Principles and Control of Flying Systems

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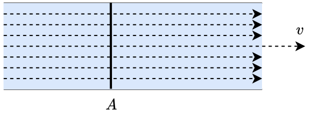
Robotic Systems

The "Volumetric Flow Rate"

Given a fliud that flows in pipe, the **volumetric flow rate** is defined as:

The volume of fluid V that passes through a certain area in the unit time

$$Q = \frac{V}{t} \qquad [Q] = m^3/s$$

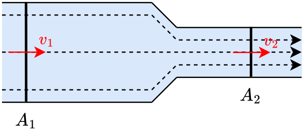


If the fluild flows through a certain area A at the speed v, the **volumetric flow rate** is:

$$Q = A\,v$$

The "Continuity Equation"

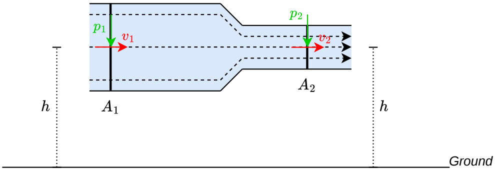
Given a **fliud** that flows in pipe, without losses or derivation, then the **flow rate is <u>constant</u> through the whole pipe**:



$$Q = A_1 v_1 = A_2 v_2 = const$$

In the example figure, since $A_2 < A_1$, then $v_2 > v_1$

The “Bernoulli Theorem”

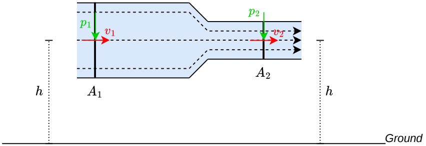


$$p + \frac{1}{2}\rho v^2 + \rho g h = const$$

(ρ = fluid density, $g = 9.81\ m/s^2$)

hence:

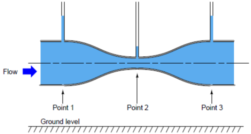
$$p_1 + \frac{1}{2}\rho v_1^2 + \rho g h = p_2 + \frac{1}{2}\rho v_2^2 + \rho g h$$



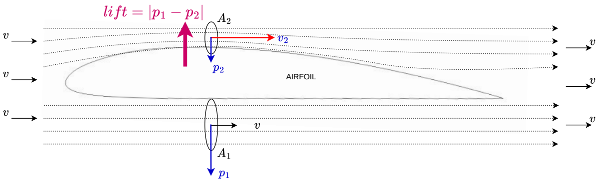
$$p_1 + \frac{1}{2}\rho v_1^2 = p_2 + \frac{1}{2}\rho v_2^2$$

since $v_2 > v_1$, then

$$p_2 < p_1$$



This is also called the Venturi effect

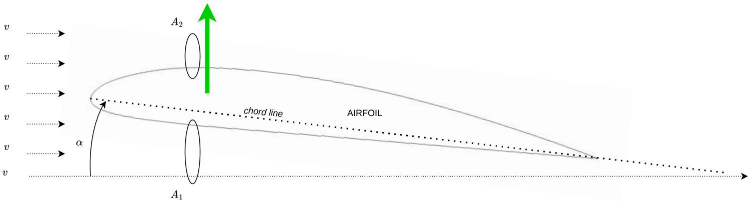


We have:

$$
\begin{aligned}
v &= \text{Wind speed + drag speed(engine + propeller or turbine)} \\
A_2 &< A_1 \\
v_2 &> v \quad \text{Venturi effect} \\
p_2 &< p_1 \quad \text{Bernoulli theorem}
\end{aligned}
$$

A **lift force** appears that pushes up the wing

The Angle-of-Attack



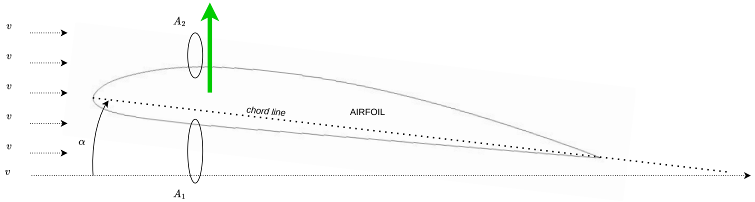
Angle of Attack (AOA) α

The angle between the airflow direction and the airfoil chord line

When α increases, A_2 become narrower and the **lift increases**

This is the reason why airplanes take-off immediatelly when they rotate with "nose up"

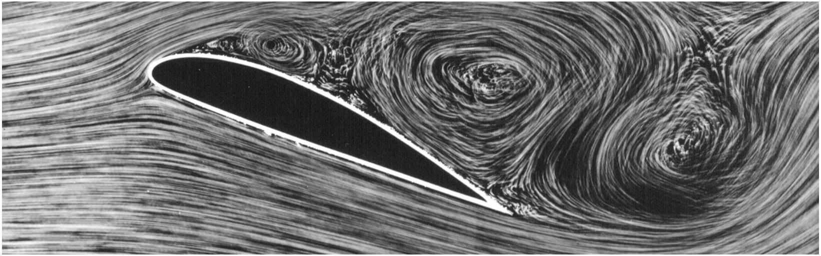
Lift Dependance



The lift depends on

Airspeed	The higher the airspeed, the higher the lift
Angle of attack	The higher the AOA, the higher the lift

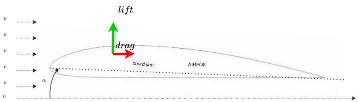
The Critical Angle-of-Attack

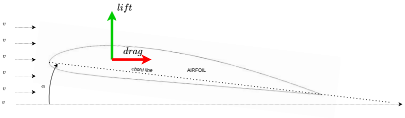


Critical AOA

If the AOA becomes greater than a **critical value**, the airflow detaches from the upper wing surface, turbulence is formed, and the **lift disappears**

This effect is known as **stall**

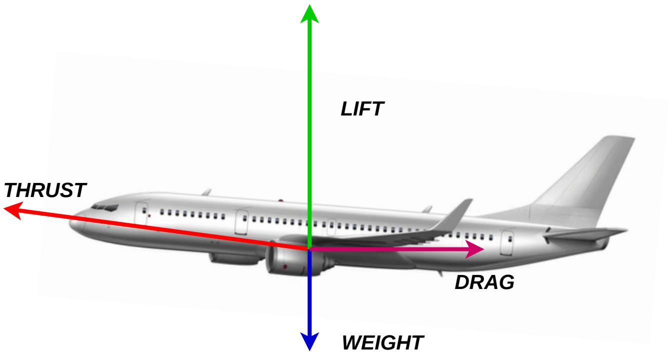




Drag Force

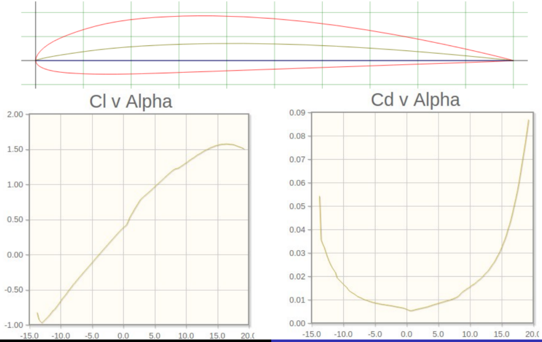
- The wing is a rigid body than “travels” in a fluid, so it is also subject to **friction**
- The friction is dependent on (among other factor) the **surface incident** to the airflow
- A **drag force** is generated, that limits airplane (wing) travel speed and thus the airspeed
- When the AOA increases, also the incident surface increases, thus **the more the drag**

The Four Forces of a Flying System



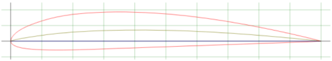
Name	Generated by	Depends on
Thrust	Engines	Engine Power
Lift	Wings	Airfoil, Wing area, Airspeed, AOA
Drag	Wings	Airfoil, Wing area, Airspeed, AOA
Weight	Body	Airplane mass, passengers, luggages

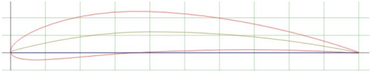
- Given a certain airfoil, the **polar** is a curve that shows the trend of lift and drag on the basis of airspeed and angle-of-attack
- The polar uses pure numbers:
  - **Lift Coefficient,** C_L (aka C_Y)
  - **Drag Coefficient,** C_D (aka C_X)
- They represent the ability of the airfoil to generate a certain amount of lift/drag

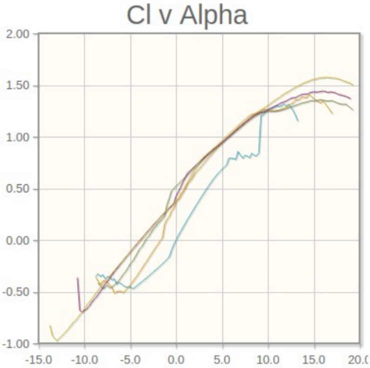


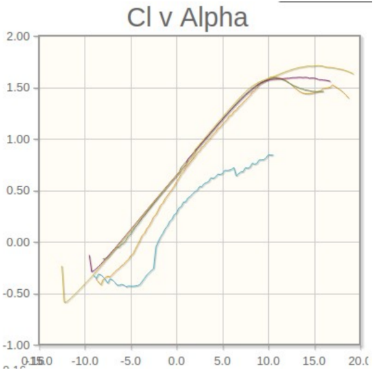
Planar-Convex vs. Concave-Convex Airfoils

Planar-Convex Clark-Y	Concave-Convex NACA6412

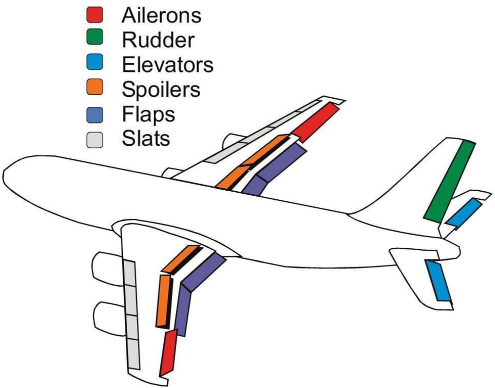




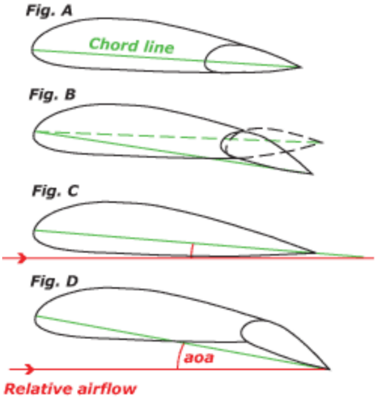




Mobile Surfaces

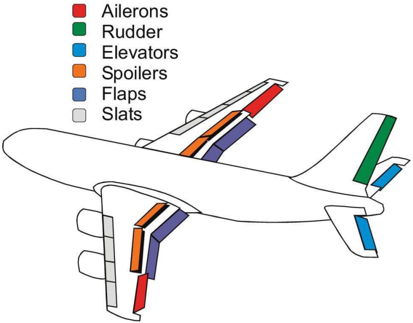


- **Mobile surface** are parts of the airplane that move on the basis of pilot's actions
- They are able to modify the shape of the element and thus its **airfoil**, changing the ability of the element to generate lift and drag



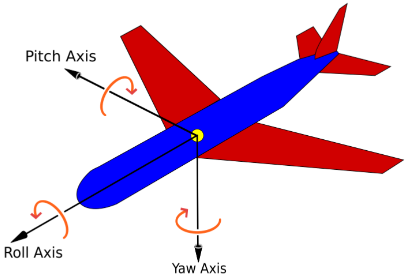
- Fig. C: the mobile part is “horizontal”, the overall airfoil is planar-convex
- Fig. D: the mobile part is “down”, the overall airfoil becomes **concave-convex**, thus wing’s ability to generate lift **increases**

Mobile Surfaces



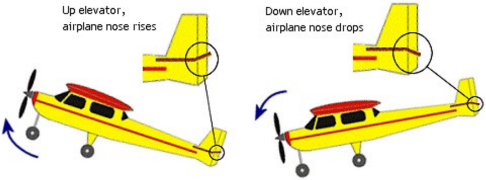
- This is the reason why airplanes perform take-off and langing using "flaps down"
- During those manoeuvres, speed is low and thus **more lift ability is needed**

Euler Angles

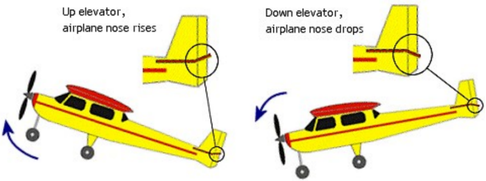


- Mobile surfaces cause **rotations** w.r.t. the mass' center of the airplane
- Rotations change the Euler angles
- As consequences, rotations trigger **linear movements**

Elevators

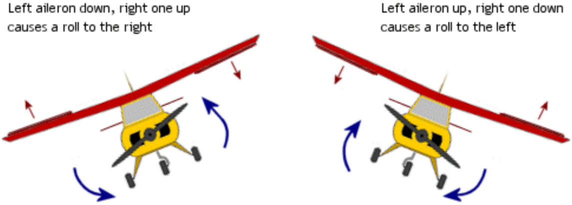


- They are the mobile surfaces of the tail
- **Elevators up**: airfoil lift ability is reduced, the tail is **pushed down**, a **pitch rotation** is triggered
- **Elevators down**: airfoil lift ability is increased, the tail is **pushed up**, a **pitch rotation** is triggered

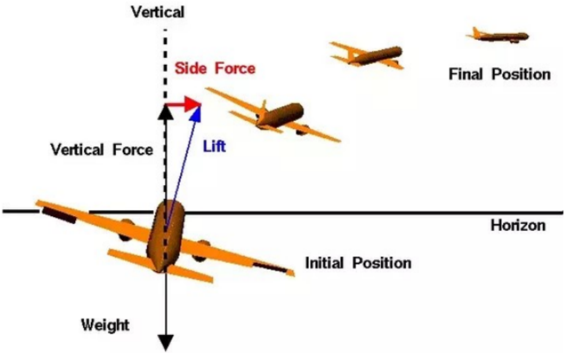


- The airplane is pushed at a (air-)speed that makes wings able to generate the “necessary lift”
- This speed, called V_R (rotation speed), depends on the weight of the overall plane
- When (air-)speed is V_R, the pilot pulls the cloche causing an **“Elevators-up”** movement
- The tail is pushed down, the nose is pushed up, the **angle of attack** of the wings increases causing the generation of more lift

Aleirons

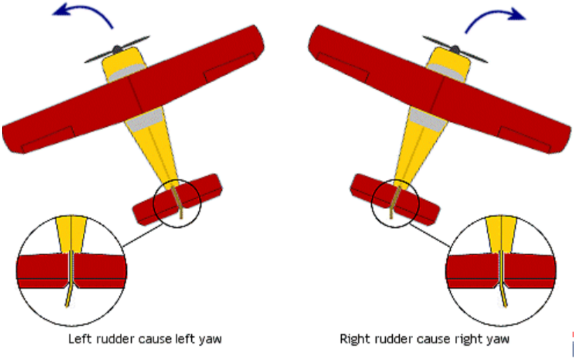


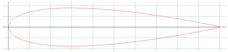
- They are the mobile surfaces placed at the end of the wings
- Their movement is complementary: when left aleiron goes up, right aleiron goes down
- Thus one wing generates more lift, the other generates less lift
- As a result, the plane rotates along roll's axis



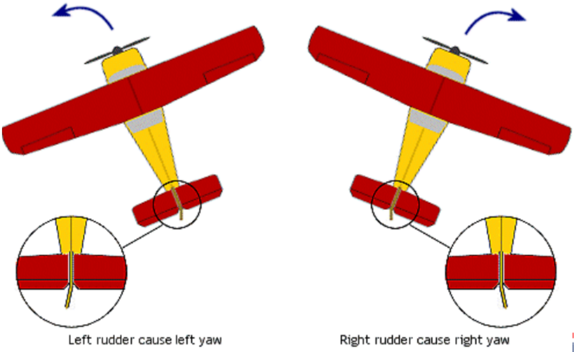
- If roll angle is $\neq 0$, the lift vector is no more vertical
- It decomposes in two forces:
  - **vertical:** it keeps the plane in flight
  - **horizontal:** it causes a side moviment
- The result is a **turn**

Rudder



- The “tail” of an airplane, even if it is vertical, has the shape of wing
- It’s airfoil is **convex-symmetric** 
- The rudder changes the airfoil letting that “wing” to generate a lift to the left or to the right

Rudder

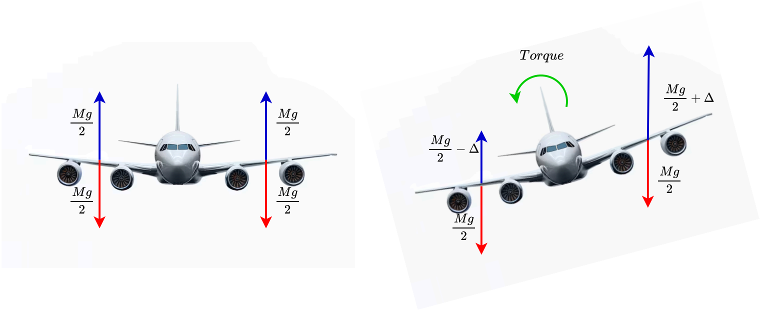


- Rudder causes a **yaw rotation**
- **left rudder** causes a right lift (push), the tail goes right, nose left
- **right rudder** causes a left lift (push), the tail goes left, nose right
- Rudder is used to turn at the ground and to turn in-flight together with aleirons

The Control System of an airplane (Examples)

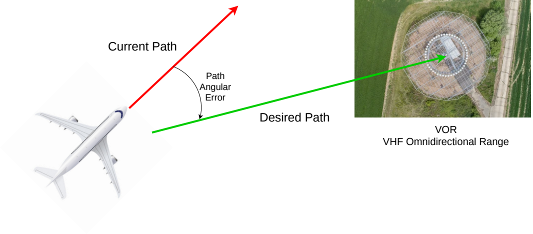
- To understand how to auto-pilot an airplane, it is necessary to know the (manual) controls that the aircraft has
- **Throttle:** increases/decreases the engine power
- **Cloche:**
  - left/right movement changes the inclination of aleirons
  - push/pull movement changes the inclination of elevator
- **Pedalboard:** changes the inclination of the rudder


Effect of Aleirons

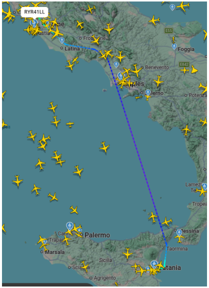


- The cloche controls the **inclination of aleirons**
- This causes more lift in a wing and less lift in the other wing
- The force difference generates a **torque**
- The torque generates and certain **angular speed**
- As a result aleirons drives **roll angle rate (speed)**, that causes a **turn**

Path Control

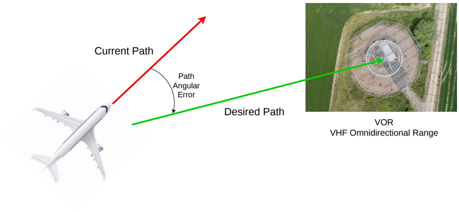


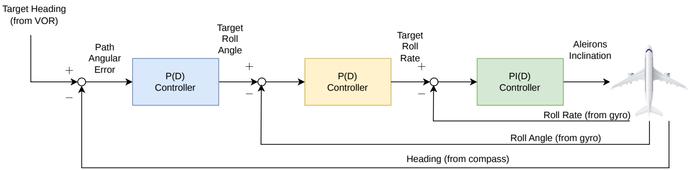
VOR
VHF Omnidirectional Range



- Airplanes use **beacons** placed all over the World
- They are called **VOR: VHF Omnidirectional Range**
- They indicate the **compass** (yaw angle/heading) needed to reach the VOR point
- If a plane is following a different path (heading) a turn must be applied in order to intercept the right path

Path Control





- A set of controllers is employed
- The **heading error** generates the desired roll (angle)
- The **angle error** generates the desired roll rate
- The **rate error** drives the aleiron's inclination

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