## Constants

- Normdruck: $p_{ref} = 1atm = 1.01325\,bar$
- Normtemperatur: $T_{ref} = 298\,K \approx 25°\,C$
- Pferdestärke: $1\,hp = 1\,PS = 0.735\,kW$
- Elementarladung: $e = 1.60219 \cdot 10^{-19}\,C$
- Faraday-Konstante: $F = N_A \cdot e = 96485.3 \frac{C}{mol} = \frac{A \cdot s}{mol}$
- ppm = parts per million: $1\,ppm = 10^{-6}$
- Gaskonstante: $\overline{R} = 8.314 \frac{J}{molK}$, spez. – $R = \frac{\overline{R}}{M}[\frac{J}{kgK}]$

## Parameters

- Aerodynamic Force $F_A$
- Lift Force $L$
- Drag Force $D$
- Aerodynamic Moment $M_A$
- Lift Coefficient $C_l = L/(1/2\rho V^2 c)$
- Drag Coefficient $C_d = D/(1/2\rho V^2 c)$
- Moment Coefficient $C_m = M_A/(1/2\rho V^2 c^2)$
- Angle of Attack $\alpha$ angle between connection leading and the trailing edge and reference line
- Lift curve slope $a = C_l/\alpha$

## Steady Aerofoil and Wing Section Aerodynamics

- Aerofoil = 2-D wing section with goal to generate lift force perpendicular to the relative airspeed
- Convention: Lift is up, Drag is in direction of windspeed and Aerodynamic moment in clockwise direction acting on the aerodynamic center. Aerodynamic center is normally at the quarter chord position $c_{m,c/4}$ for syymetric airfoils. $x_{ac} = -m_0/2\pi + 0.25$ with $m_0$ as a shape constant
- Further assumptions: No viscosity, incompressible fluid, $Ma < 0.2, 0.3$, no vortices, potential flow (Navier-Stokes)
- Another centre is the shear center (elastic axis) from mechanics
- $L = 1/2\rho V^2 c a \alpha$, with $a$ from tables (CFD and Wind Tunnel)
- $M_a = 1/2\rho V^2 c^2 c_{m\phi}$ with $c_{m\phi}$ also from tables

**Lift curve $C_l(\alpha)$ and drag curve $C_d(\alpha)$**

- At small ranges of $\alpha$, both lift and drag increase with: $C_l \propto \alpha$ and $C_d \propto \alpha^2$
- In aeroelasticity and this course, $\alpha$ will be very small, hence drag will be negligible small

**The aerodynamic moment $M_A$**

- The aerodynamic moment is much more important than drag $C_d$
- $M_A$ varies with $\alpha$ in the small ranges of the angle of attack
- **Important to note:** There exist a point at which the aerodynamic moment does not depend on $\alpha$. This is the the aerodynamic centre
- The aerodynamic centre is not the same as the centre of pressure, which is defined as the point where the aerodynamic moment is zero given a certain angle of attack $\alpha$
- Symmetric airfoils at $\alpha = 0$ have no aerodynamic moment at all times ($M_A = 0 = const$). At the aerodynamic centre for symmetric foils results into no moment
- Asymmetric airfoils at $\alpha = 0$ have a non-zero aerodynamic moment at all times (all angles $\alpha$)

**Assessment of $C_l/\alpha$**

- The linear part of the lift curve is characterised by the slope $a = C_l/\alpha(M) = \frac{C_l/\alpha_{M=0}}{\sqrt{1-M^2}}$
- The Prandtl-Glauert factor is $1/\sqrt{1-M^2}$
- The factor is depending on the Mach number. The slop increases with increasing $M$ (between 0 and 1)
- The dependence on $Re$ is more subtle (p. 8)

## Extension to wing aerodynamics (p. 8)

Aerofoil dynamics (2D) refer to the previous topics, however the 3-D case can be also modeled by through a couple examples. A finite wing is less stable and efficient than the airfoil since the tips have vortices on at the wing tips. These “induce” a velocity, which locally reduces the angle of attack. An important parameter is the so called **Aspect Ratio** $AR = b^2/S$. If the wing is assumed to be of surface $S = b \cdot c$, it follows $AR = b/c$.

- The lift curve can become a function of $AR$ if due to the different tips. Approximately, the lift slope $a_0$ is adjusted via following formula:
- $a = a_0 \frac{AR}{AR+4}$

**Strip Theory (p.9)**

- If $AS$ is very small (delta wings), the integral of multiple airfoils
- Example, the wing is an elliptical $f(y) = \sqrt{1 - (\frac{y}{b/2})^2} \cdot \overline{f}_\phi$
- $f(y) = a\alpha c = C_l c$ with $c$ = chord length.

# Steady-state (static) Aeroelasticity

## Typical Section

2-D problem with a rigid wing and 2 degrees of freedom (free rotation / pitch and plunge). We can have multiple typical sections. The pitch is modeled via a torsional string and the plunge via a longitudinal one. The idea is later on to model the torsional spring to be a torsional stiffness of a beam (since a real wing is actually a beam with a certain stiffness).

- The torsion acts in a beam section on the shear centre, however in aeroelasticity on the elastic axis
- The goal of engineering is alwayt to move the shear center to the front (comes with risk to thin out the rear longeron and thicken the front longeron)
- In equilibrium, we know that the aerodynamic forces are equal to the spring forces
- $M_t + L \cdot e = \theta k_\theta = (qc^2 c_{m0} + qca\theta e) \cdot b$
- $L =$

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**How to solve typical sections**

1. Check the number of DOF (= size of problem and unknowns), which defines the matrices later
2. Define angles $\alpha$ (true angle of attack) and $\theta$ (elastic twist)
3. Define the measures $h$ (plunge) and $e$ (distance aerodynamic centre and elastic axis)
4. The pitching moment $M_t$ and the lift $L$ can be described on one hand as the response from the springs ($\alpha$ )
5. And on the other hand via the