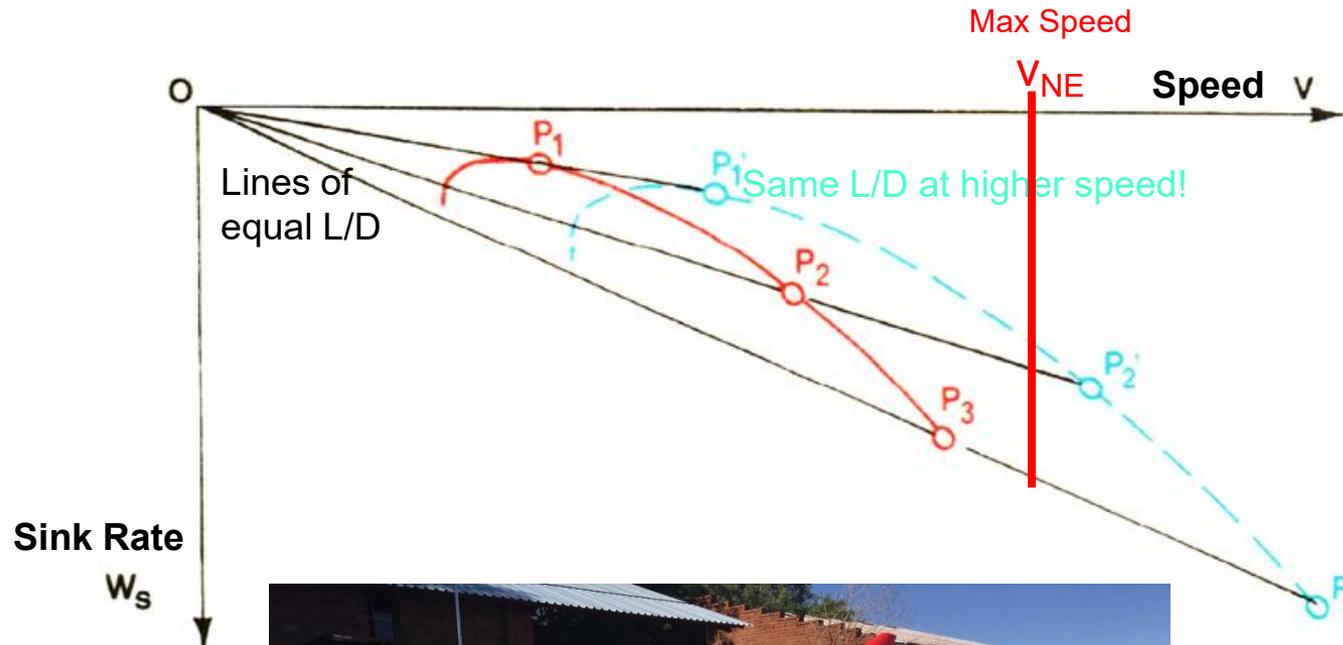
Relationship of Speed, Drag and Sink Rate



Glider Polar Diagram



Polar “Scales” with Aircraft Weight and Air Density



Scale Factors

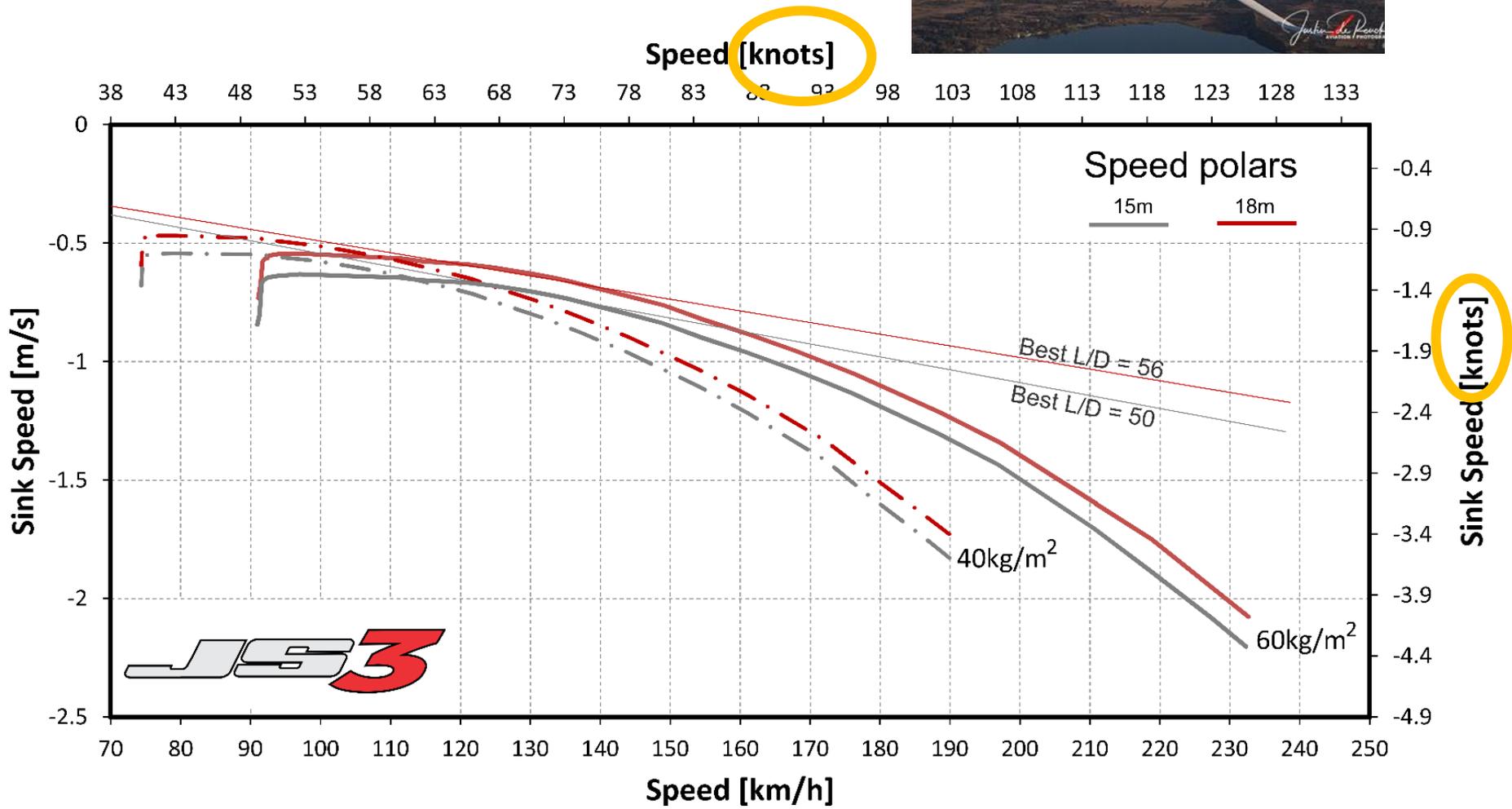
$$\frac{\sqrt{\text{aircraft weight}}}{\sqrt{\text{air density}}}$$



Polars of "JS3" Glider

4 Configurations:

- Wing Span: 15m and 18m
- Wing Loading: 40 and 60 kg/m²



Design Parameters for Gliders (post WW2)

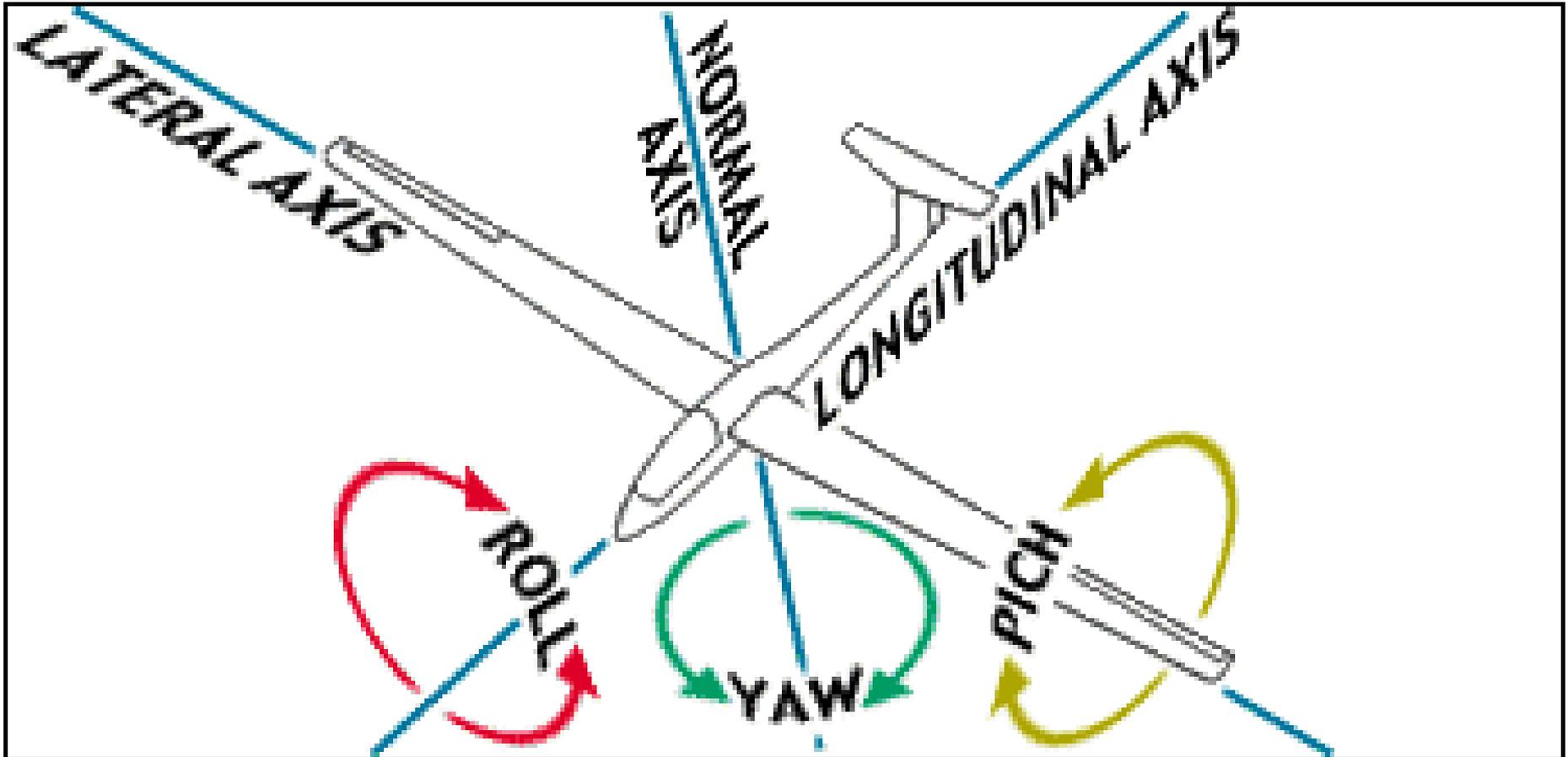
Number of Seats:	1 or 2	
Take-off weight:	300 – 900 kg	660 - 2000 lbs
Wing span:	12 – 30 m	39 – 98 ft
Most common span:	15 – 20 m	50 – 66 ft
Wing area:	10 – 18 m ²	108 - 194 sq ft
Best L/D:	20 - 70	
Aspect Ratio:	12 – 53	
Wing loading:	20 - 60 kg/m ²	4 - 12 lbs/sq ft

Control & Stability

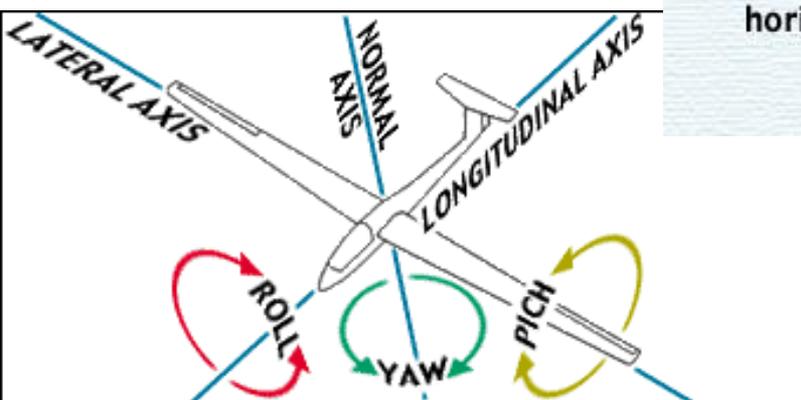
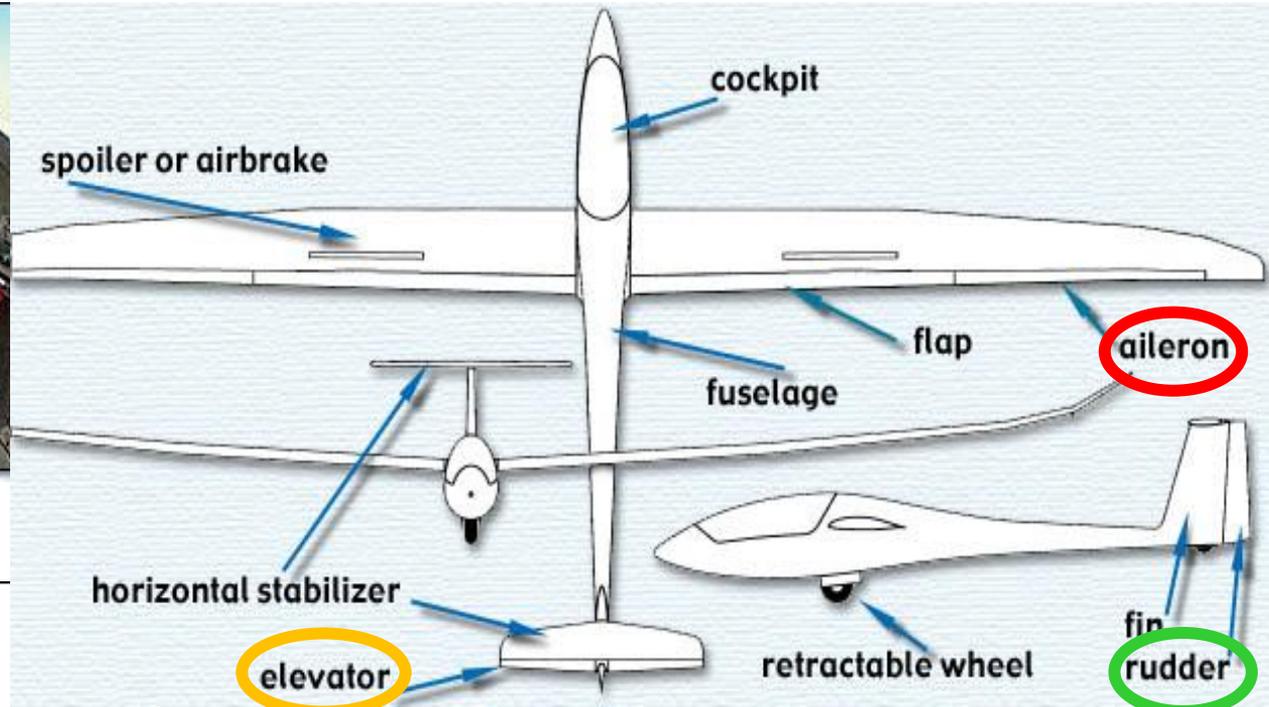
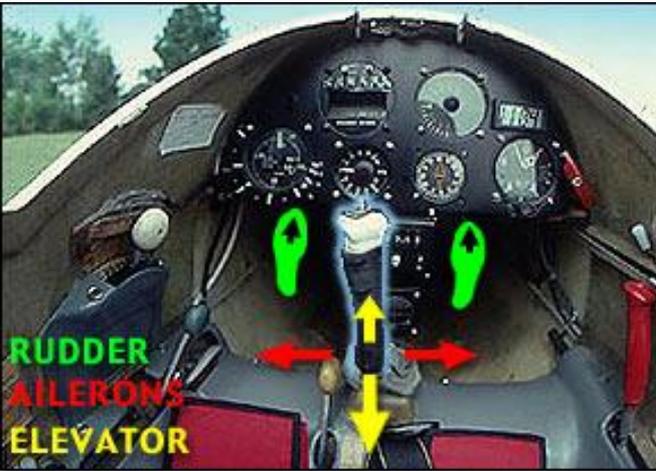


**! Exam !
Question**

The 3 Axes of Motion

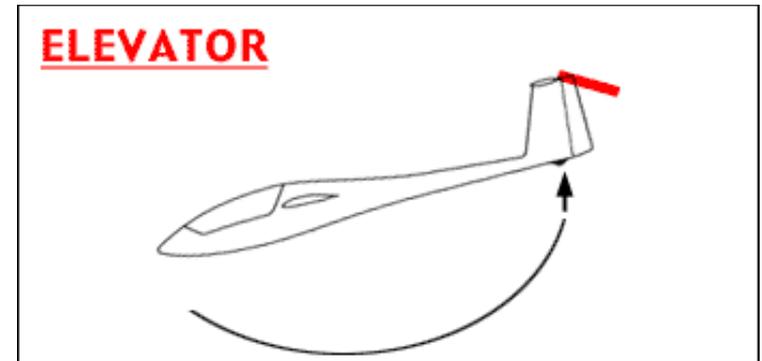


3 Controls for 3 Axes of Motion



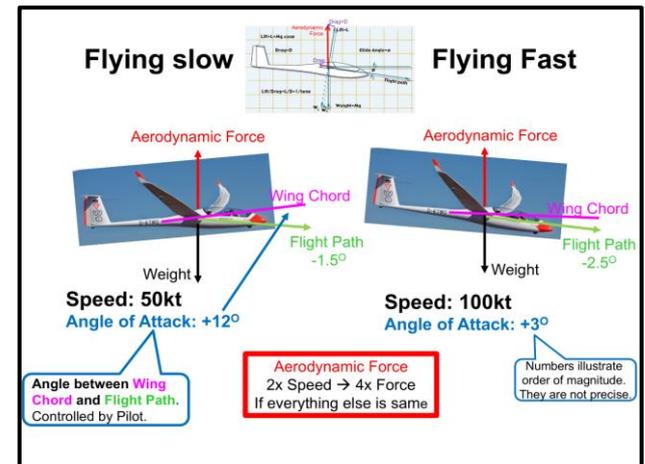
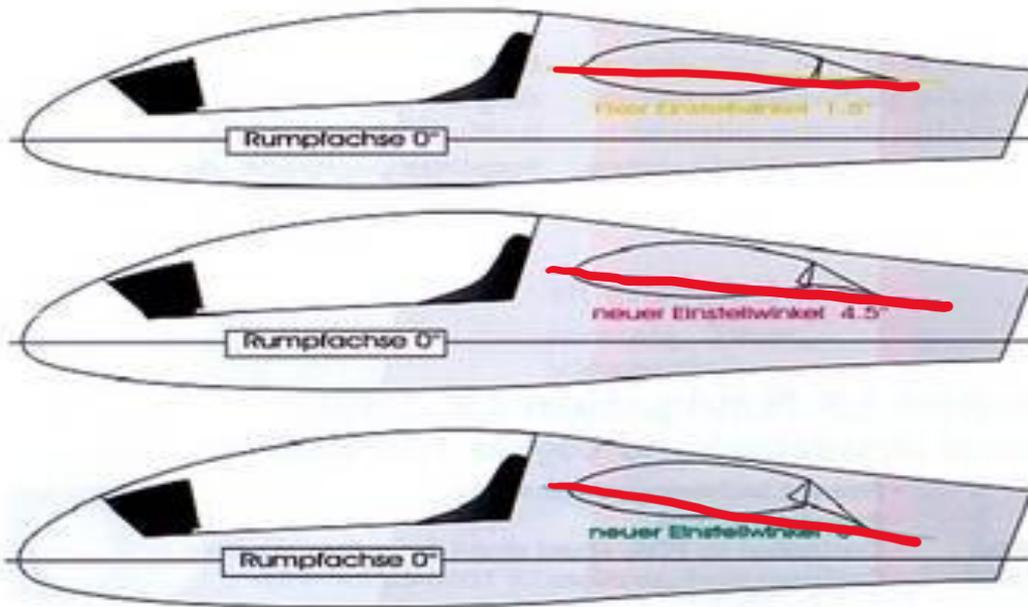
Controls

- **Elevator controls pitch**
 - controls angle of attack on wings
 - controls air speed
 - no effect on roll or yaw
- **Aileron controls roll**
 - secondary effect: adverse yaw
 - near stall: possibility of reversal of normal function
- **Rudder controls yaw**
 - secondary effect: slight positive roll



Trailing Edge Flaps

Adjust angle of Wing Chord relative to longitudinal axis for different speeds, to reduce fuselage drag on high-performance gliders. Flap operation usually integrated (“mixed”) with aileron operation.



Dive Brakes & Spoilers

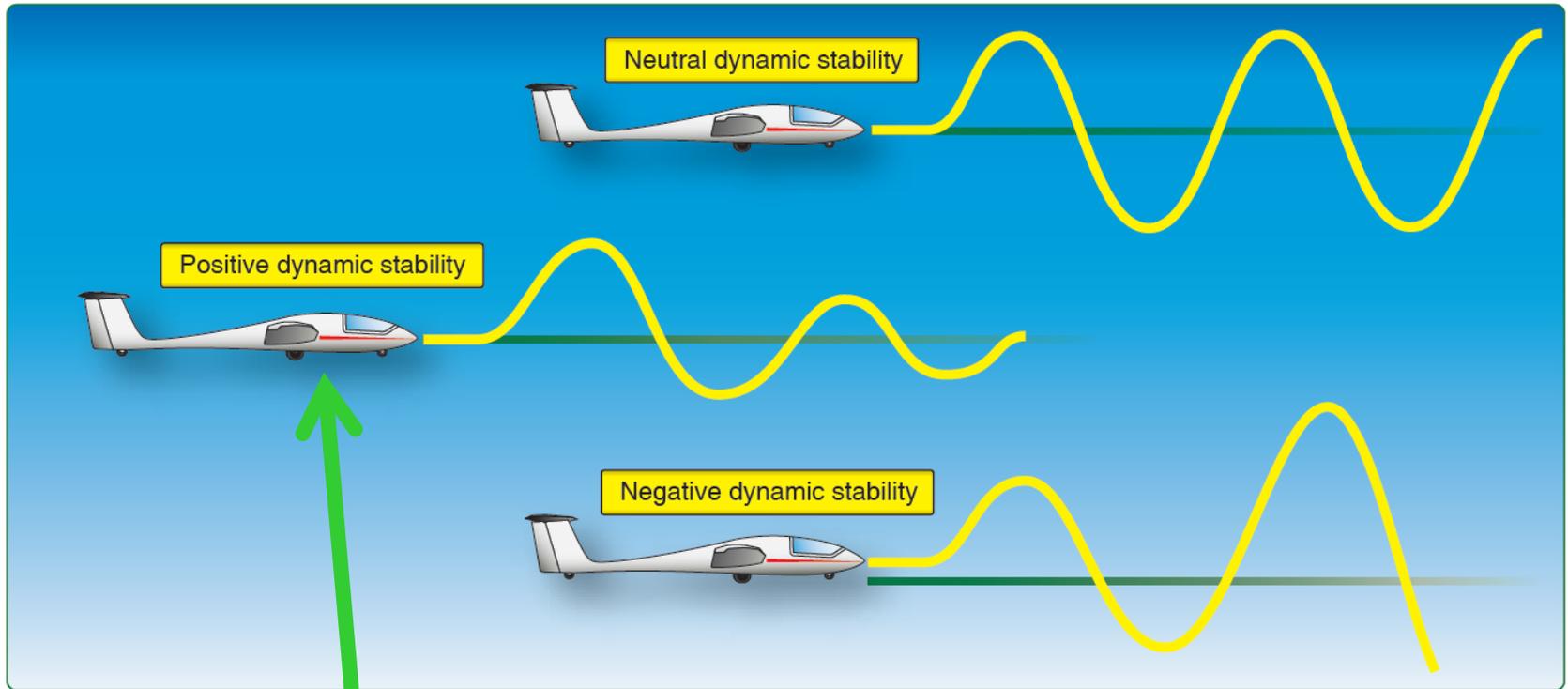
Dive brakes / spoilers are used to control glide path



They

- reduce lift
- increase drag
- increase sink rate

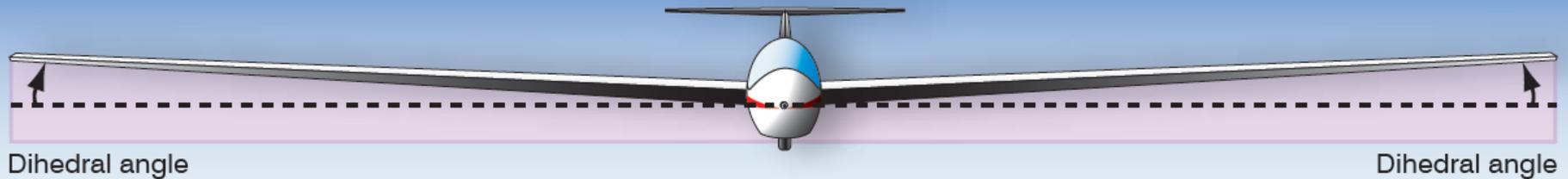
Dynamic Stability



Gliders are positively dynamically stable and easy to control

- Exeption: In steep turns, some gliders show “spiral divergence” (mild negative roll stability), which can lead to a “spiral dive”. Easy to control.

Wing Dihedral

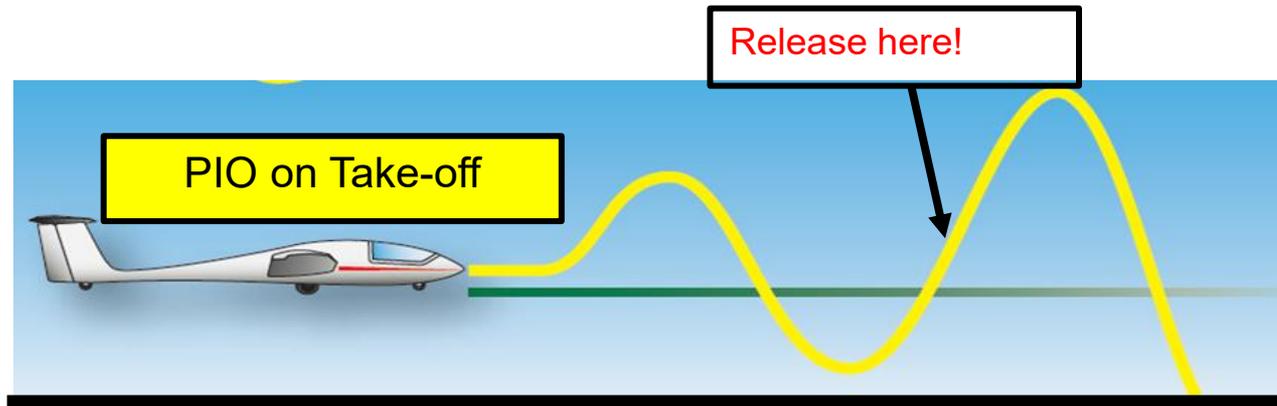


Improves aircraft handling

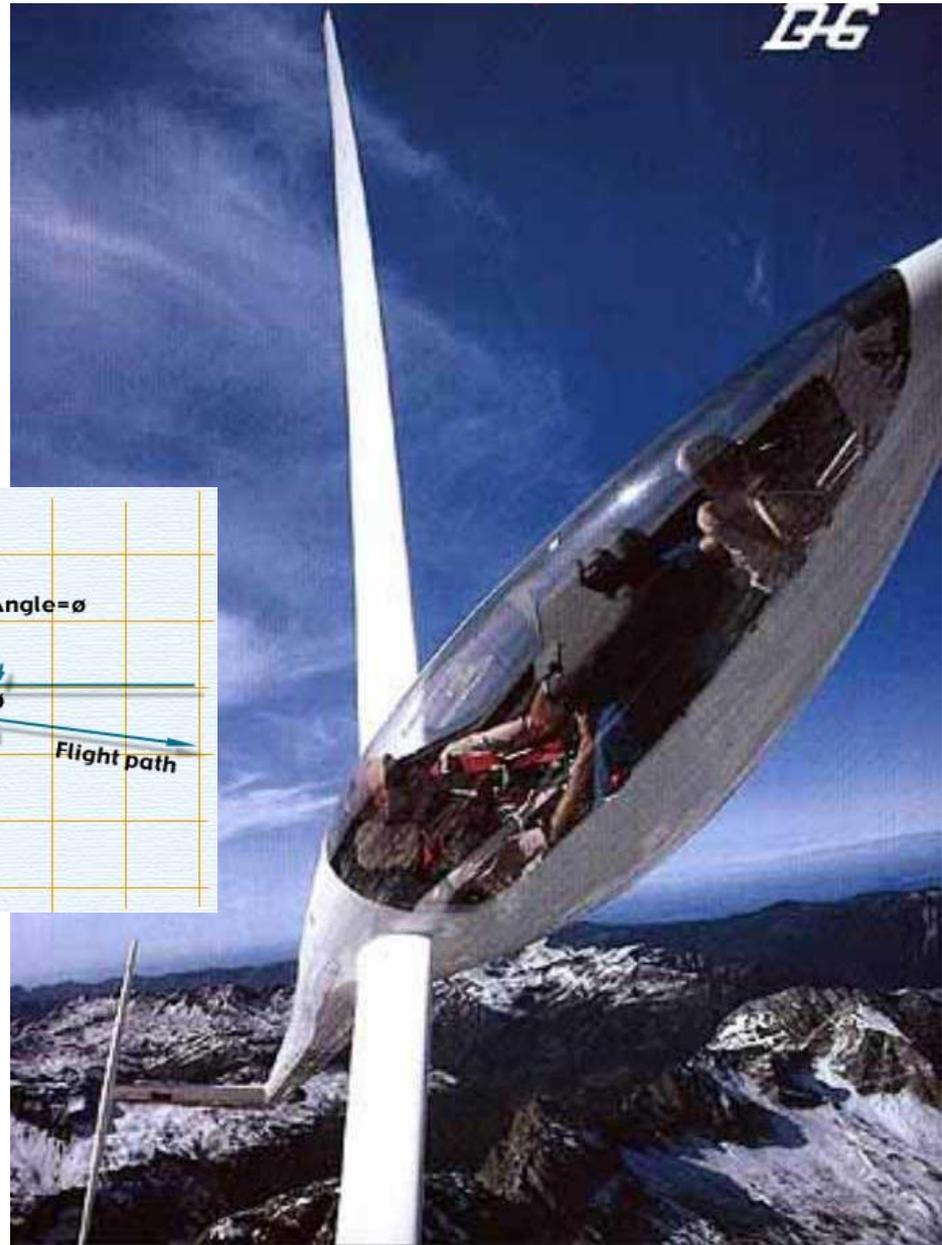
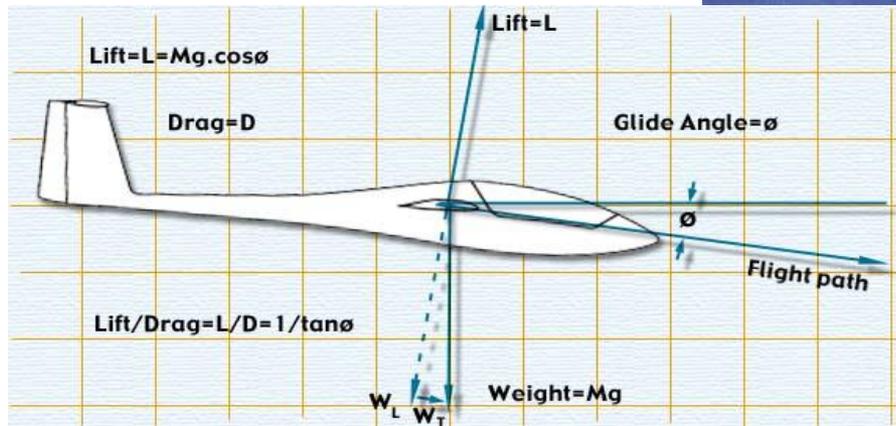
- Reduces spiral divergence
- Reduces Dutch Roll motion

Pilot-Induced Oscillation (PIO)

- **What is a PIO?**
 - Dynamic instability **caused by pilot**, often on tow
 - Due to lack of anticipation/slow reaction or/and over-reaction
 - Requires training & practice



Maneuvres

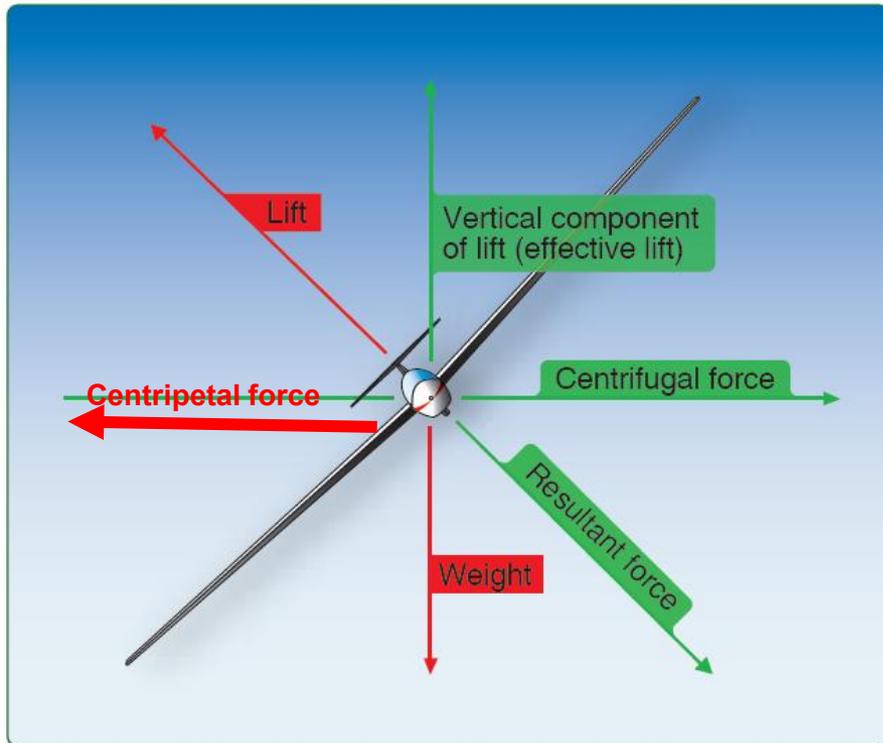


The Turn



- Glider pilots spend **a lot of time** in **tight** turns (in thermals)
 - High bank angle (around 45°) and slow speed required to thermal efficiently
 - Glider pilot must develop “feel” for flight with high Angle of Attack
- Gliders **don't** have an equivalent to the steering wheel of a car for controlling turns
 - Use combination of all controls to get in and out of turn
 - Controls almost neutral during turn

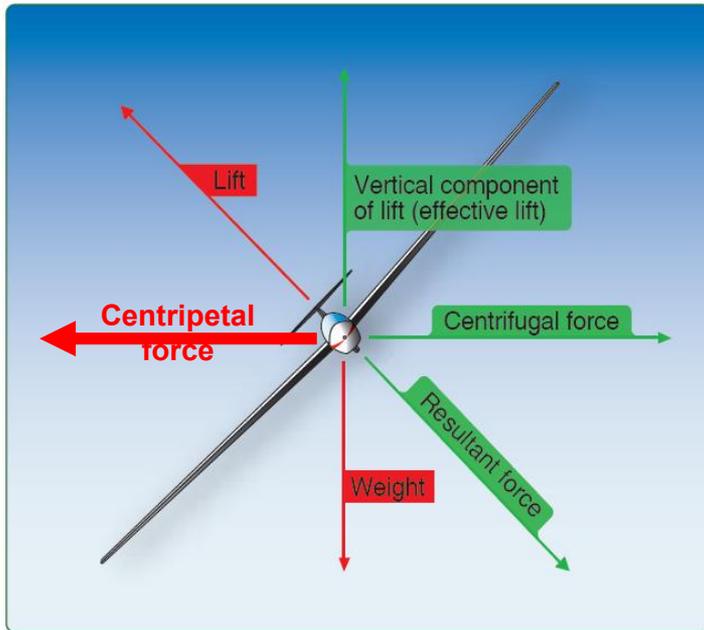
Forces in Coordinated Turn



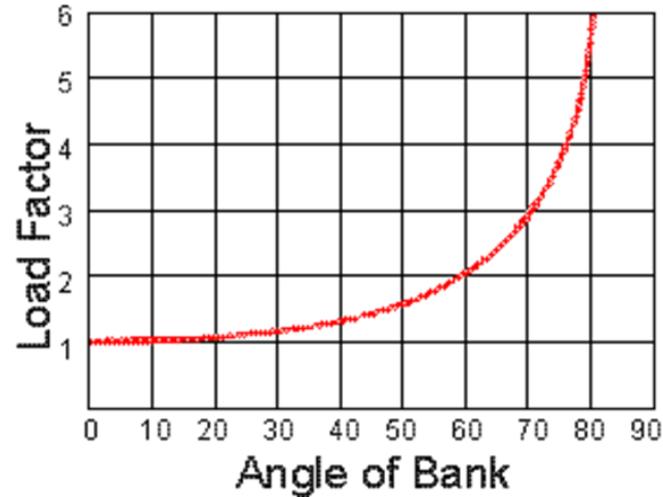
- **More lift required** than in straight/level flight
 - Lift supports weight of glider, **and**
 - **Lift pulls the glider around the turn** (centripetal force, which is opposing centrifugal force)
- Pilot and aircraft feel extra G-force
 - 1.4 G at 45° bank angle
 - Higher stress on aircraft → “Load Factor”
- Effects on wings
 - Higher Angle of Attack required
 - Increased stall speed!

! Exam !
Question

Load Factor



Load Factor vs Angle of Bank



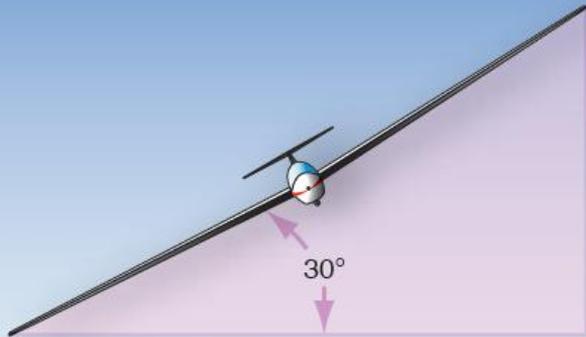
Load factor is ratio of **Lift Force** to **Weight** of aircraft

- Same as G-load, indicator for stress on airframe, **don't exceed limit**
- As the Load Factor increases, **Stall Speed** also increases

Bank Angle, Air Speed, Turn Radius and Stall Speed in a Coordinated Turn

Level stall airspeed at gross weight is 38 knots

Stall speed: 41 knots



TAS 40 MPH

Turn radius **185** feet

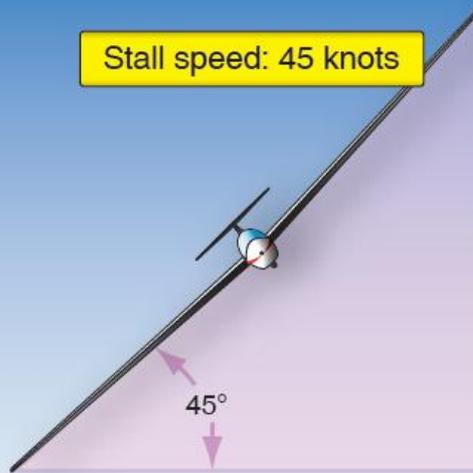
TAS 60 MPH

Turn radius **417** feet

TAS 80 MPH

Turn radius **740** feet

Stall speed: 45 knots

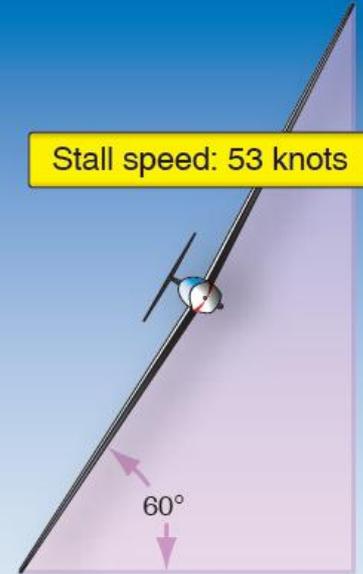


Turn radius **107** feet

Turn radius **240** feet

Turn radius **428** feet

Stall speed: 53 knots



Turn radius **062** feet

Turn radius **139** feet

Turn radius **247** feet

Thermal with
about 45° bank

Manfred Radius at Work



At this moment, “Energy” is really important for Manfred

Energy of a Glider

“Speed”

“Height”

Total Energy = Kinetic Energy + Potential Energy

$$E_{Total} = \frac{1}{2}mv^2 + mgh \quad m = \text{mass}, v = \text{velocity}, g = \text{gravity}, h = \text{height}$$



Happy Landings !



Sample TC Exam Questions

**! Exam !
Question**

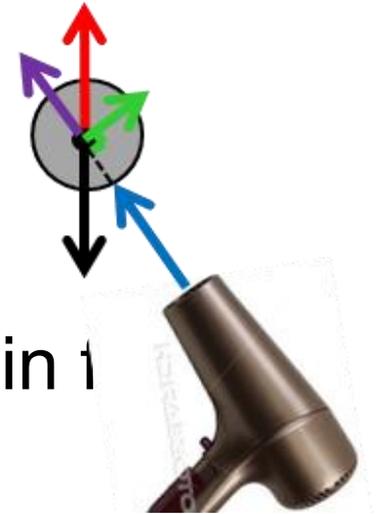


Exam Question

The total lift force acting on an airfoil in flight is considered to act:

1. Upwards with reference to the earth's surface
2. At 90 deg to the aircraft longitudinal axis
3. At 90 deg to the average relative air flow
4. At 90 deg to the average wing cord

Exam Question



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Exam Question

In gliding, an important use of wing spoilers is to

1. Increase the rate of descent at the same air speed
2. Increase lift without increasing drag
3. Make safe approaches possible at slower speeds
4. Improve the lift/drag ratio

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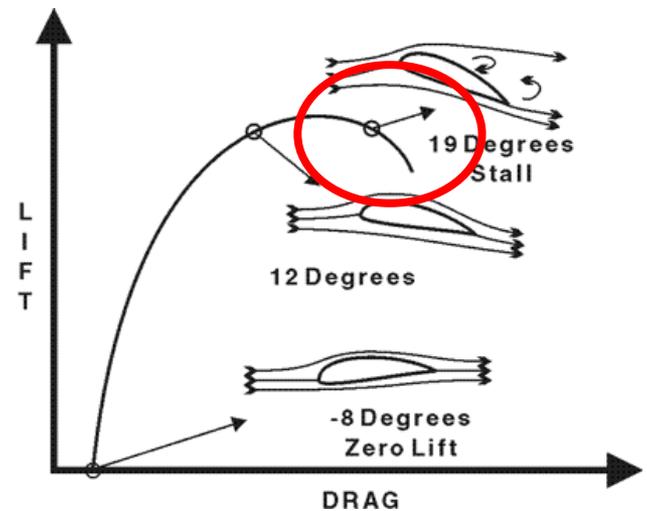
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1. More lift and more drag
2. More lift and less drag
3. Less lift and more drag
4. No effect on lift and drag

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Exam Question

At a gliding ratio of 15:1, a glider descending 1000 feet in still air will move forward a distance closest to:

1. 2.2 NM
2. 2.5 NM
3. 2.8 NM
4. 3.1 NM

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2. 2.5 NM

$$15 * 1,000 \text{ ft} = 15,000 \text{ ft}$$

$$15,000 \text{ ft} / 6,076 \text{ ft/NM} = 2.47 \text{ NM}$$

$$\text{mental calc: } 15 / 6 = 2.5$$

1. 2.8 NM

2. 3.1 NM

Exam Question

The stalling speed of a glider is:

1. The same in coordinated turns as in straight and level flight
2. Inversely proportional to the wing loading
3. Not affected by aerodynamic loads
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The ratio of the total lift force acting on the wings of a glider during flight to the gross weight of the glider is known as:

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2. Aspect ratio
3. Power factor
4. Load factor

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Longitudinal stability refers to stability about the:

1. Longitudinal axis
2. Lateral axis
3. Normal axis
4. Directional axis

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