AERODYNAMICS

Mastering the Art of Flight: Delving into Paragliding Physics

Vectors

A **vector** is a quantity or phenomenon that has two independent properties: magnitude and direction

Sign: $\bar{v}$ or $\vec{v}$

Examples in the nature?

How to say it?

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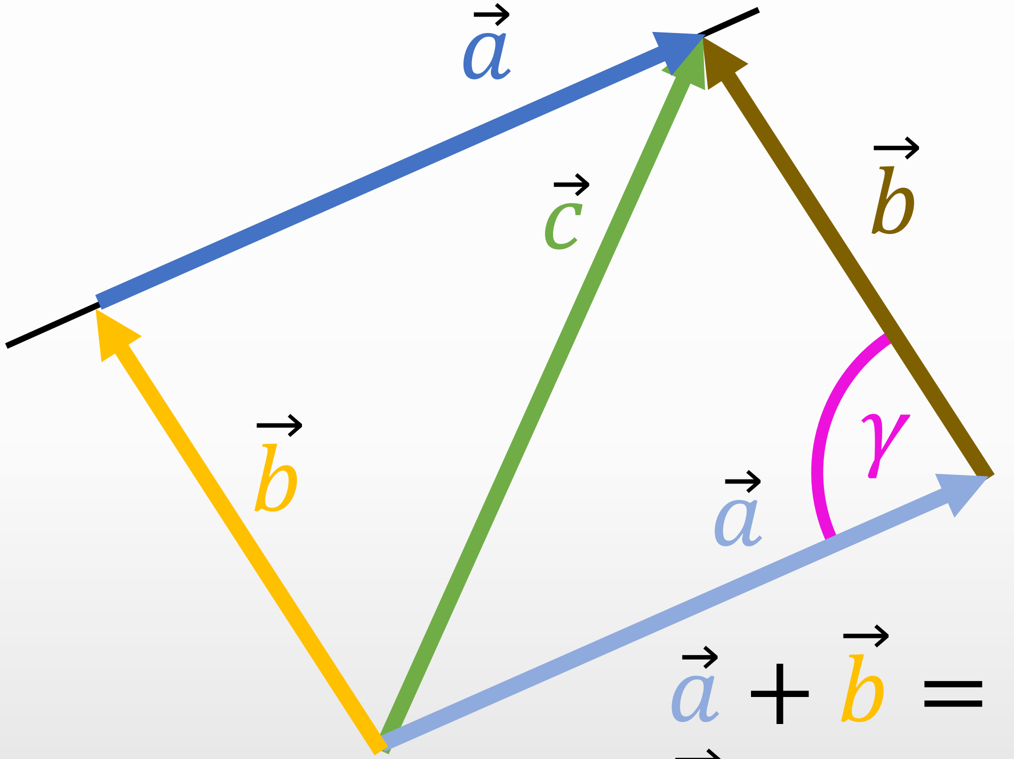
Vectors (addition)

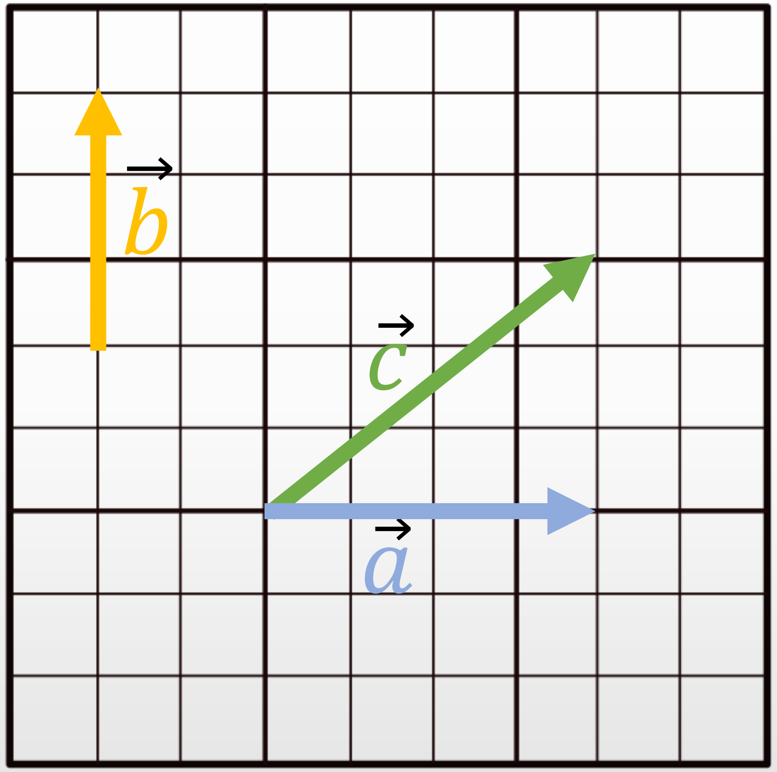


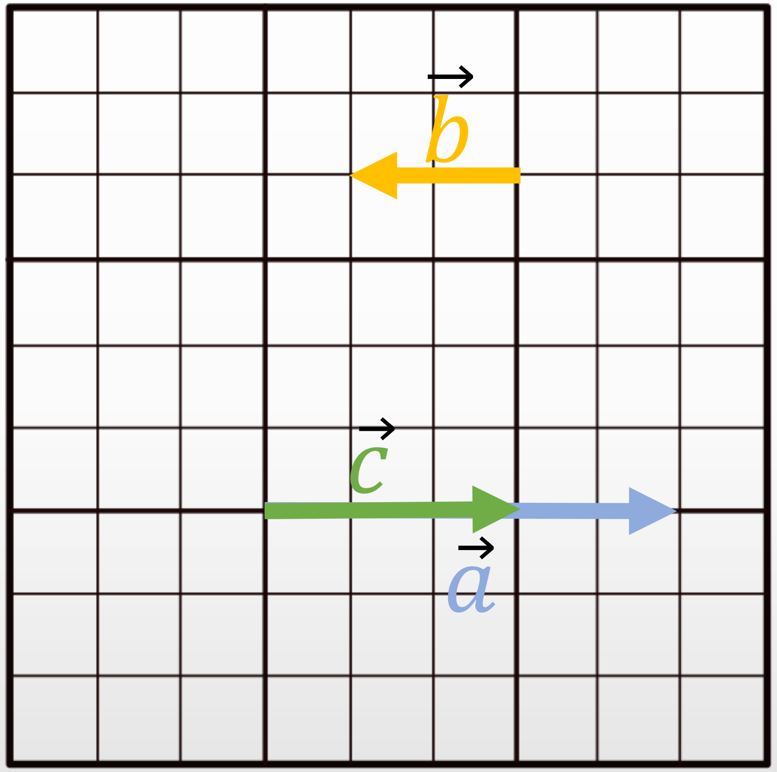
$$\vec{a} + \vec{b} = \vec{c}$$

$$\vec{b} + \vec{a} = \vec{c}$$

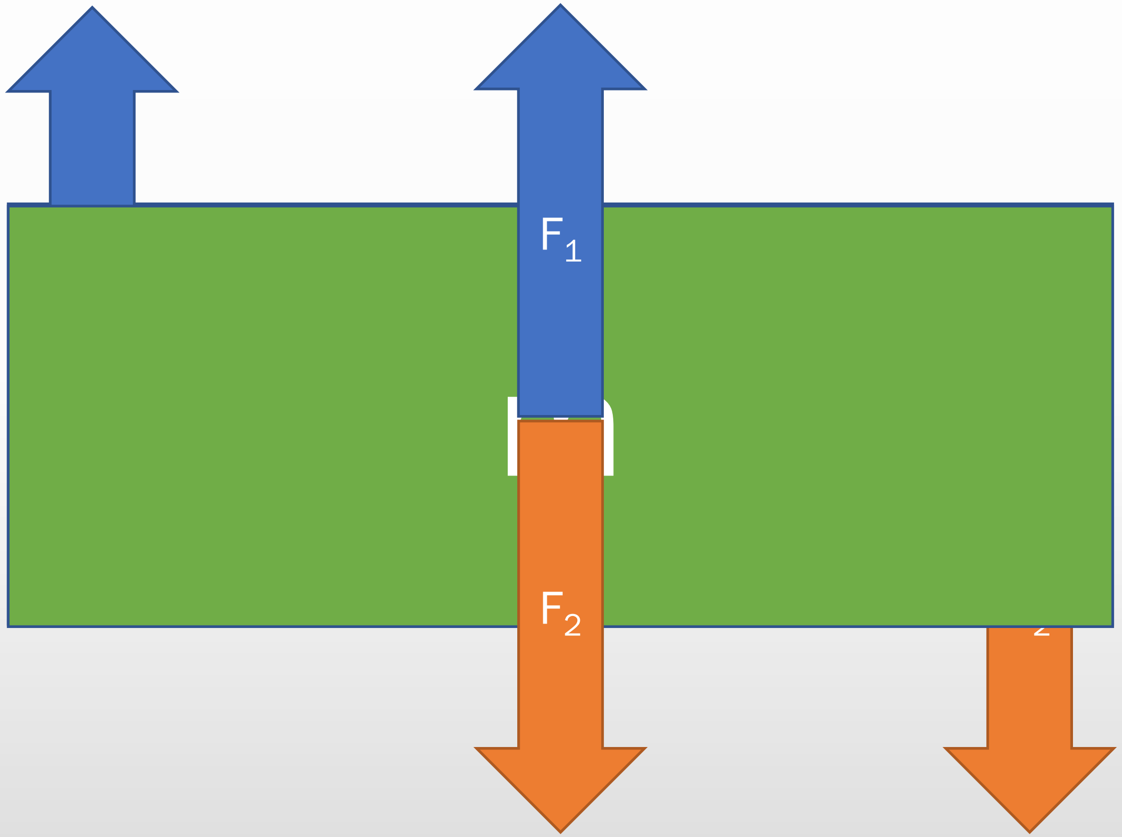
$$|\vec{c}| = |\vec{a}|^2 + \left|\vec{b}\right|^2 - 2|\vec{a}|\left|\vec{b}\right| \cos \gamma$$

Vectors (addition)





Basic physical concepts – Point of Application



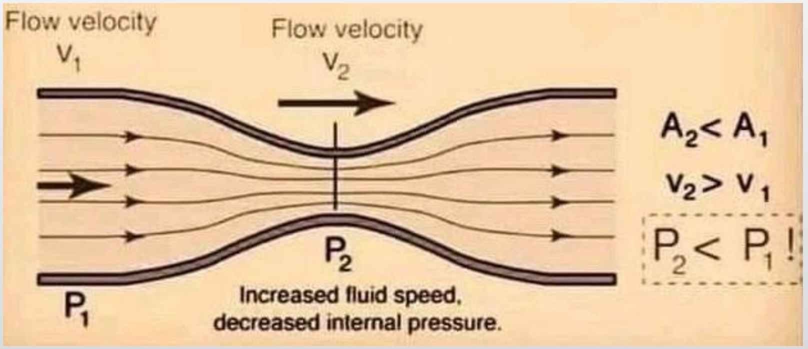
Bernoulli equation

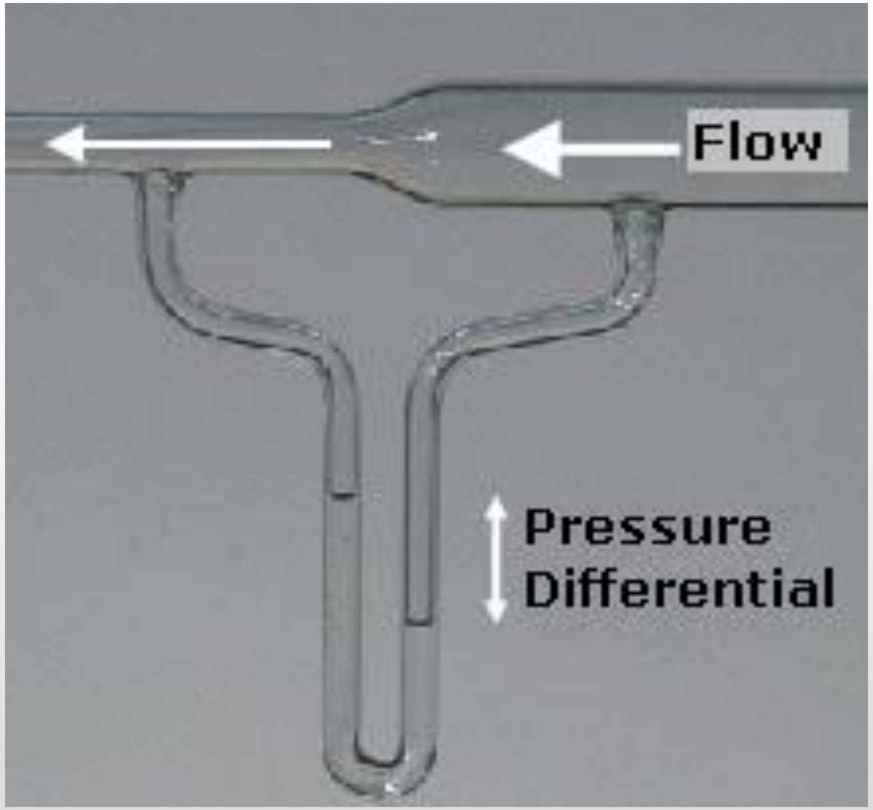
the speed of a moving fluid increases (liquid or gas), the pressure within the fluid decreases

Along the flow line of a given fluidum, velocity and pressure are inversely proportional

$$p + \frac{1}{2}\rho v^2 + \rho h g = const$$

Daniel Bernoulli
(1700-1782)





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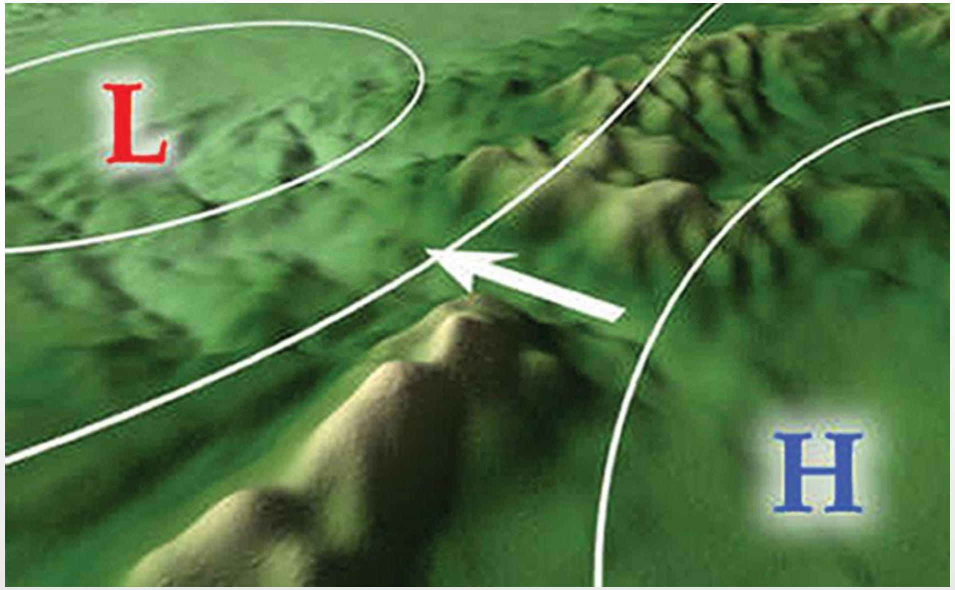
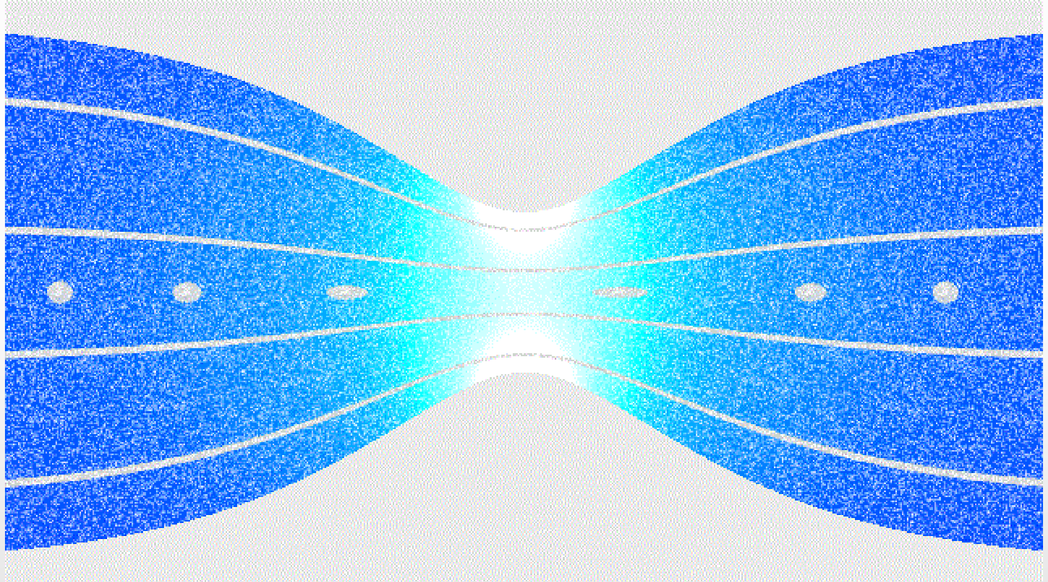
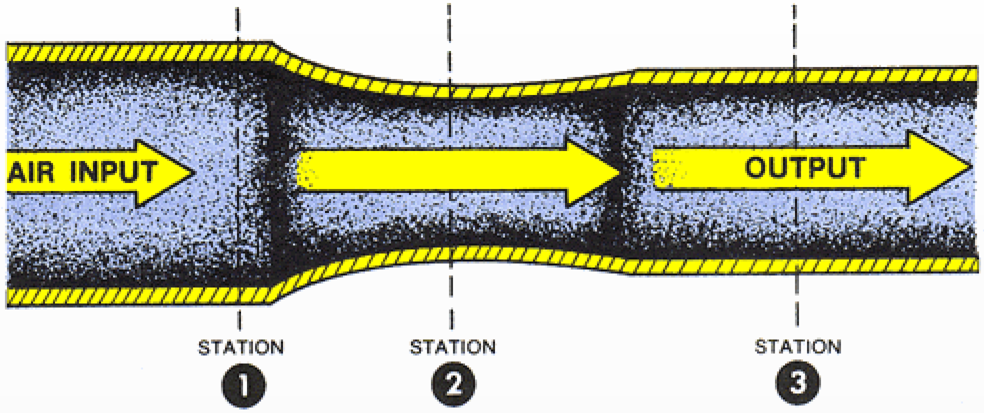
Venturi effect

$$\boxed{\frac{A_1}{A_2} = \frac{v_2}{v_1}}$$

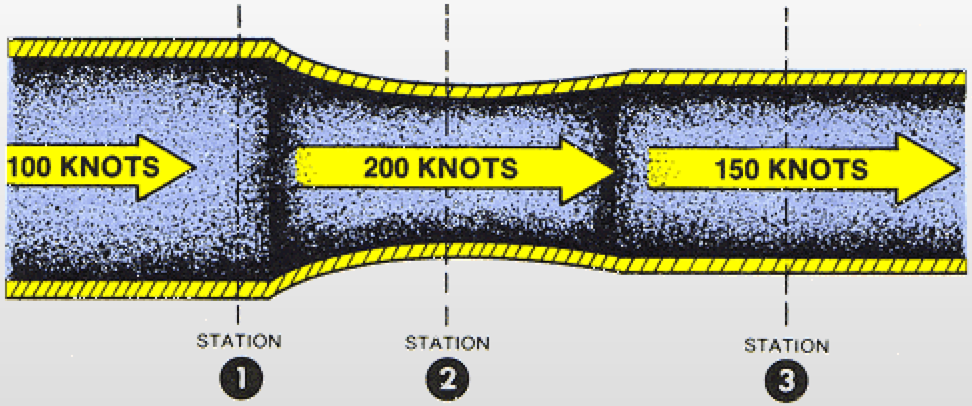




Venturi effect



Flow through a tube.



Vanturi effect.

$$p_1 - p_2 = \frac{\rho}{2}\left(v_2^2 - v_1^2\right)$$

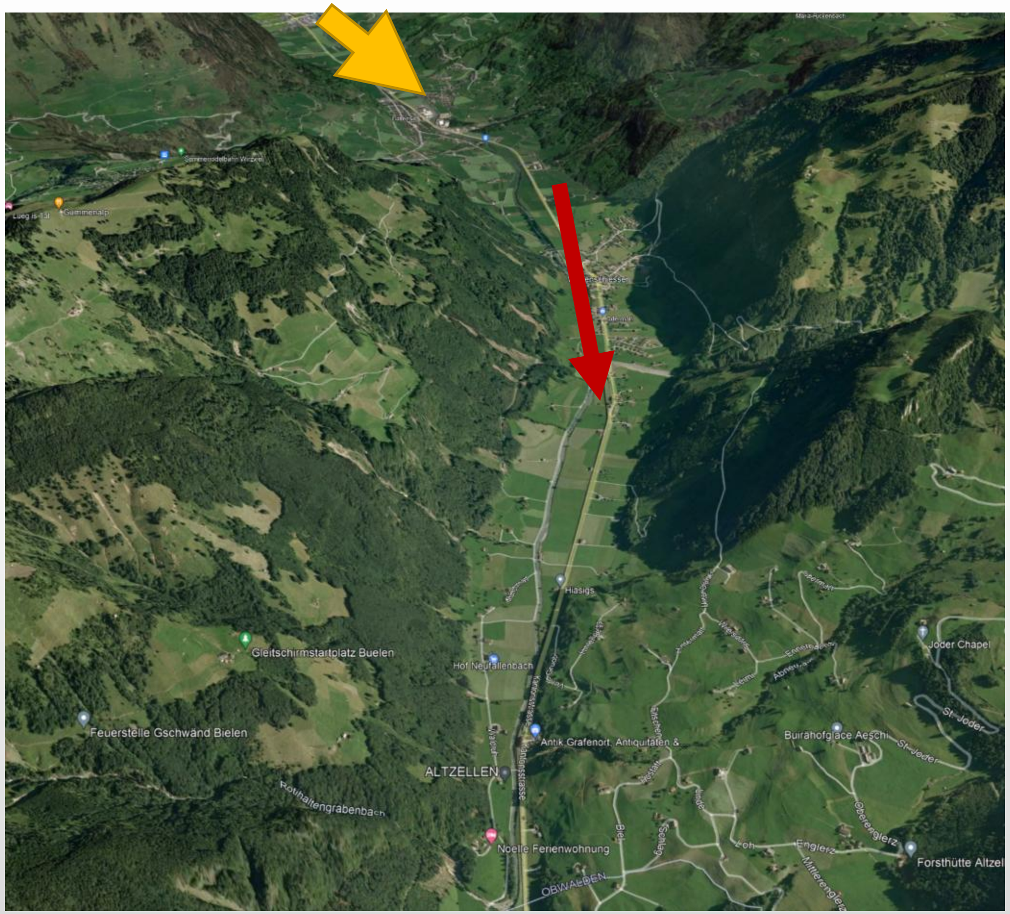
$$\boxed{\frac{A_1}{A_2} = \frac{v_2}{v_1}}$$

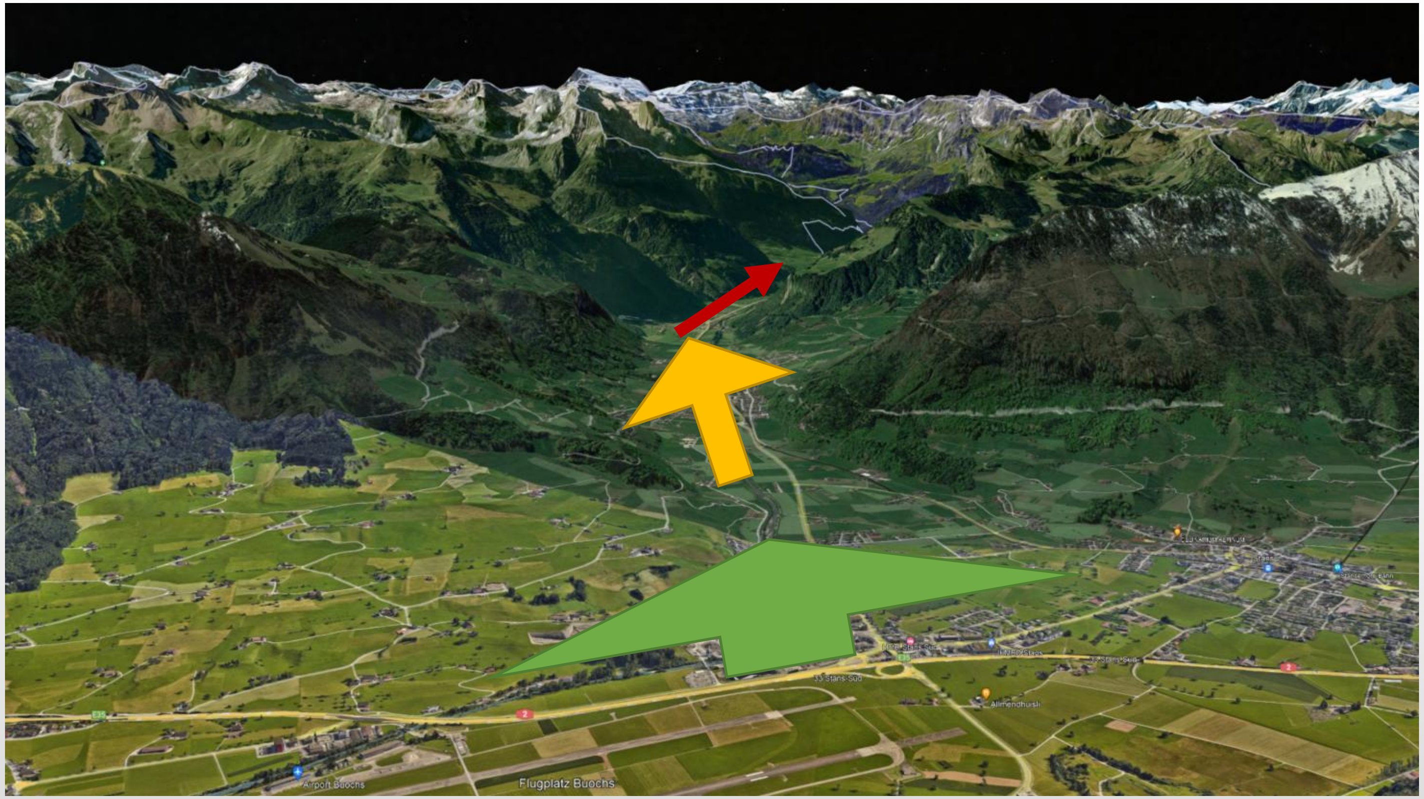

Giovanni Batista Venturi
(1746-1822)

http://www.dynamicflight.com/aerodynamics/basics
/

Venturi effect

$$\boxed{\frac{A_1}{A_2} = \frac{v_2}{v_1}}$$





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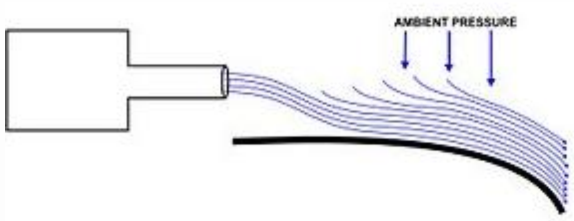
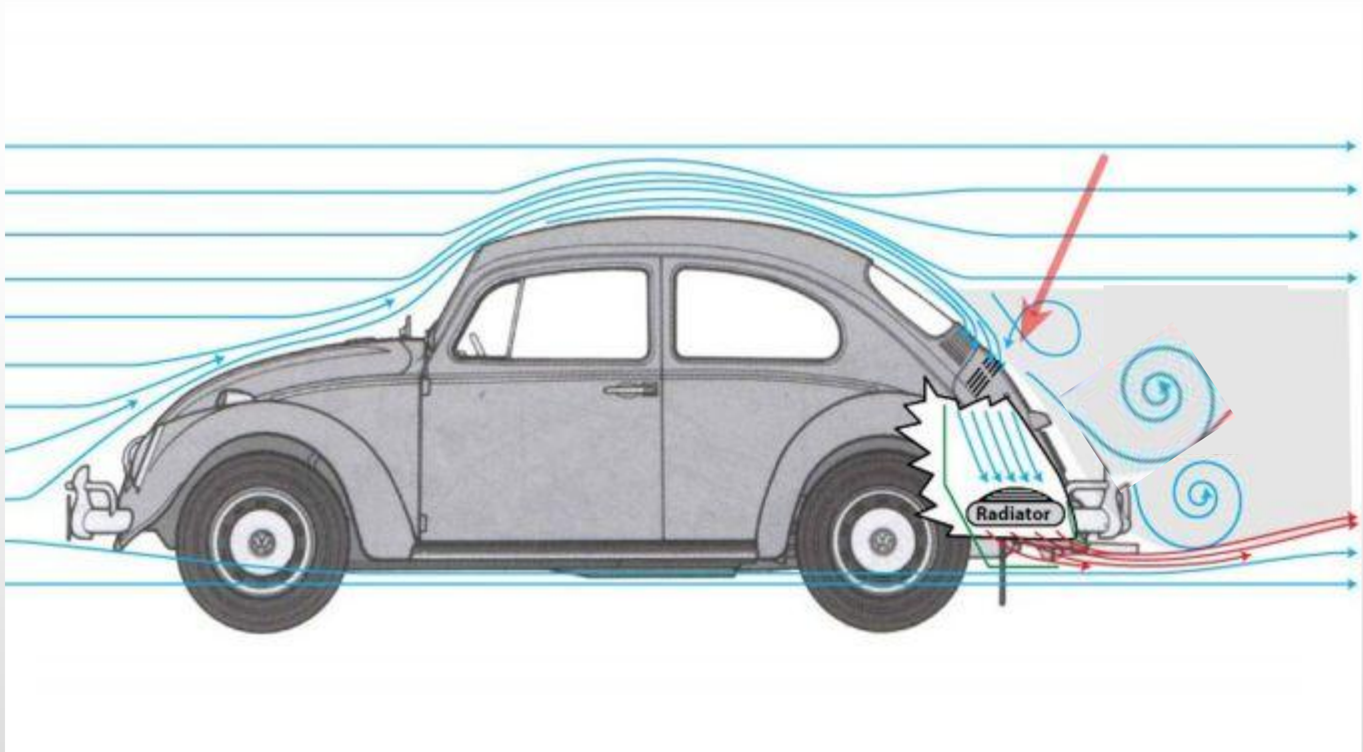
Coanda effect





http://www.dynamicflight.com/aerodynamics/basics/

Coanda effect

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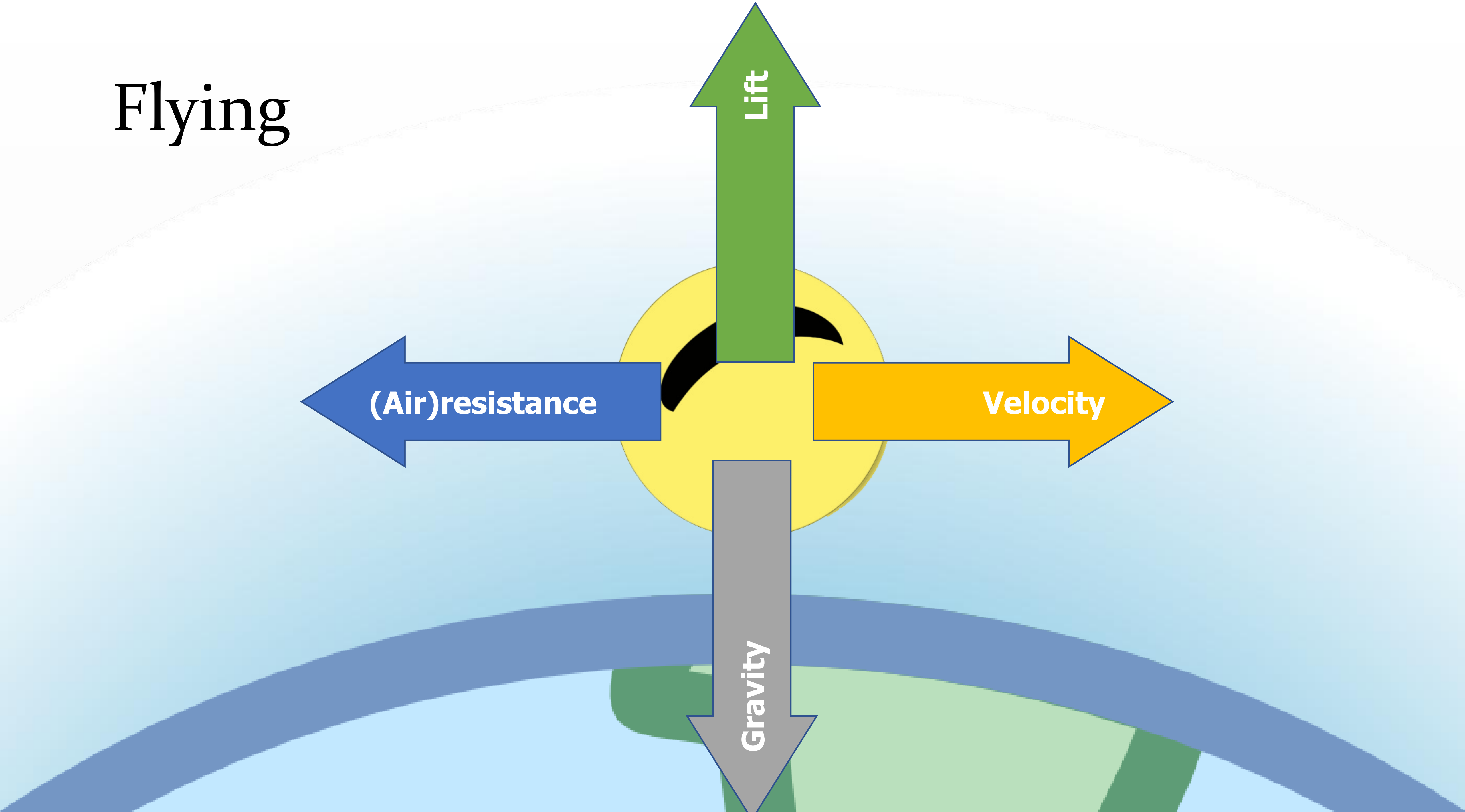
Flying

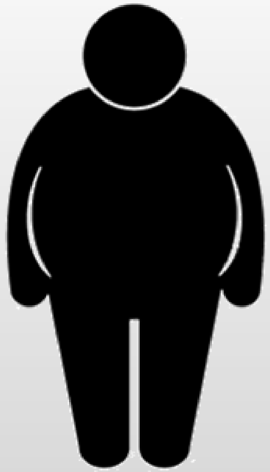


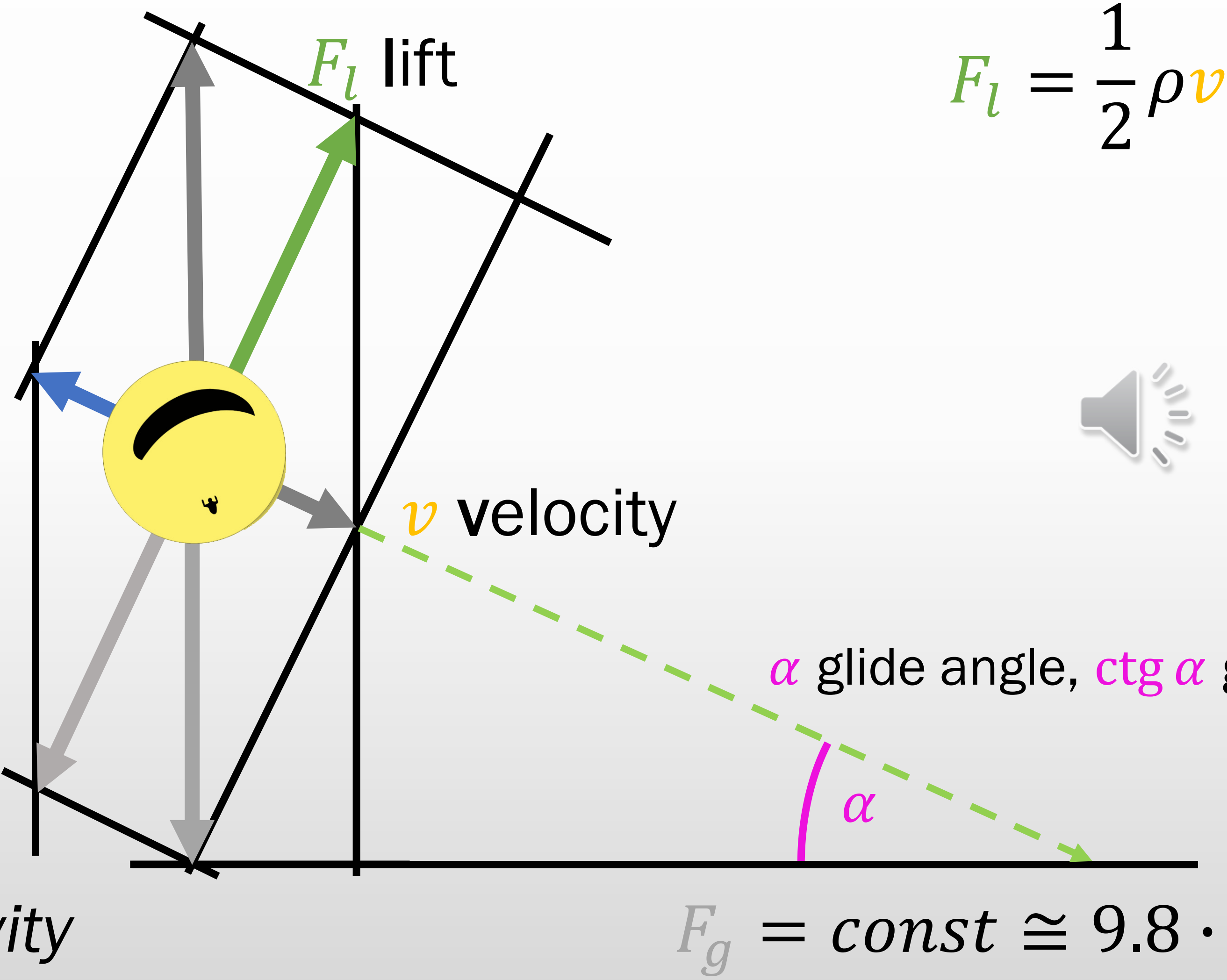
Flying – does it fly?

Flying – forces acting on a flying body

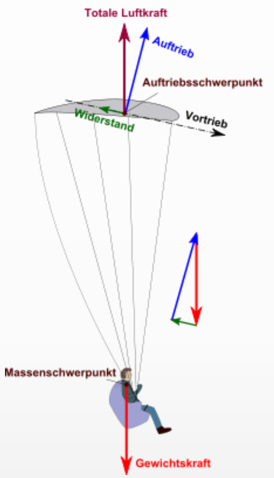
$$F_d = \frac{1}{2}\rho v^2 C_D A$$

F_d
(Air)resistance
(*drag*)





$$F_l = \frac{1}{2}\rho v^2 C_L A$$



$$F_g = const \cong 9.8 \cdot m$$

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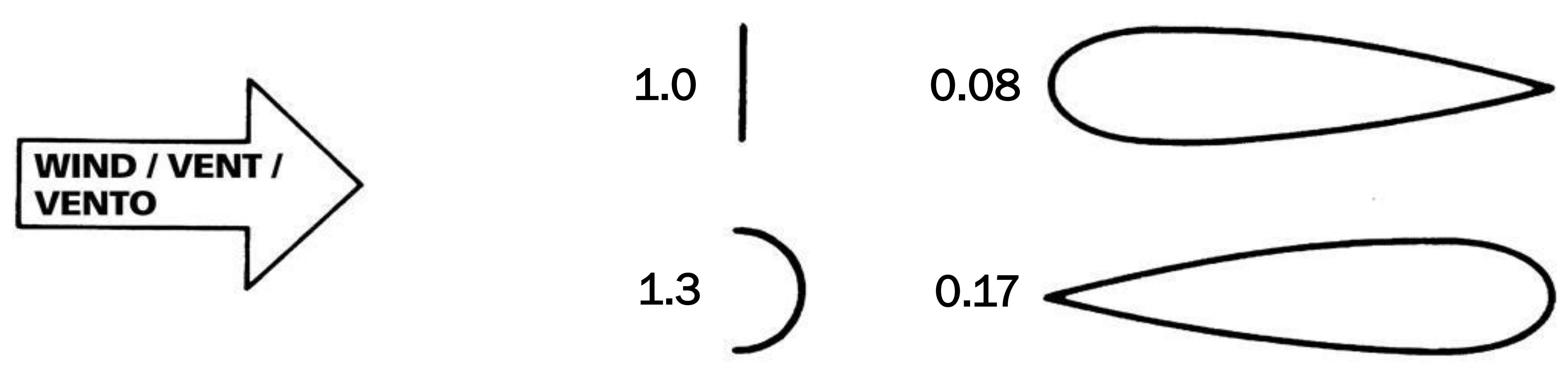
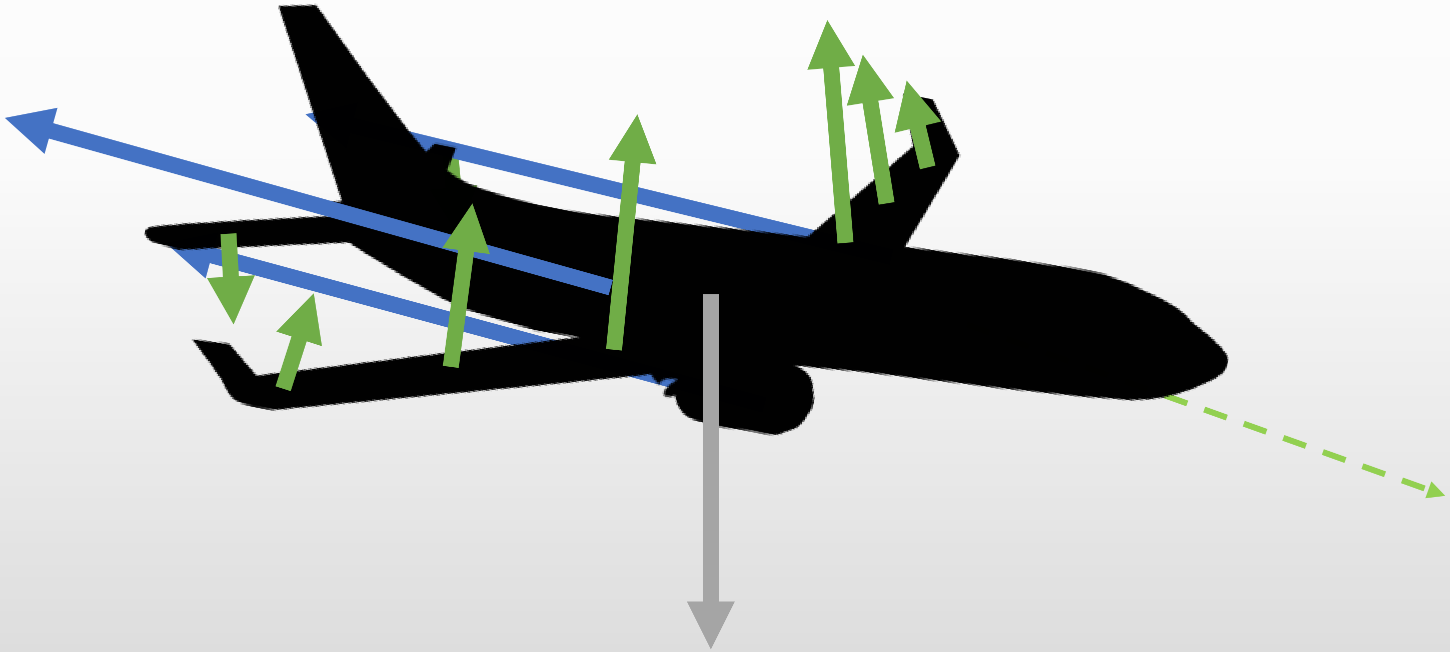
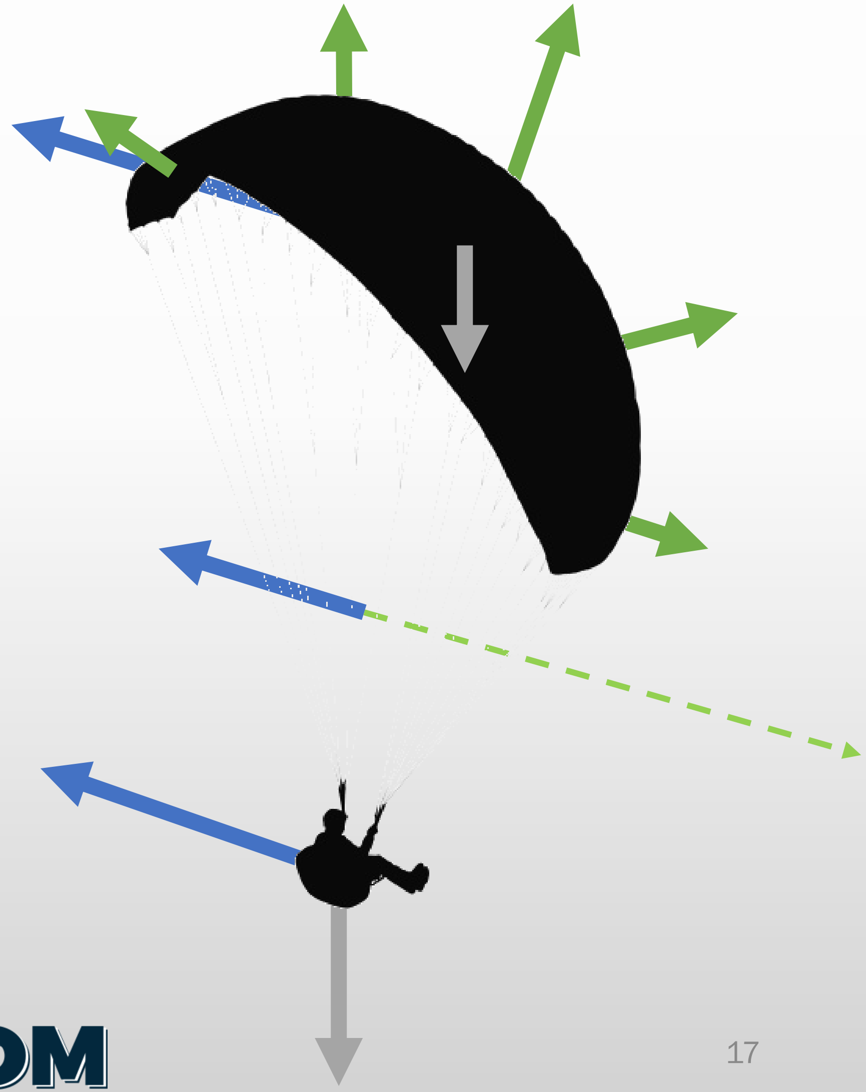
Flying – magnitude of Lift and Drag

$$F_d = \frac{1}{2}\rho v^2 C_D A \qquad F_l = \frac{1}{2}\rho v^2 C_L A$$



Flying – in reality





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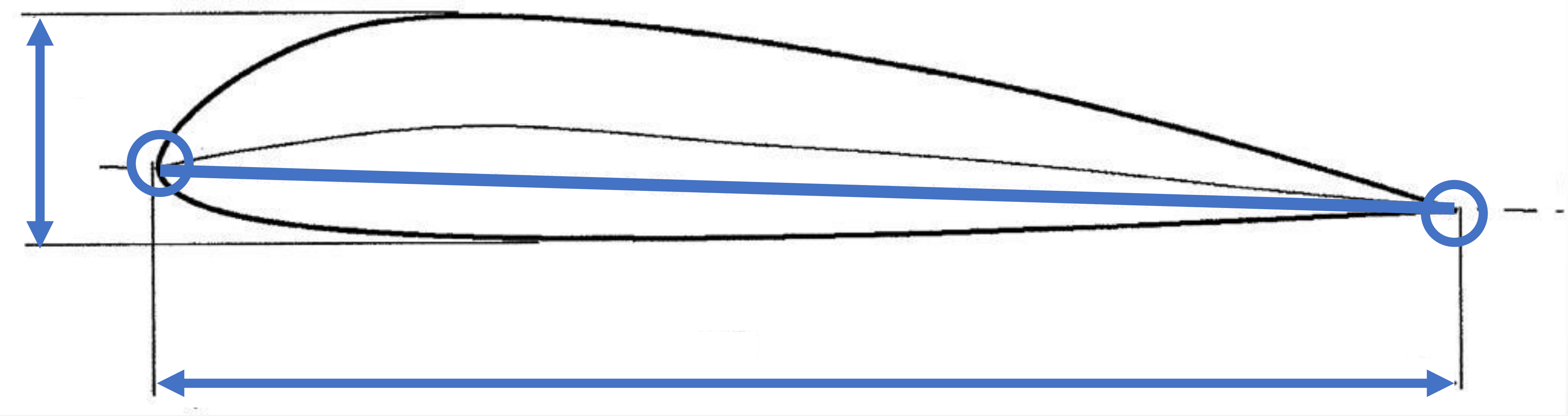
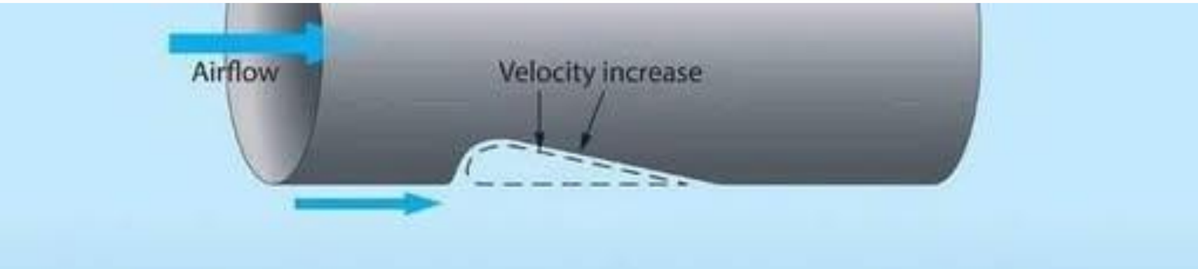
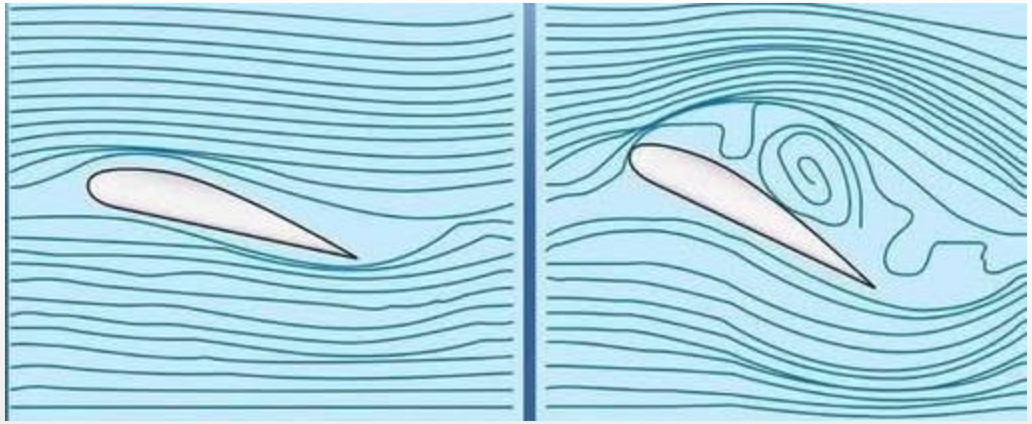
The airfoil profile (wing)

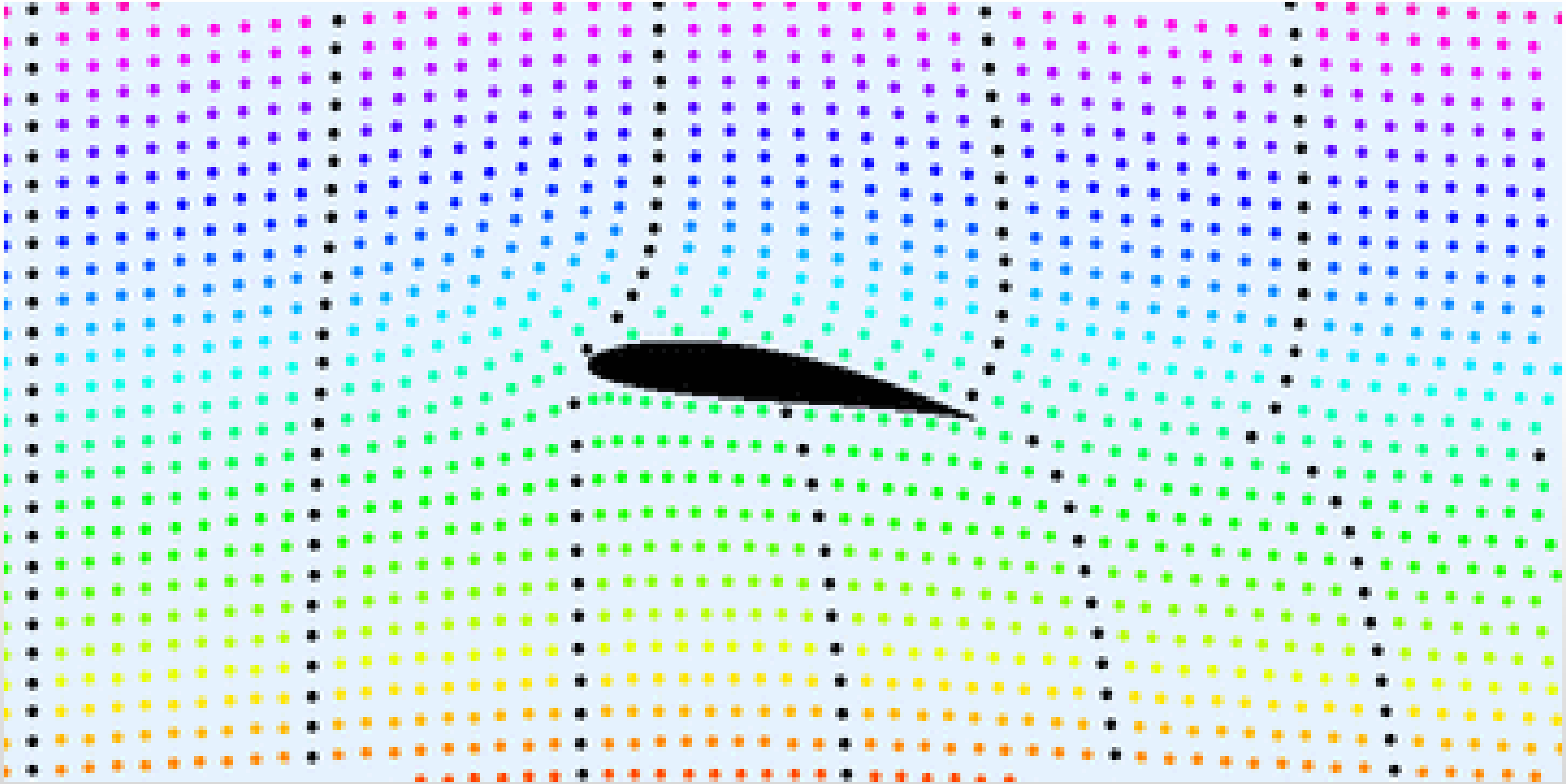


The airfoil profile (wing)





Flying – Flow around an airfoil



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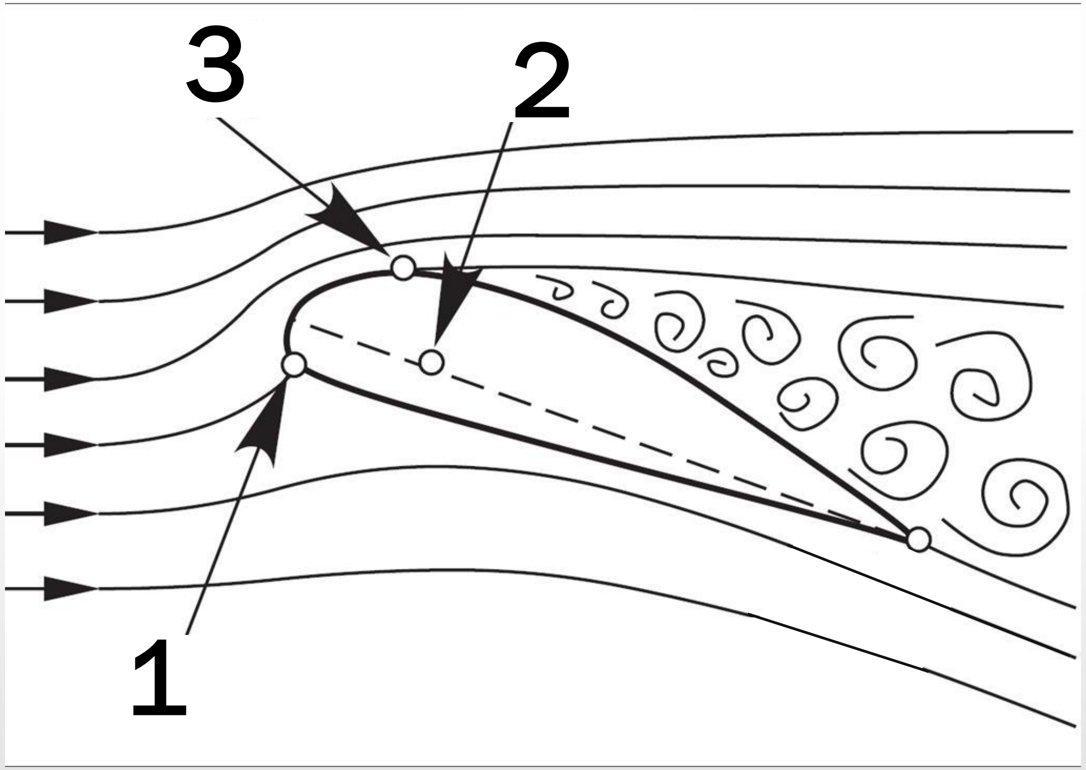
The airfoil profile (wing)

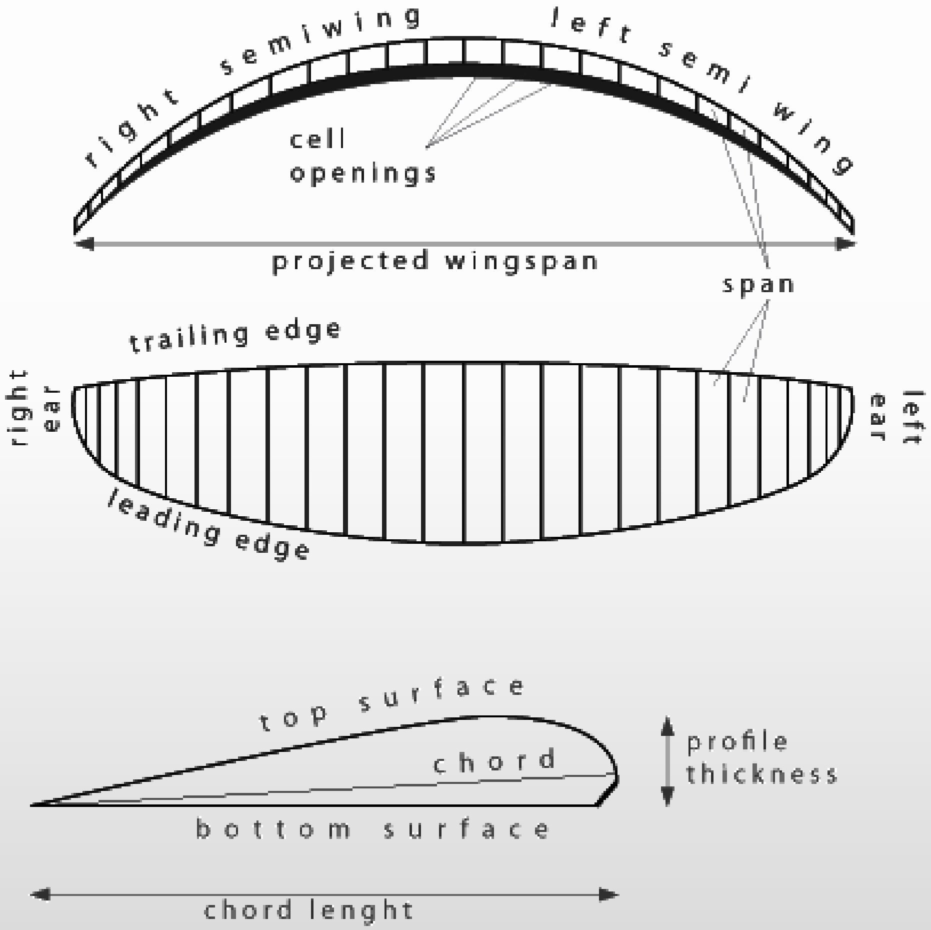


1, Stagnation point

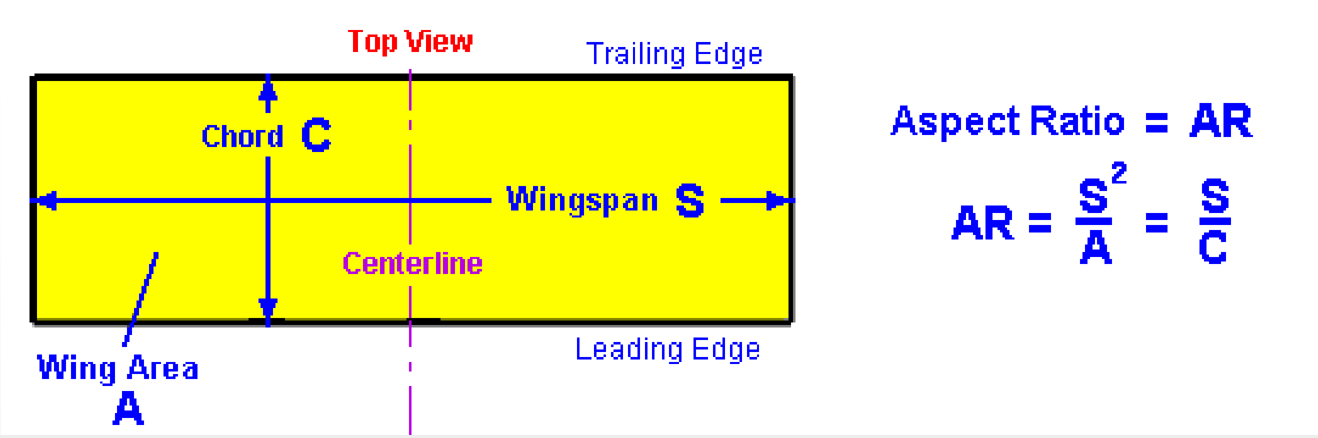
2, Center of Pressure

3, Separation point

The airfoil profile (wing)



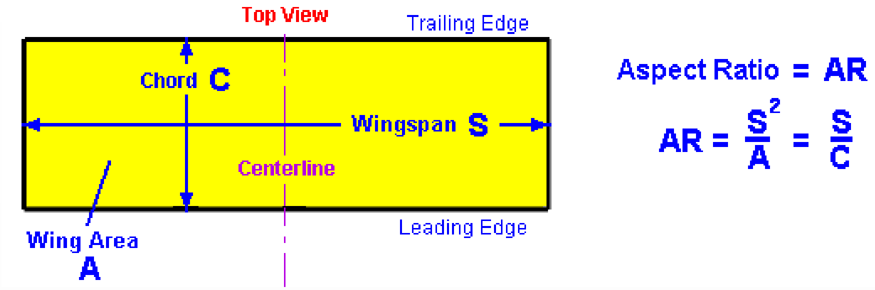
Wing elements viewed from in front, above and a profile section



Modern Intermediate paraglider: AR: 5-6

(hangglider AR: 12)

The airfoil profile (wing)



Nova SuSi (EN-A)
AR: 3.95

Advance Epsilon 6 (EN-B)
AR: 5.15

BGD Cure (EN-C)
AR: 6.75

Ozone Enzo 3 (CCC)
AR: 7.55

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Wing loading

Wing loading = Total weight / Surface area

Total weight: pilot + all equipment

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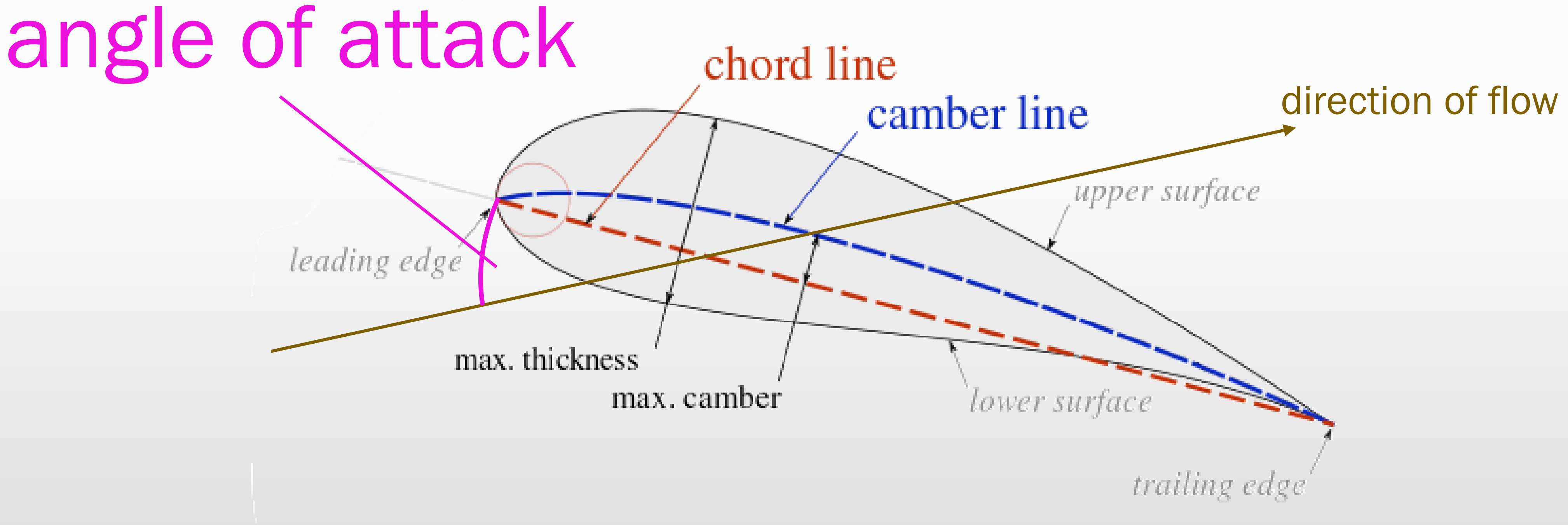
Flying – angle of attack



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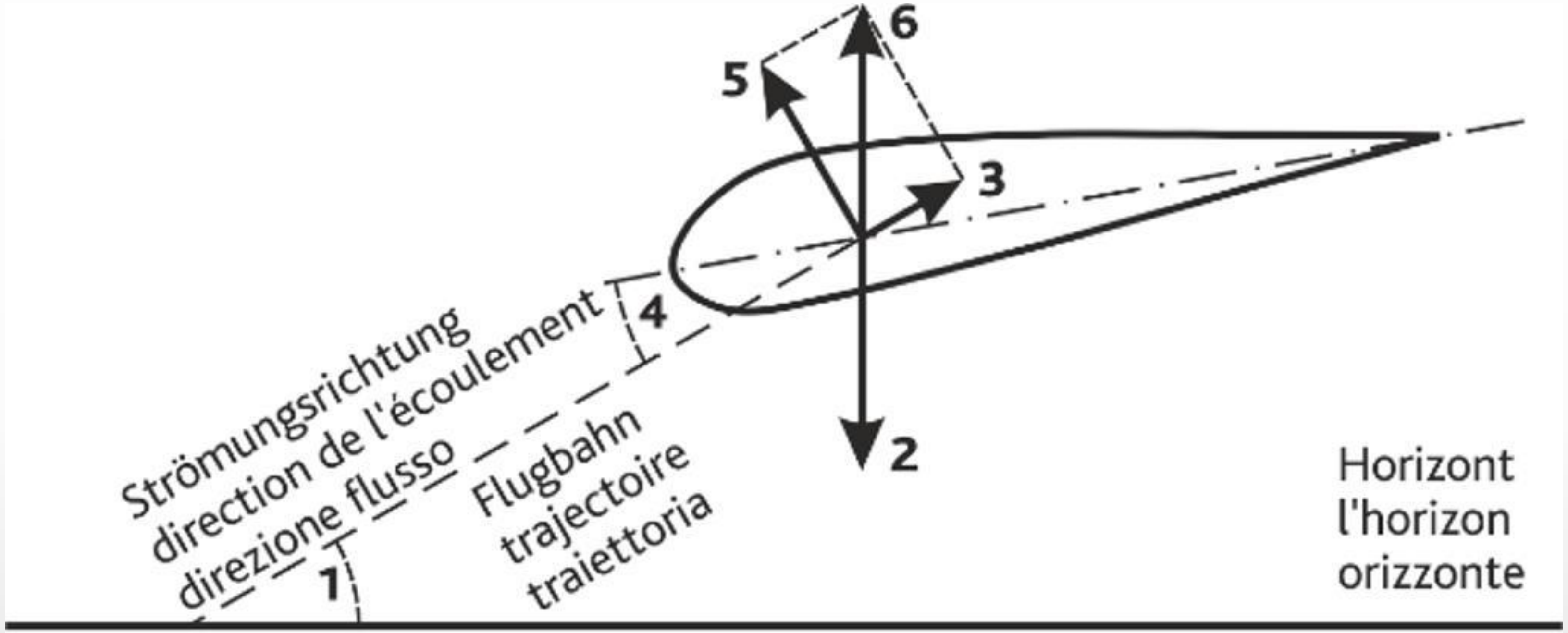
Wing in stable flight



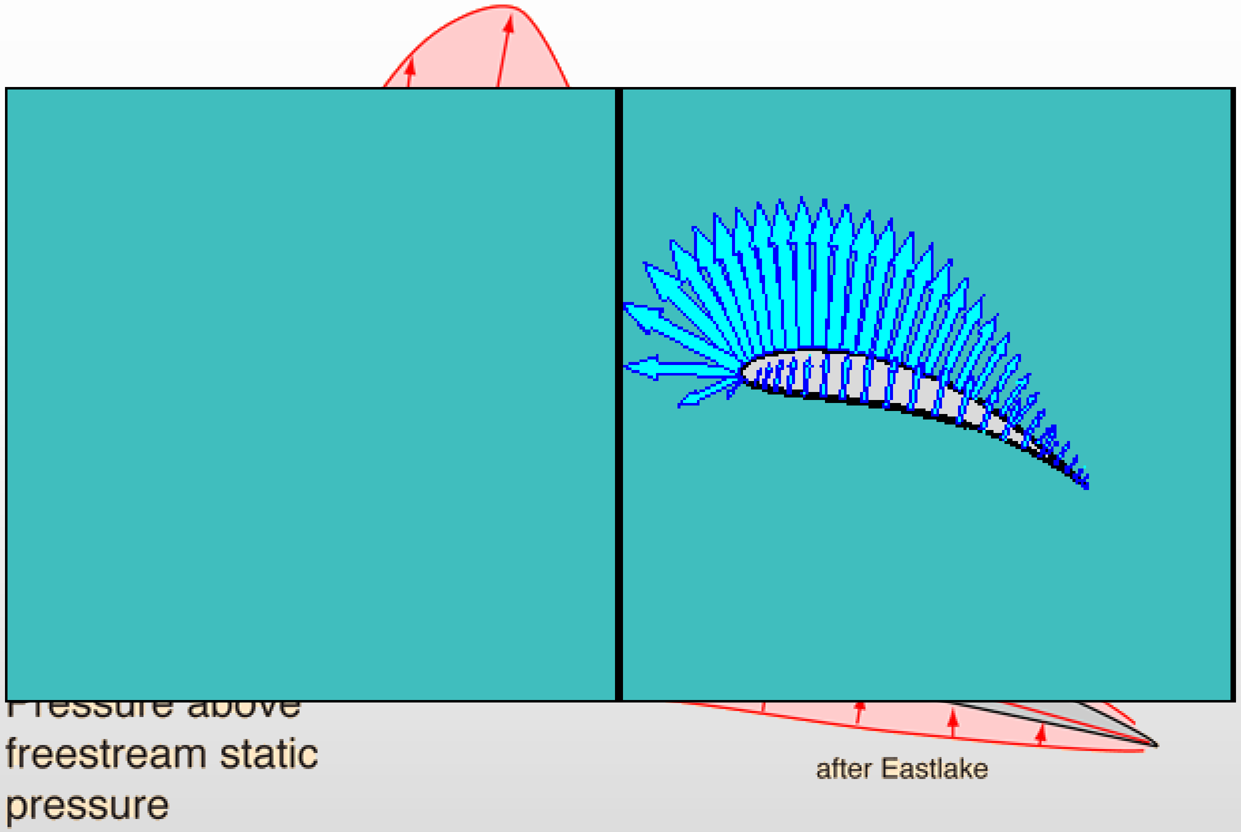
Gleichgewicht der Kräfte im stabilen Gleitflug.
Equilibre des forces en vol plané stationnaire.
Equilibrio delle forze nel volo planato stazionario.

Drag
Lift
Glide angle
Total weight
Resultant aerod. Force
Angle of attack

Flying

Most of the Lift generated at the first third of the wing

2/3 of the lift is generated on the upper surface (1/3 on lower)



Pressure profile around airfoil

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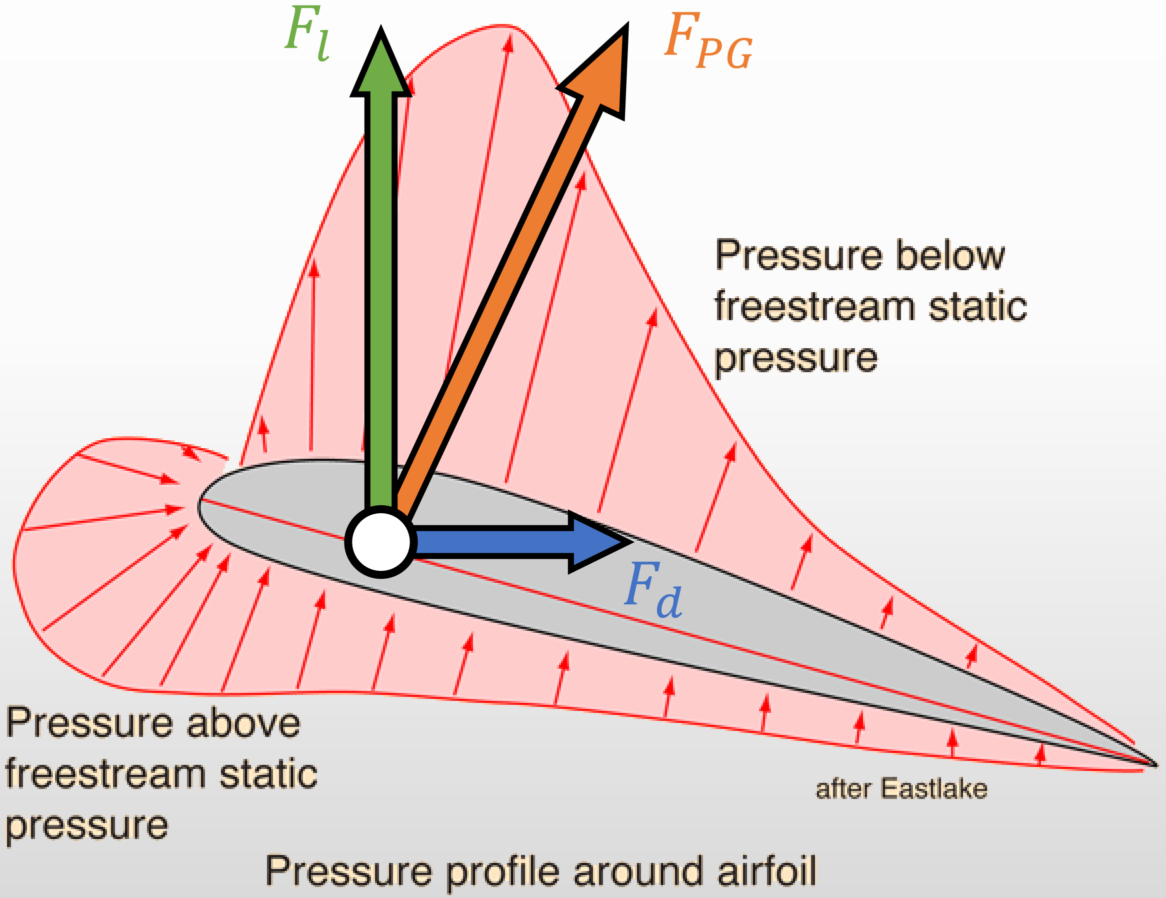
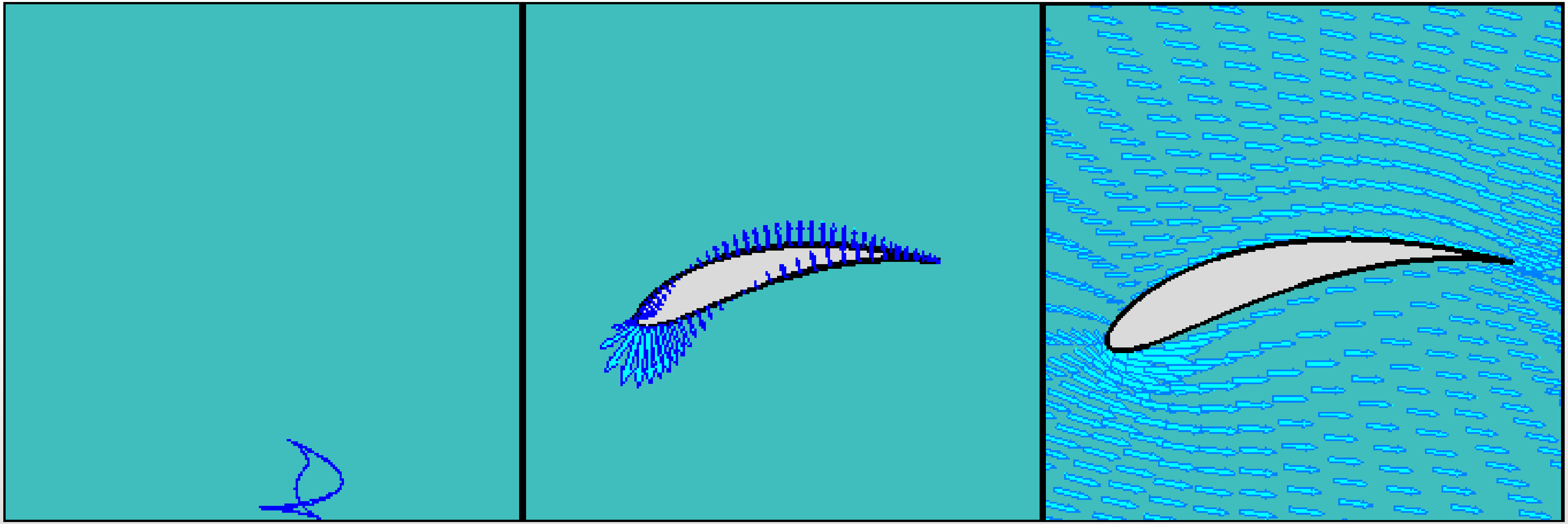
Flying

- Resultant aerodynamic force is not perpendicular to the air flow
- The generated lift will have a drag component which acts to the opposite difection to the flying (same direction as airflow)
  → **Induced drag**



Flying – effect of the AoA on the Lift



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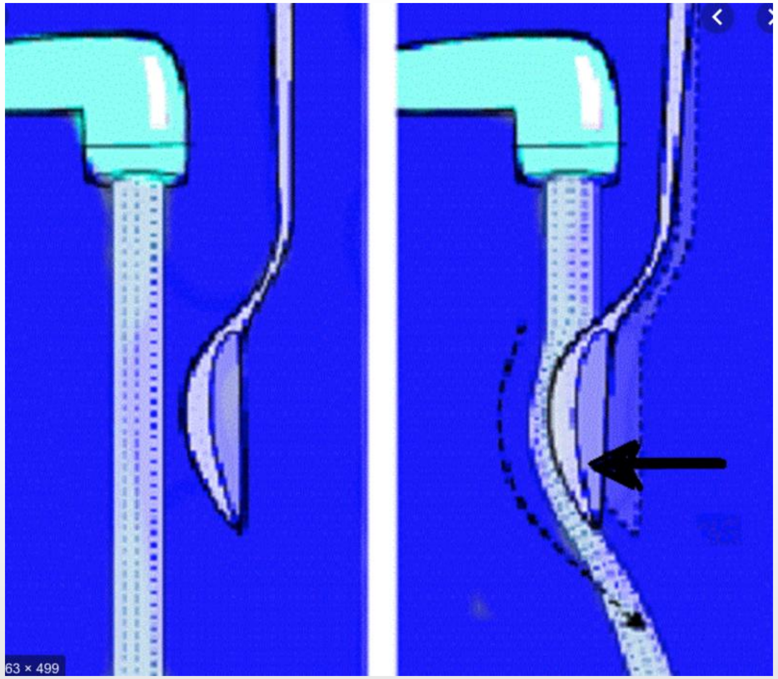
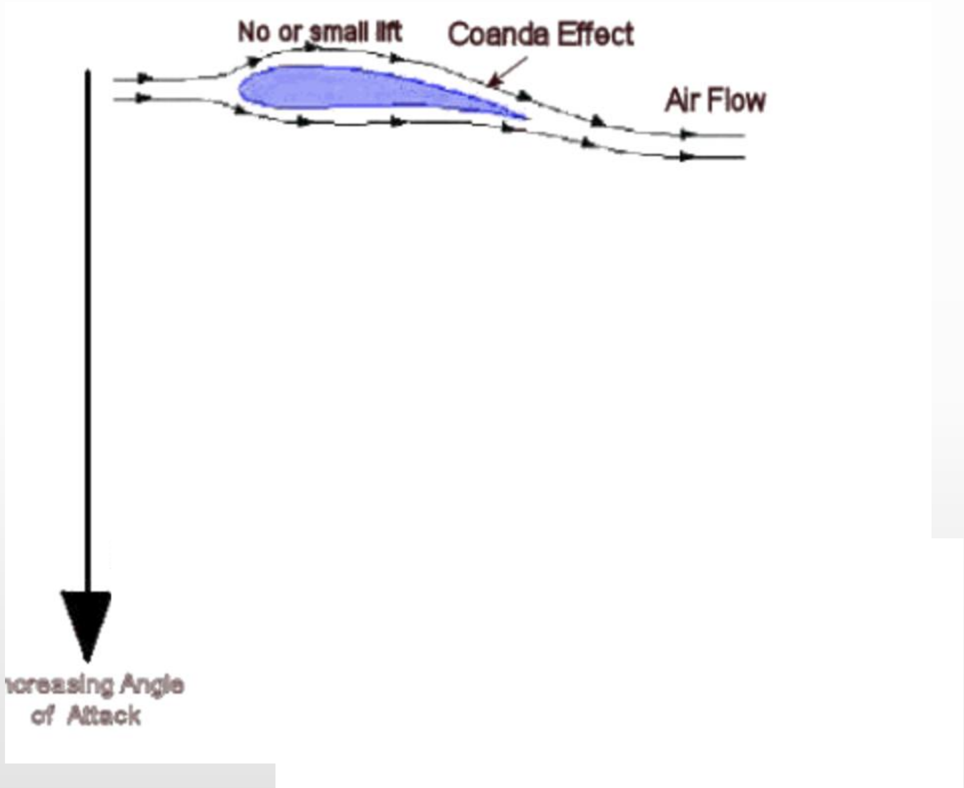
Coanda effect





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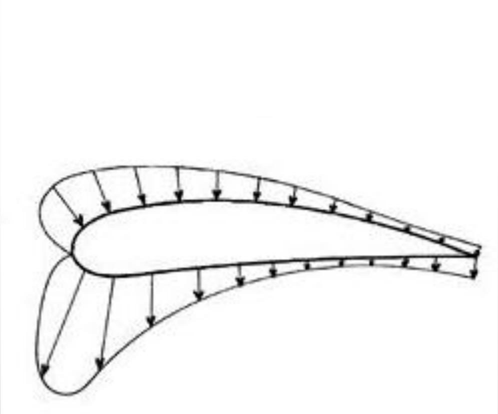
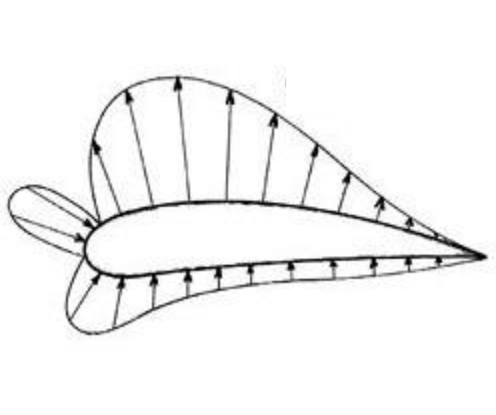
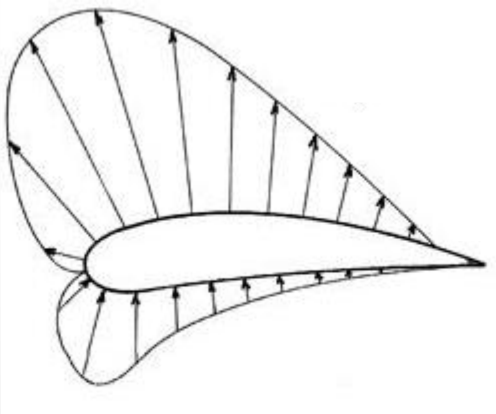
Flying – effect of the AoA on the Lift



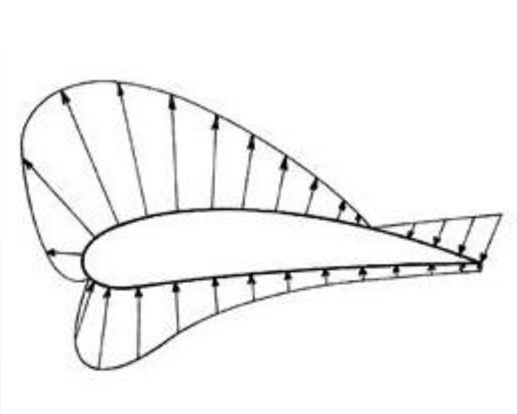
-10°



0°

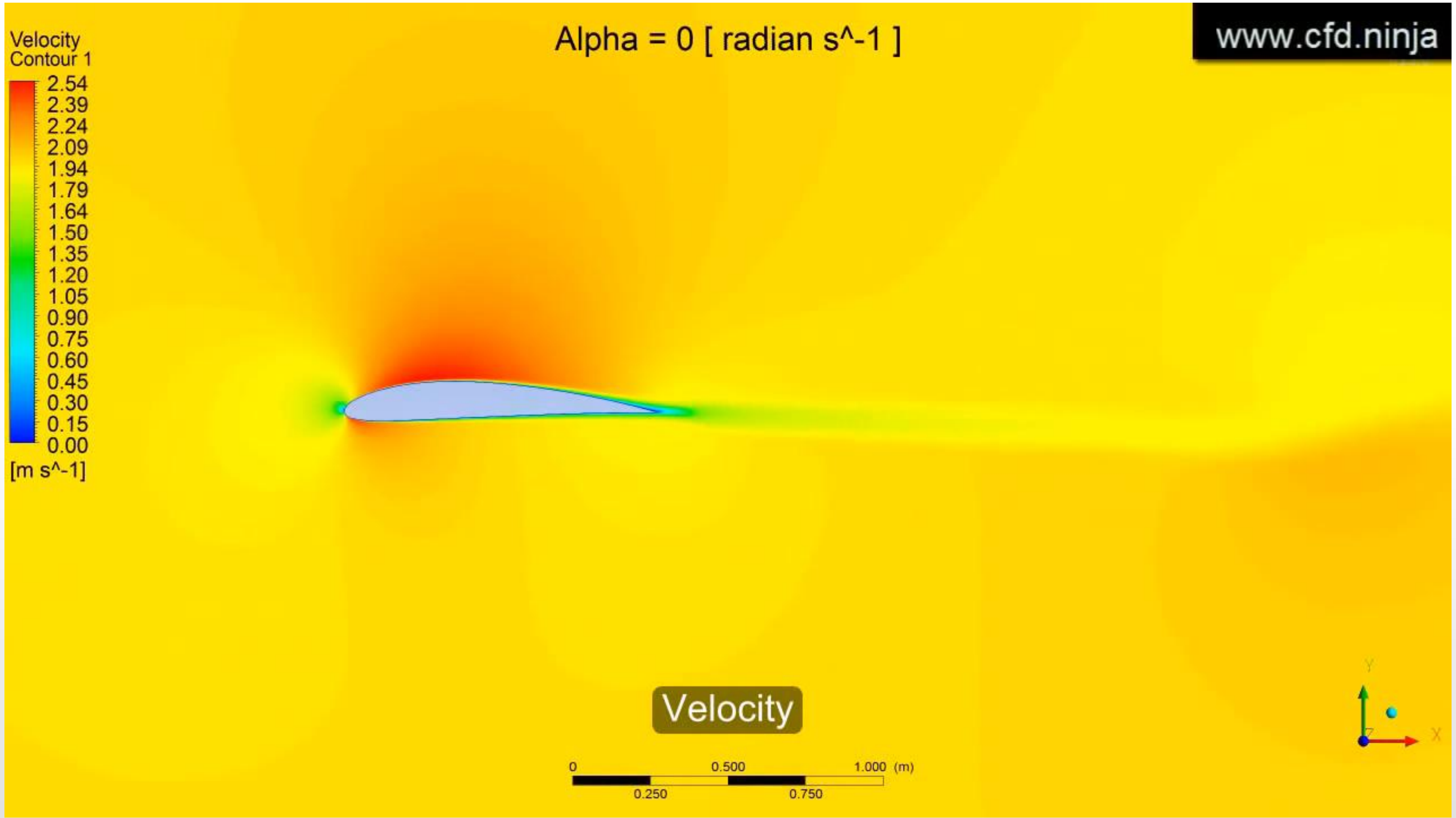


+10°

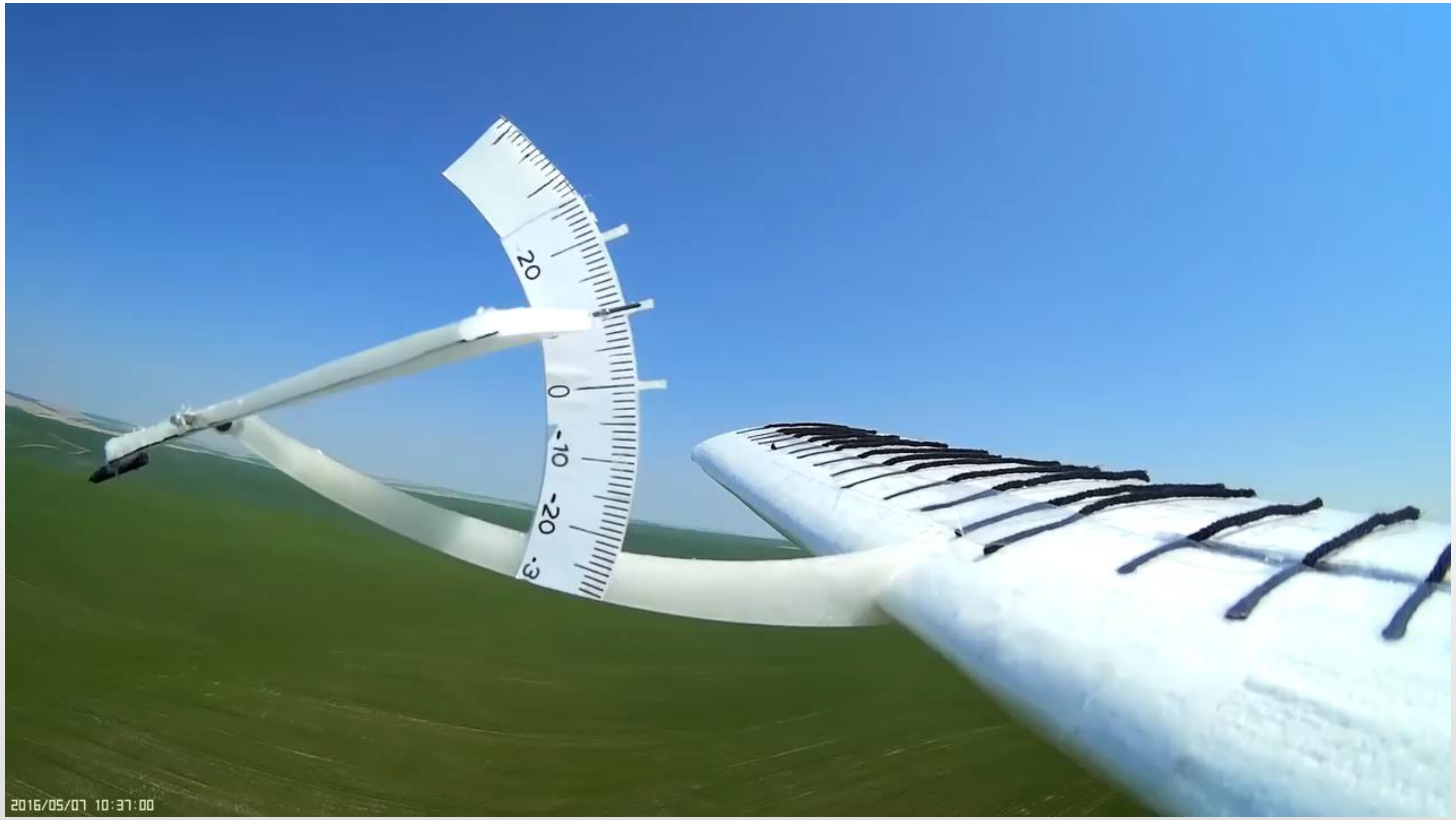


+15-20°

Flying – effect of the AoA on the Lift



Flying – effect of the AoA on the Lift



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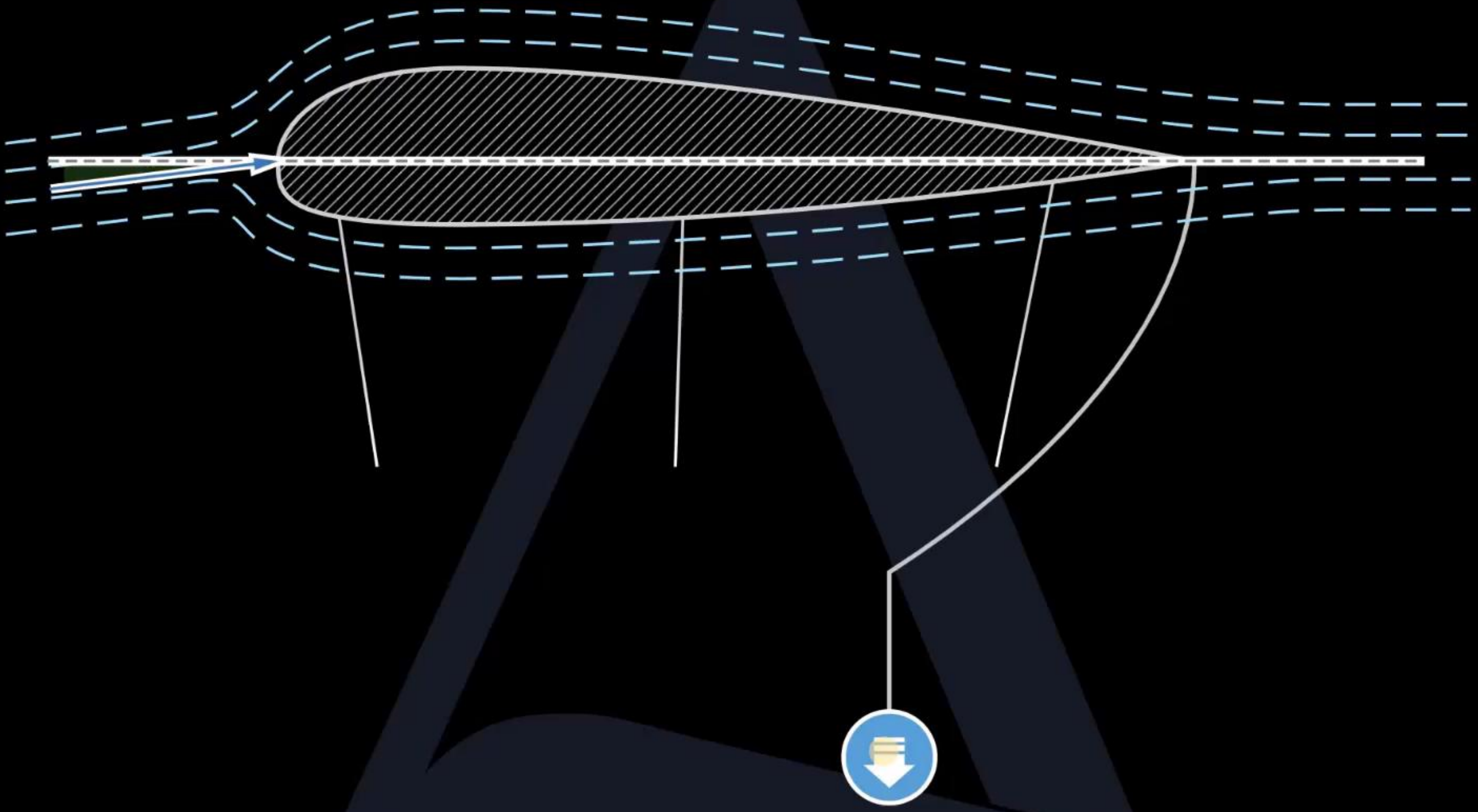
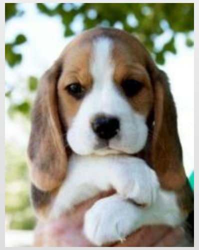


Collapses



Big Ears

Side collapse

Front collapse

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Stalls

Spin

Parachutal stall
(Sackflug)

Fullstall

Front collapse („Frontstall)”

- Angle of Attack suddenly reach a negative value (almost) on the entire wing
- No Lift generation, Profil drag increases
- Pilot swings forward → loading on the rear lines increases
- → angle of attack increases, (could be supported with a symmetrical break impulse)
- Angle of Attack goes back to the „normal value” automatically, the wing opens up by itself

„frontstall” : Grammatically not correct.
Stall happens at big AoAs

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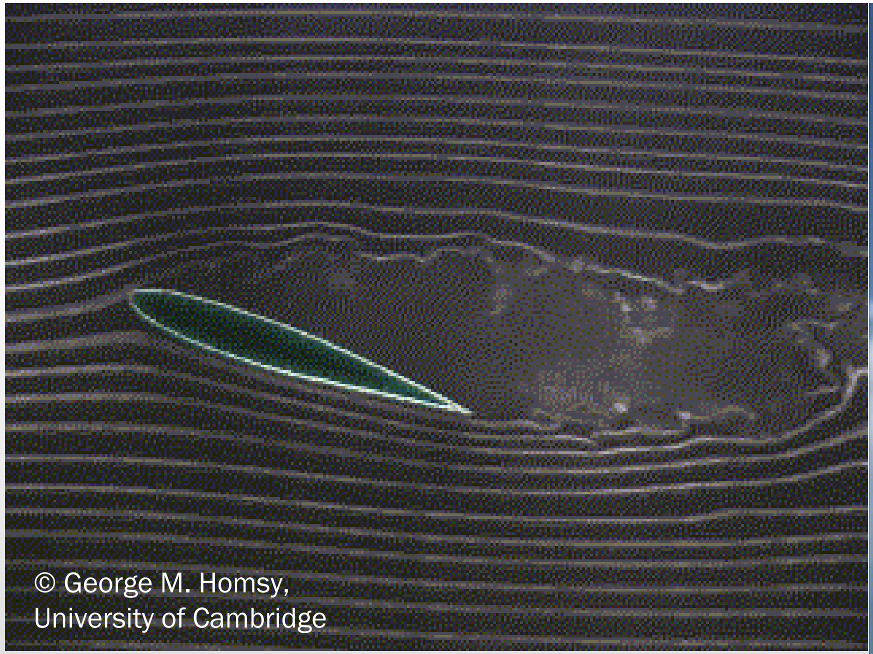
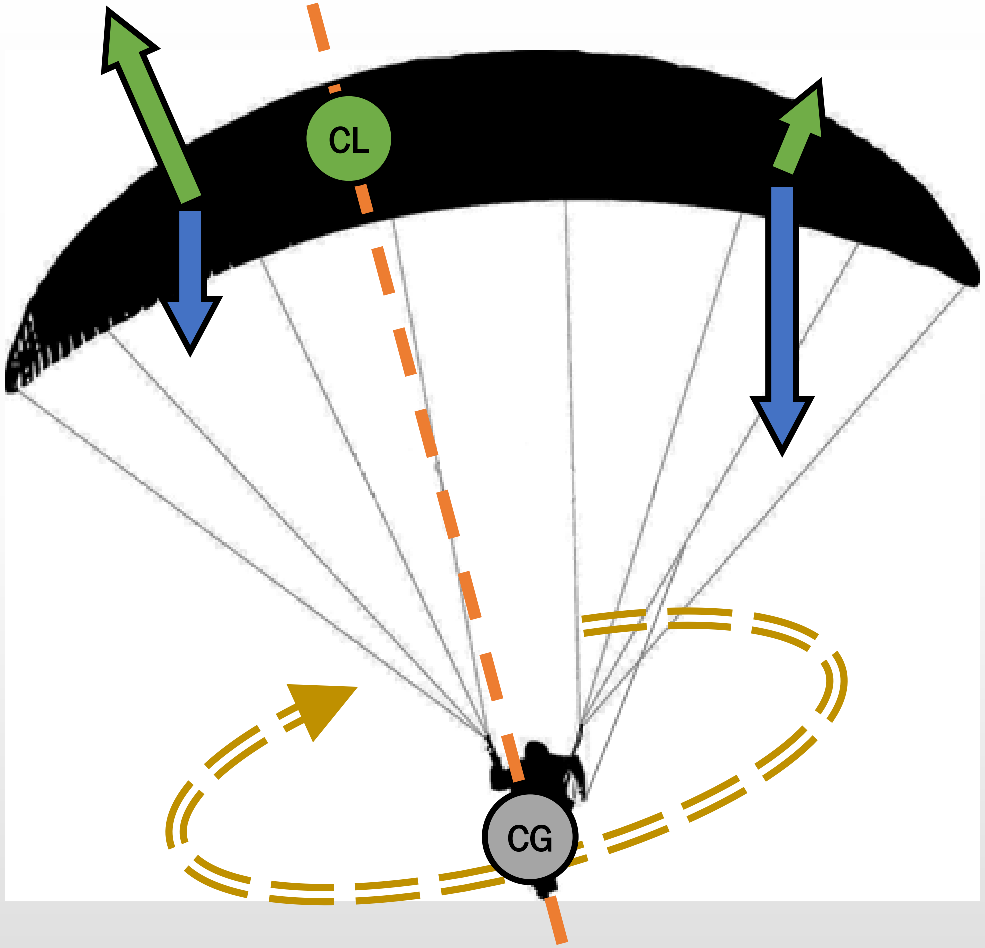
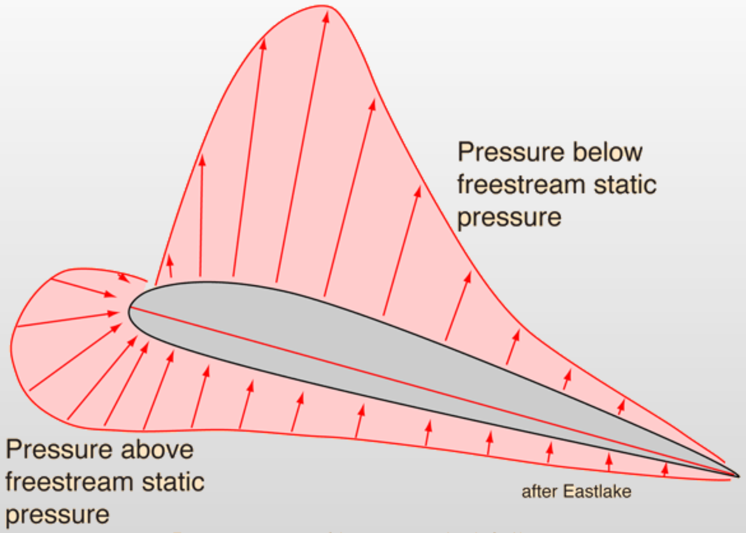
Assymetric stall (Spin)





Collapse vs. Stall

- Movement of the stagnation point
- Change in pressure distribution
- Reduced inner pressure



Pressure profile around airfoil

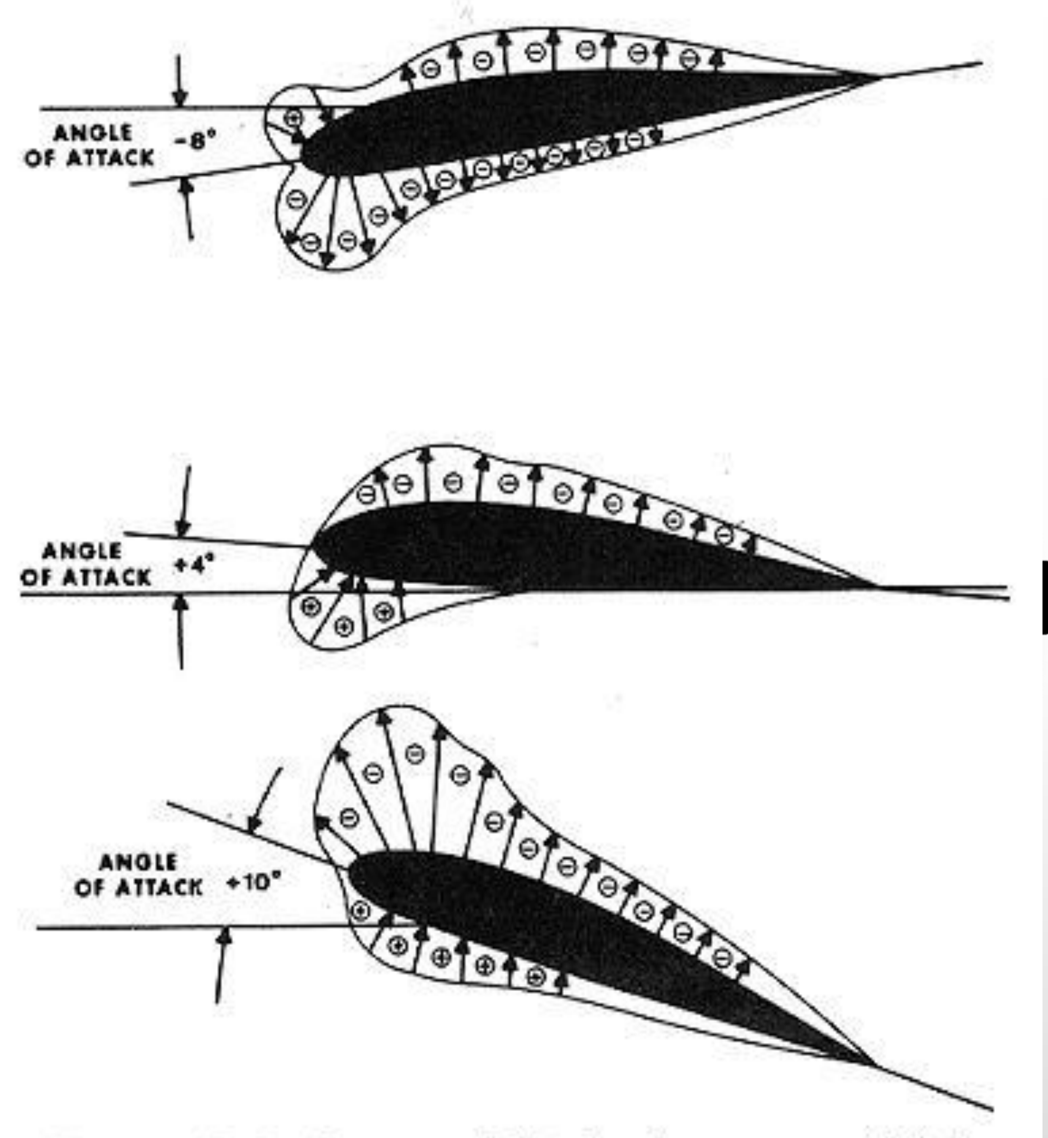


Figure 17–7 Pressure Distribution on an Airfoil

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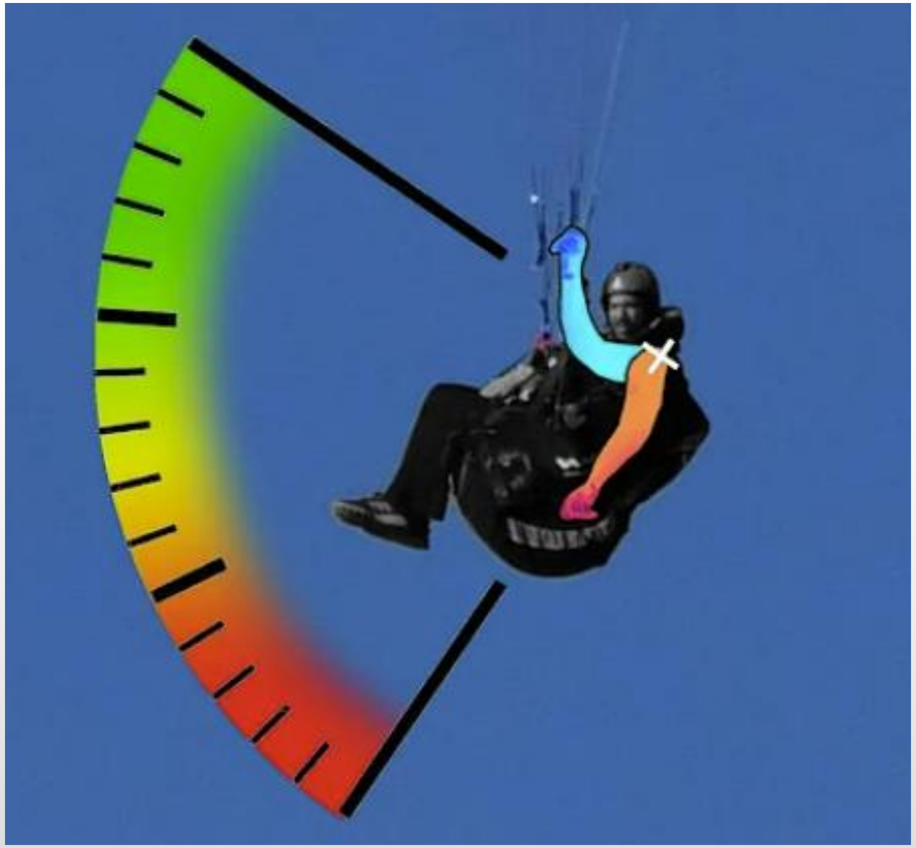
EPIC2

Effect of the Angle of Attack

Too small → collapse

Too big → Stall

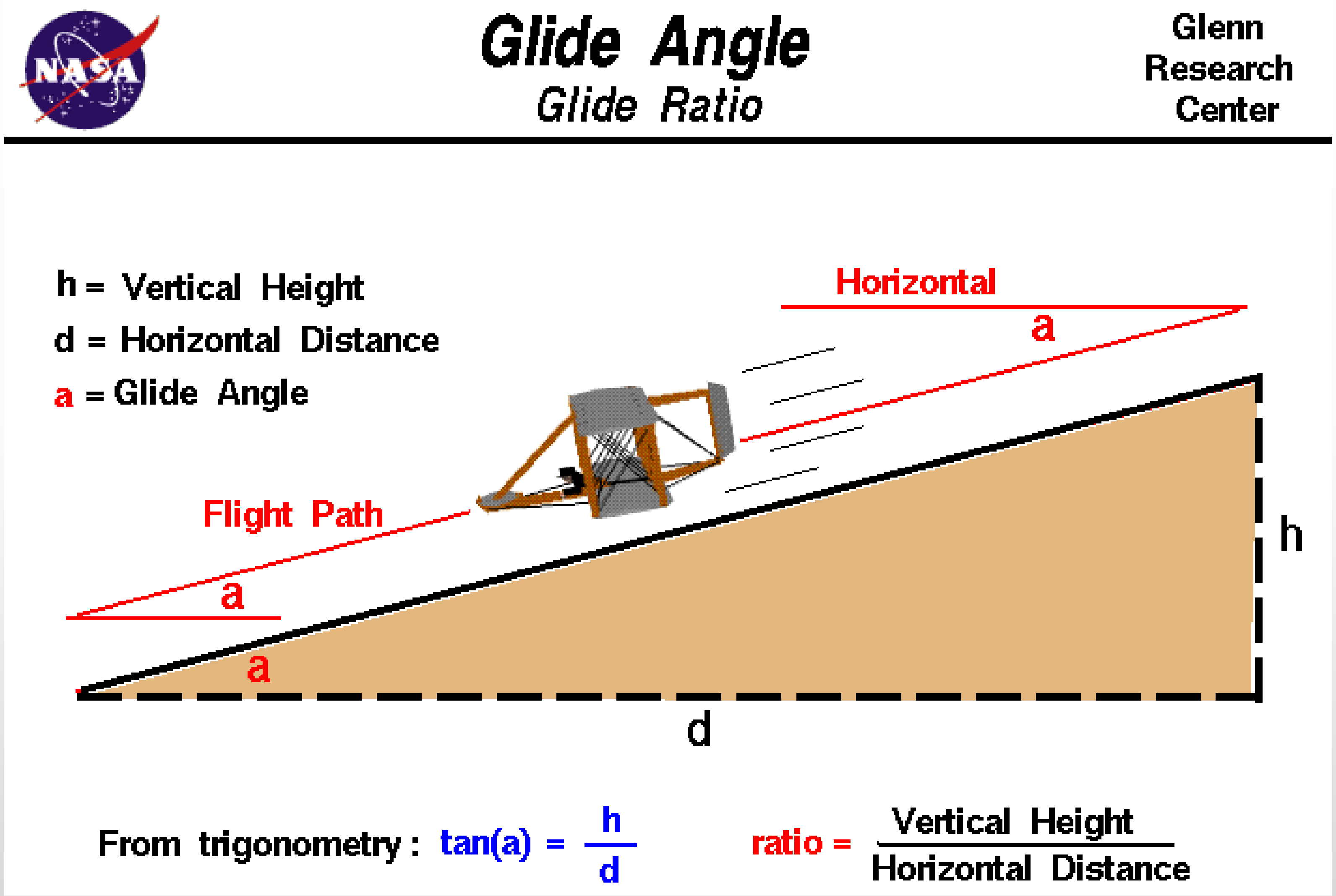
Active flying: keeping the AoA in a certain range so the glider can fly



Kahoot time!

- https://kahoot.it

Flying – Glide ratio



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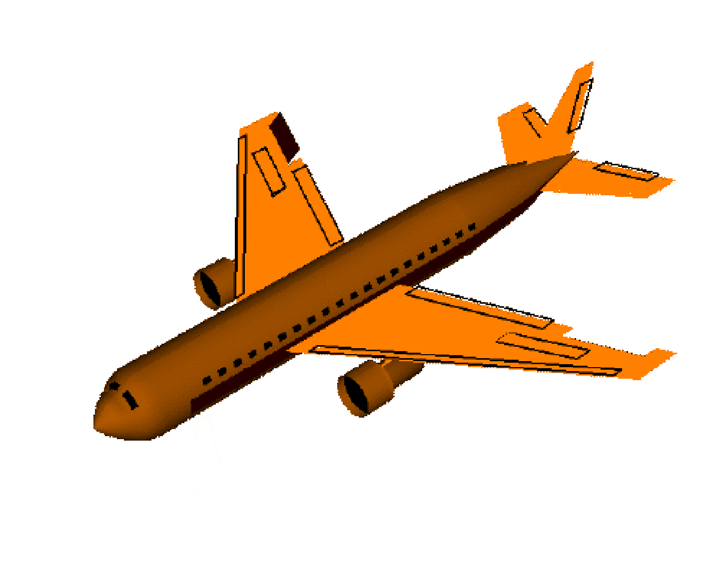
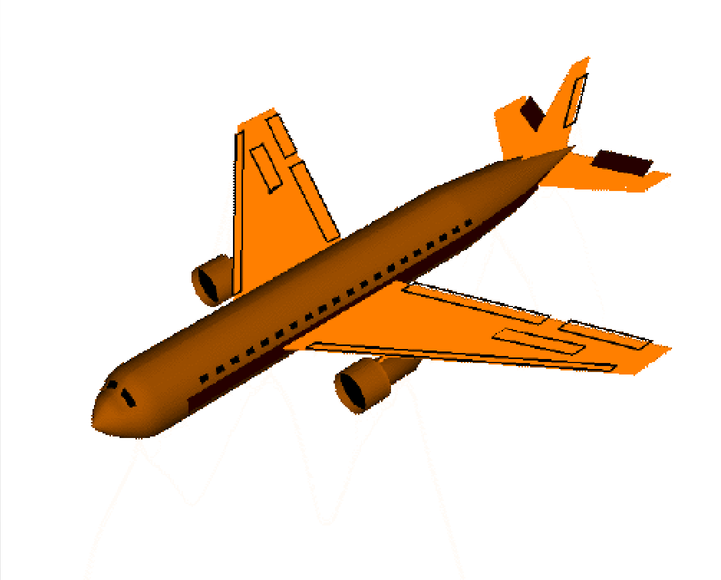
Flying - movements along the different axes

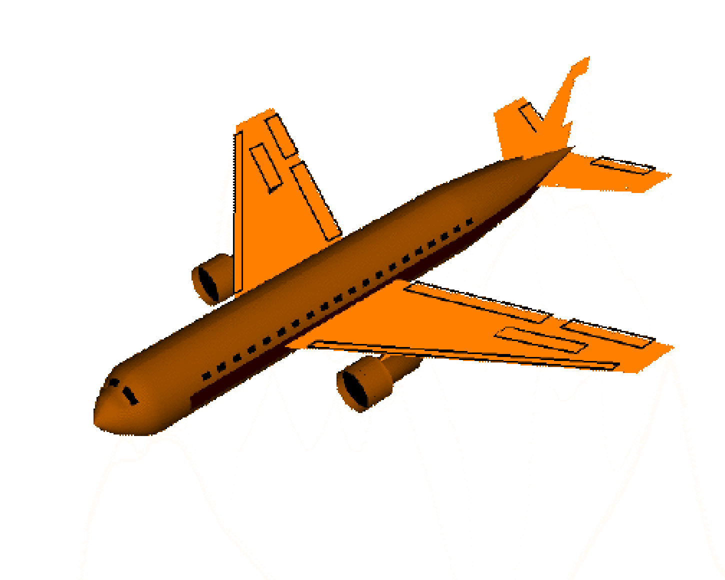
- Rolling (rollen) (φ)



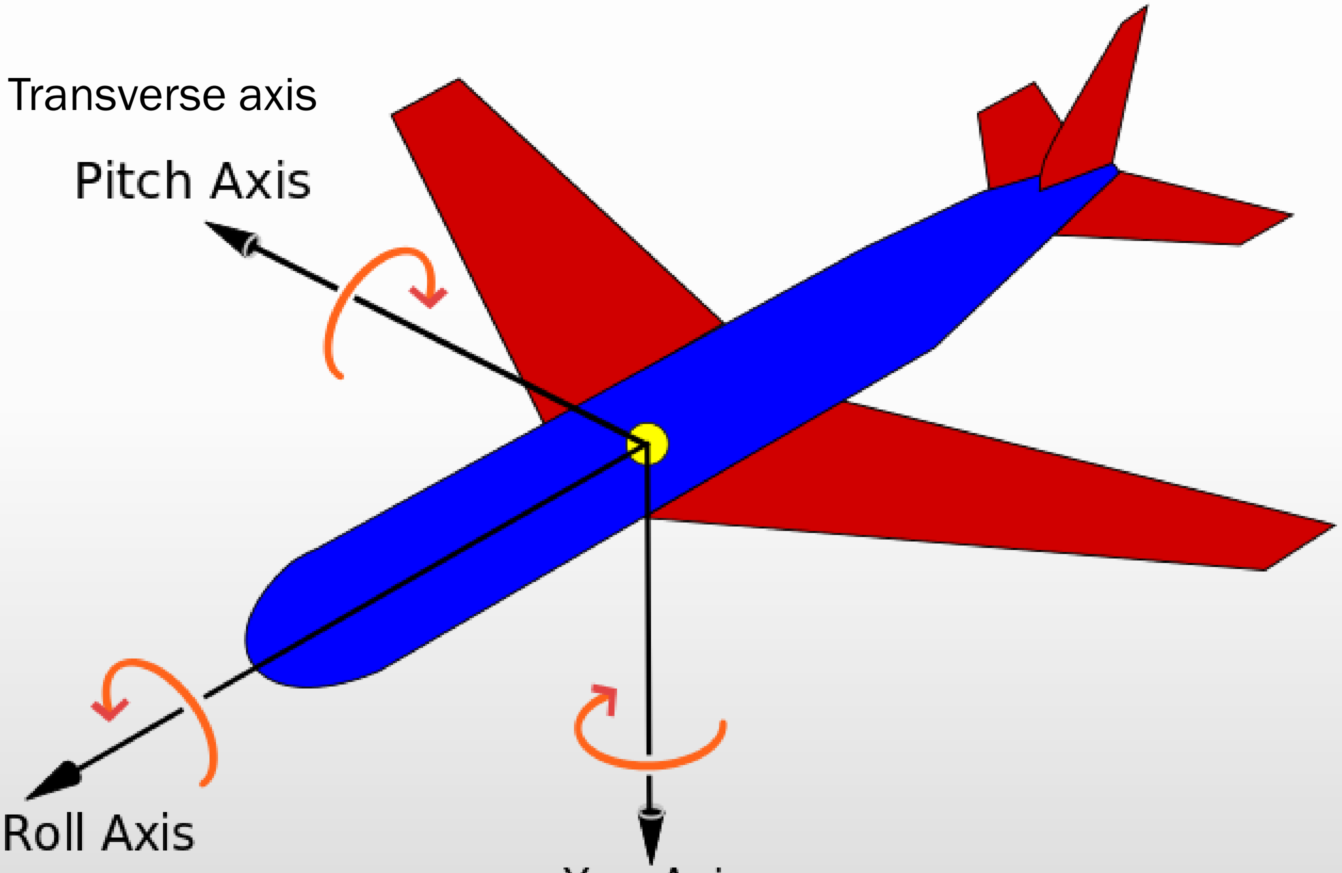
- Pitching (nicken) (θ)



- Yaw (yaw) (ψ)



3. Flying – movements along the different axes



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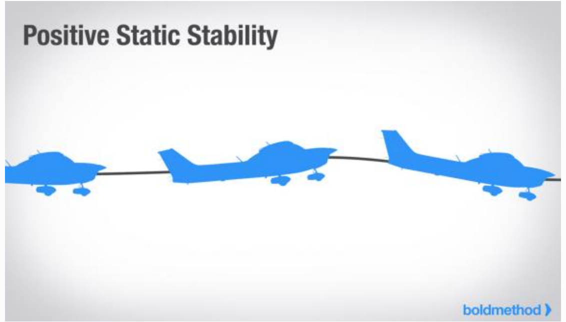
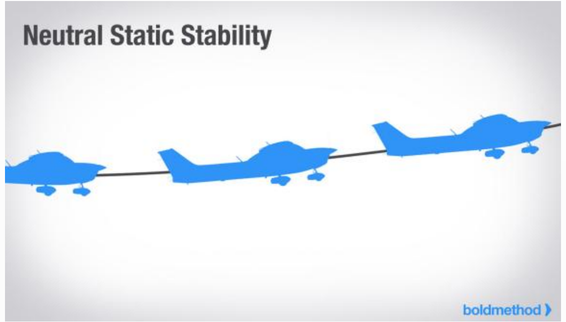
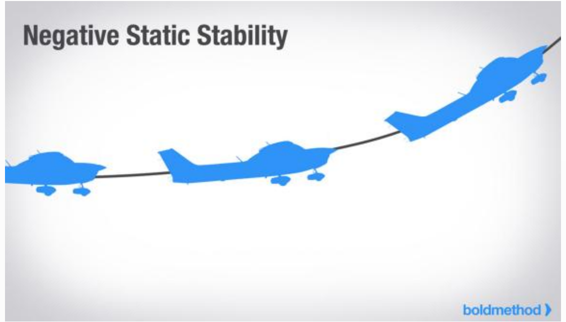
Stability

Stability

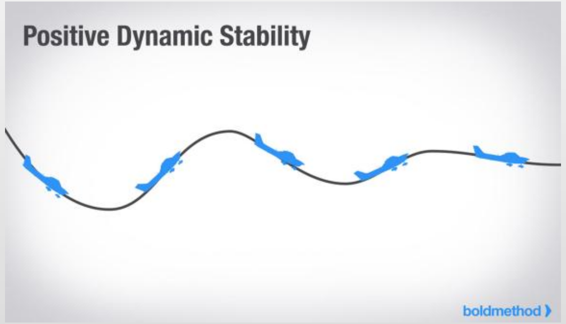
Static stability

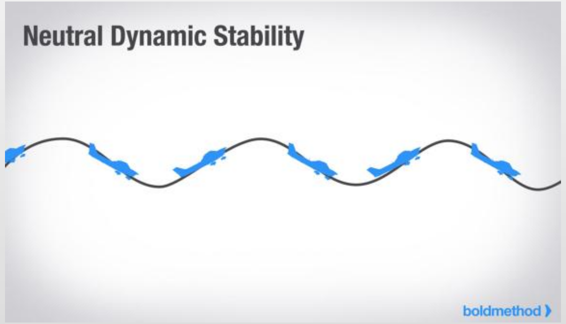


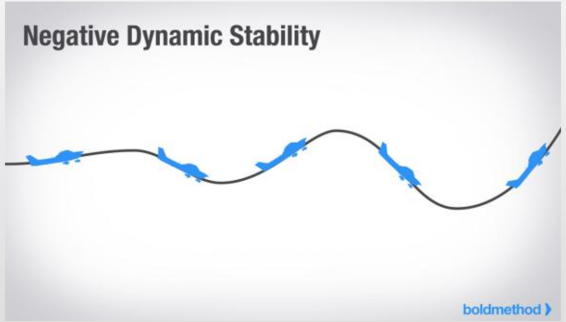




Dynamic stability



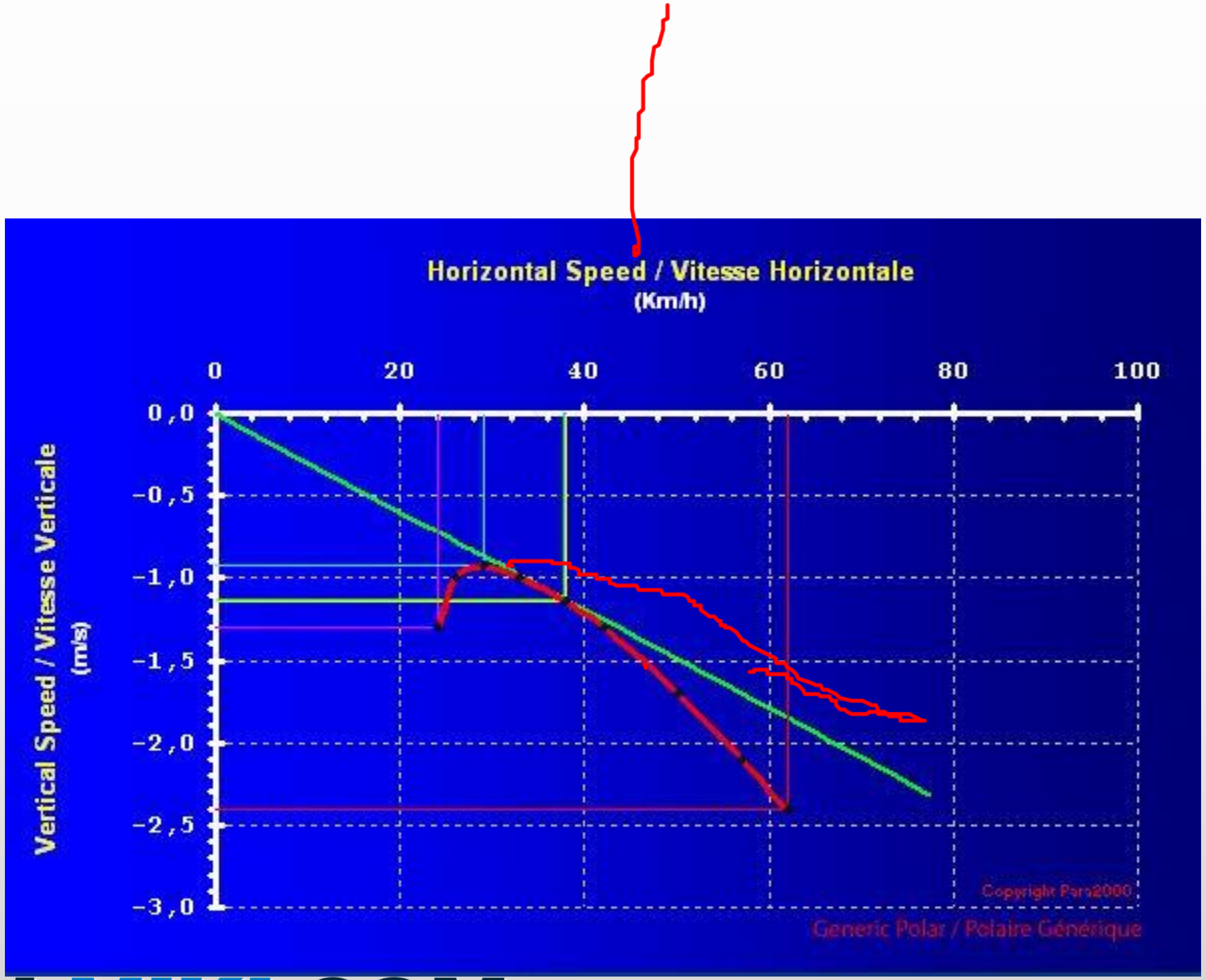




Speed Polar Curve

- Representing the speeds of the glider at different states (different speed, AoE)

Minimum (horizontal) speed
Minimum sink
Best glide
Maximal speed



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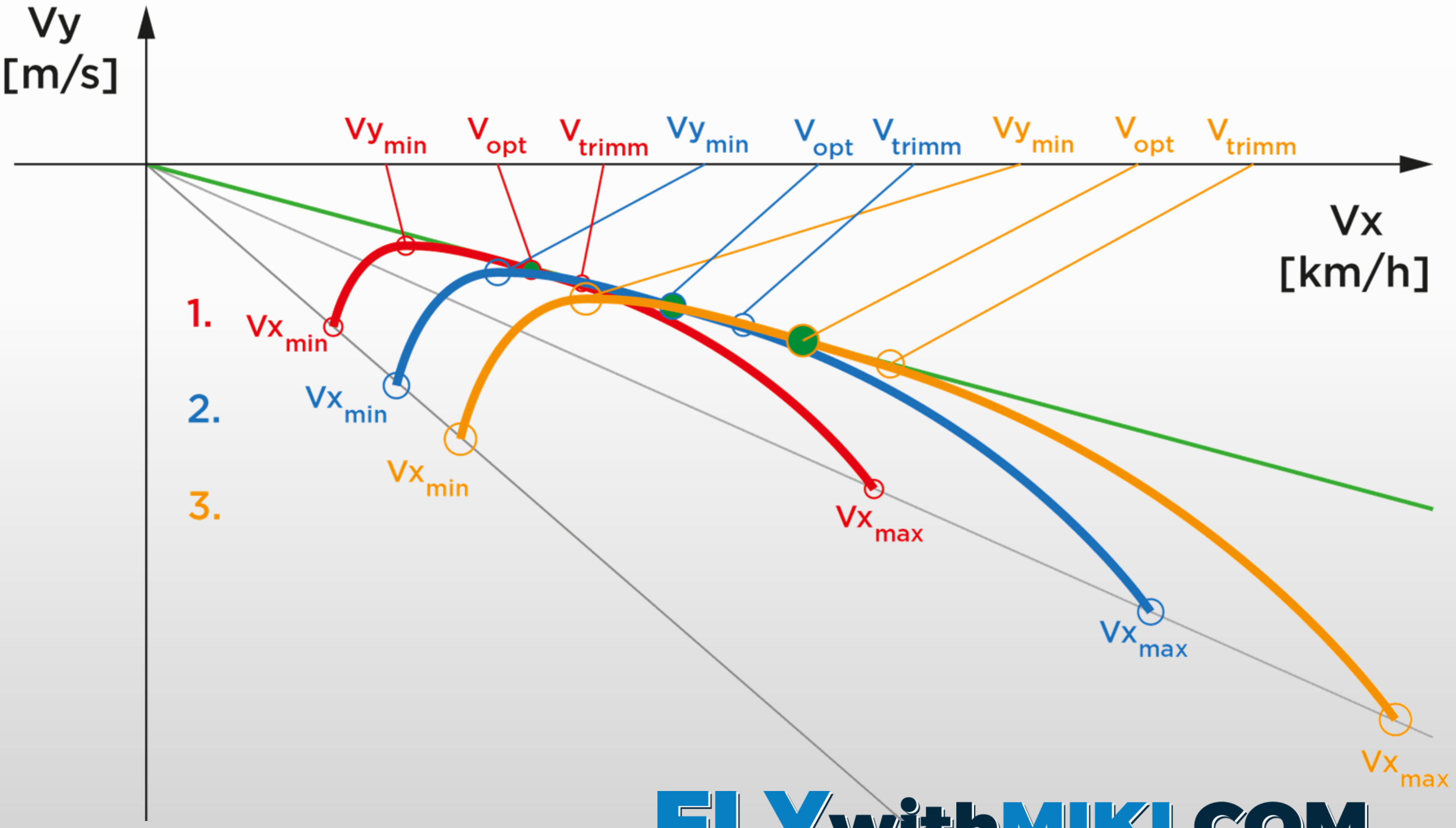
Speed Polar Curve under load



https://mer.re/labs apps/polarmagic/

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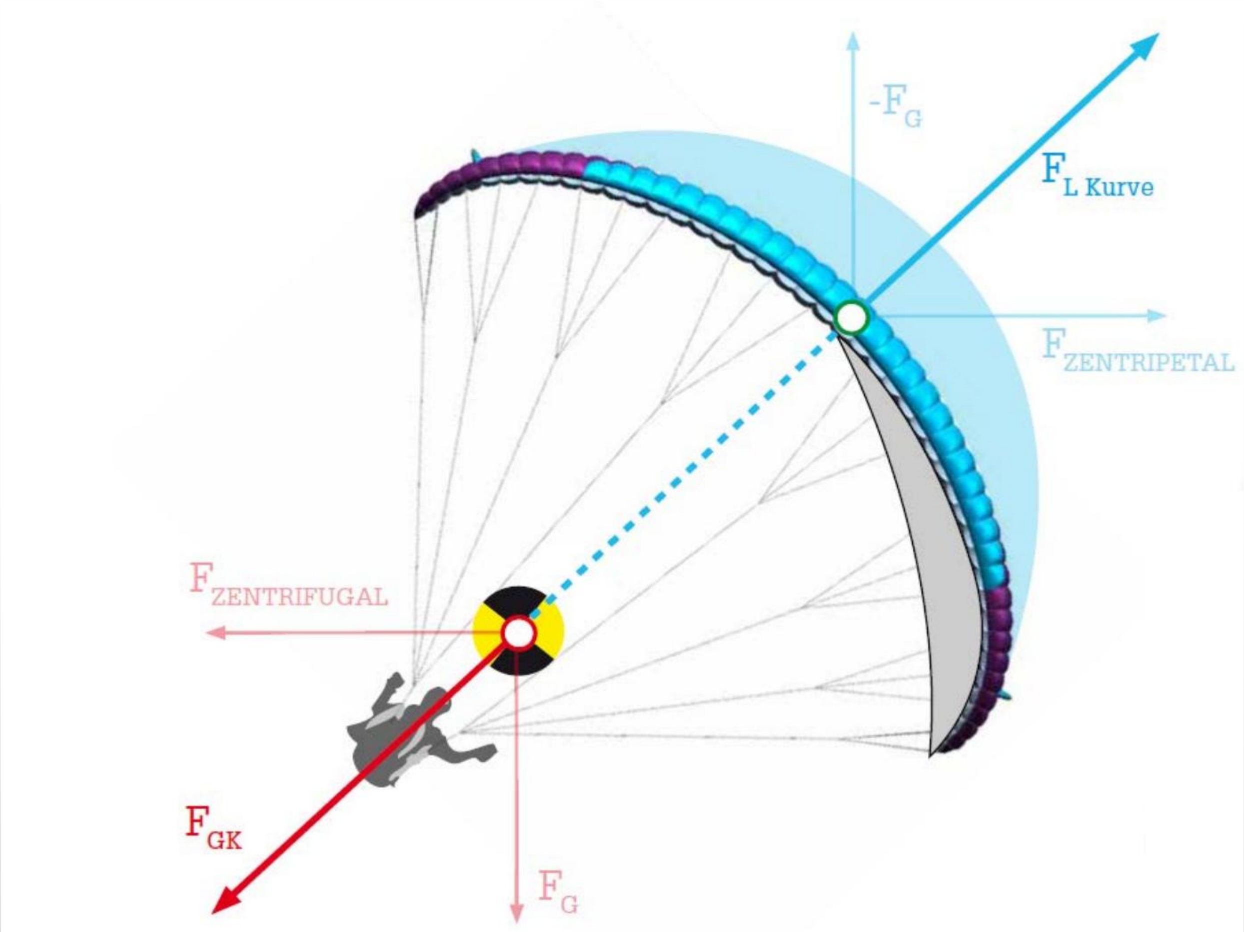
Load in curve



An object with a frontal area of $2m^2$ exposed to an airflow of 30km/h produces a drag of 300N (approx. 30kp) at sea level. Under the same conditions, how much drag is produced by an object of similar shape but with a frontal area of $4m^2$?

- a) about 150 N
- b) about 300 N
- c) about 600 N
- d) about 900 N

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What is the wing loading of the following glider at minimum load? Span: 10 m, Surface area: 25 m^2, Minimum load: 70 kg, Maximum load: 95 kg, Glider weight: 5 kg

- a) 3.0 kg/m^2
- b) 3.5 kg/m^2
- c) 4.0 kg/m^2
- d) 4.5 kg/m^2

A paraglider with a glide ratio of 8 flies 800 m above the ground. What is the longest distance it can fly with this glide ratio in calm air?

- a) 24.0 km
- b) 6.4 km
- c) 10.0 km
- d) 8.1 km