UNIVERSITY OF Southampton

SESA2025 Mechanics of Flight
Background knowledge & definitions

Lecture 0.3: Aerodynamics

Aerodynamics background

Building on SESA2022

Introduction

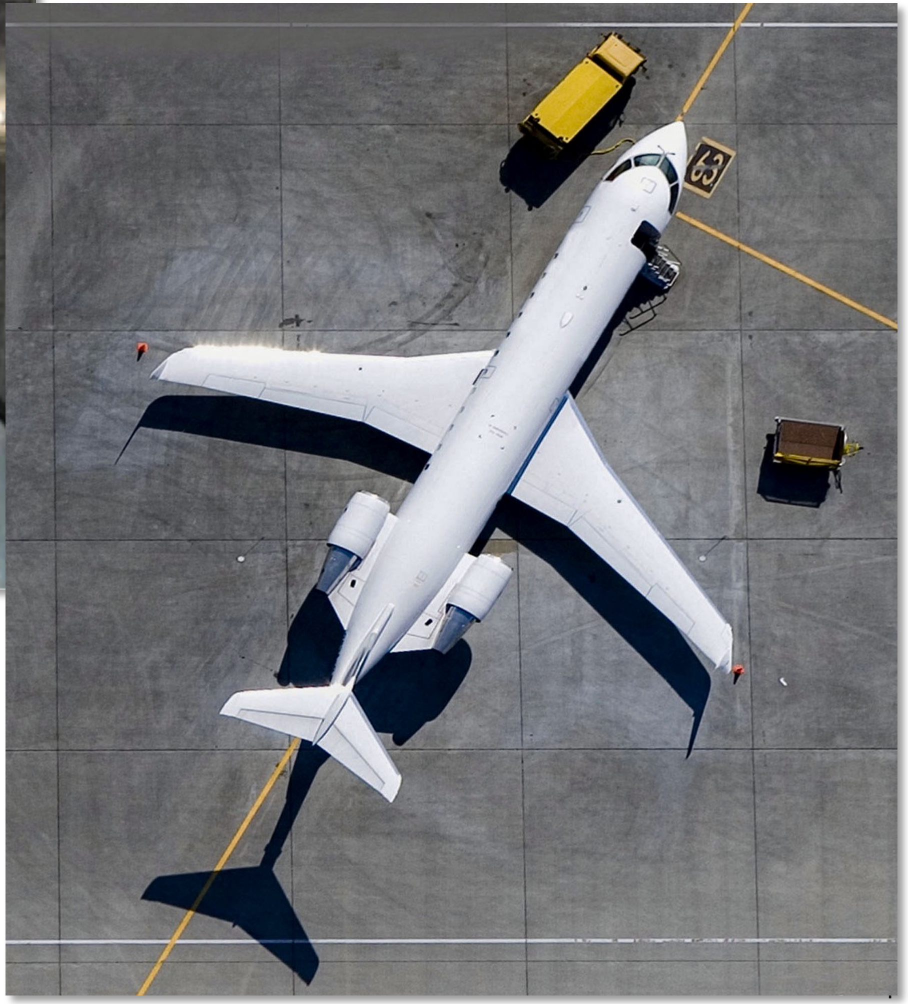
Just a note before we start

- We look at the effect of aerodynamic forces on the motion (trim, static stability, response to perturbations) of the aircraft (**Mechanics** of Flight)
- We make use of aerodynamic tools/concepts/equations from SESA2022
- We do not rederive these tools, but you need to know:
  - where they come from
  - when they can be used

Wings/Airfoils
Nomenclature

- Airfoils (Aerofoils) are 2D sections
  - 2D simulations or theory
  - wall-to-wall wind tunnel models
  - infinite span
- Wings have ends
  - finite-span
  - new flow physics

- Different aerodynamic performance, but …
- For this module, we need to understand the impact on the aircraft performance




REPLAY
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LIVE
Sauber
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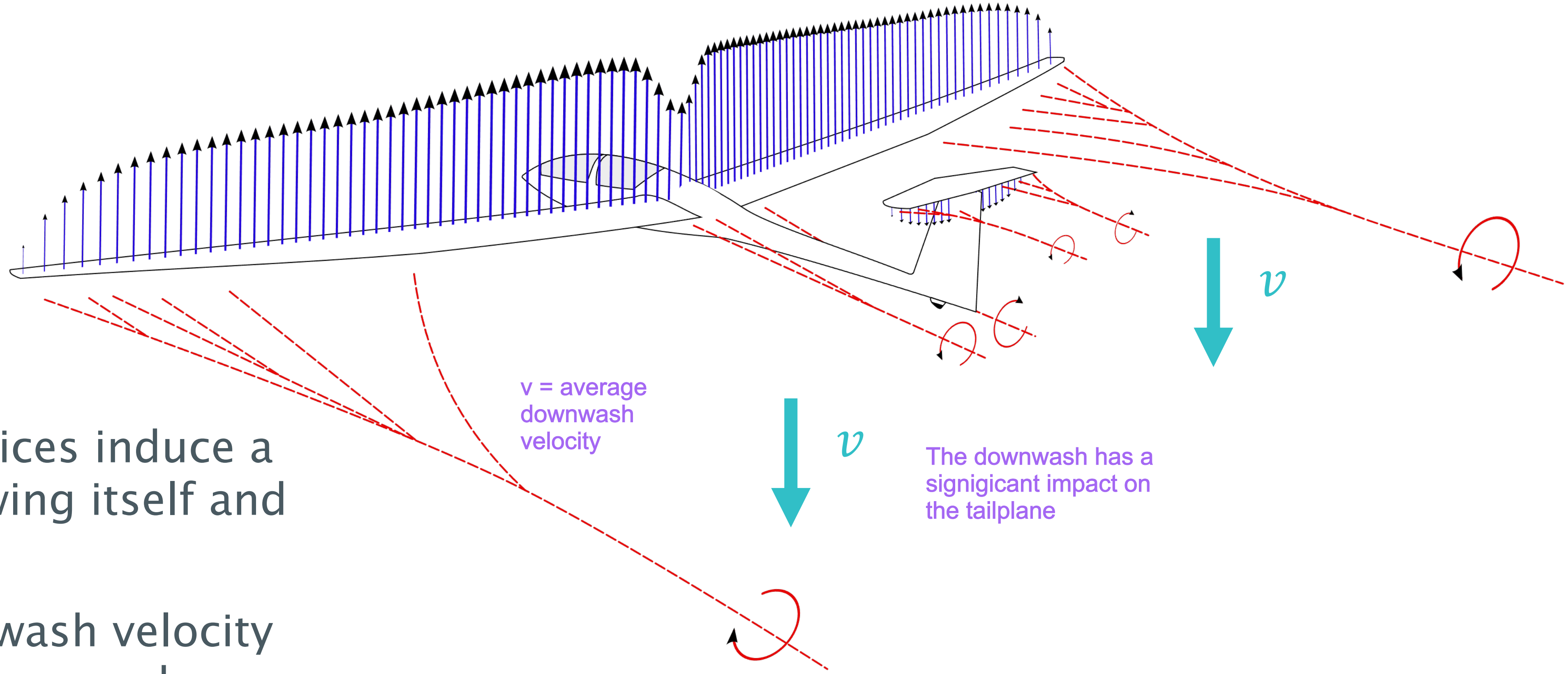
Finite wing influence

Downwash effect III

As known from aero the lift follows an ellipticish distribution, both on the main wing and tailplane



v = average downwash velocity

The downwash has a signigicant impact on the tailplane

These wing tip vortices induce a downwash on the wing itself and in its wake.

The effective downwash velocity for the complete wing can be obtained by using lifting line theory.

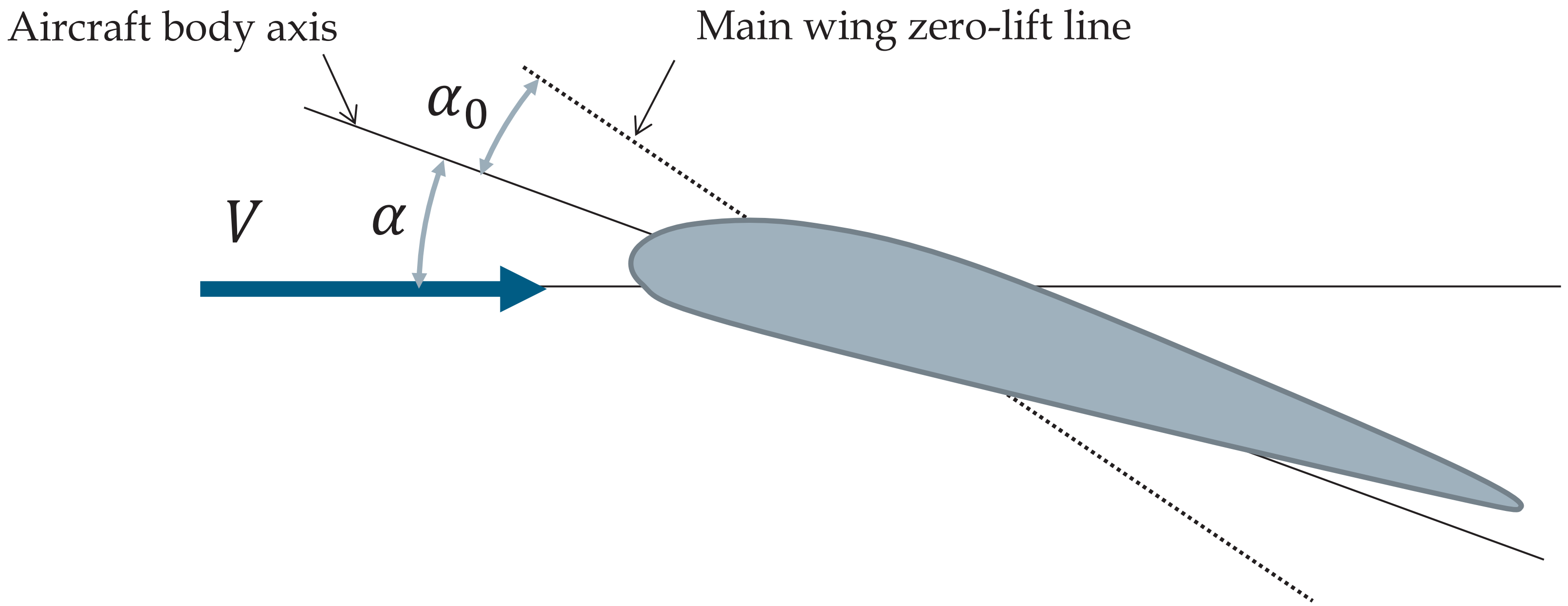
(2D case)

Finite wing influence

Downwash effect on lift

For a 2D (infinite) wing:

$$C_l = C_{l_\alpha}(\alpha - \alpha_0) = a_0(\alpha - \alpha_0)$$



$$\boxed{C_{l_\alpha} = \frac{\mathrm{d}C_l}{\mathrm{d}\alpha} \stackrel{\text{def}}{=} a_0}$$

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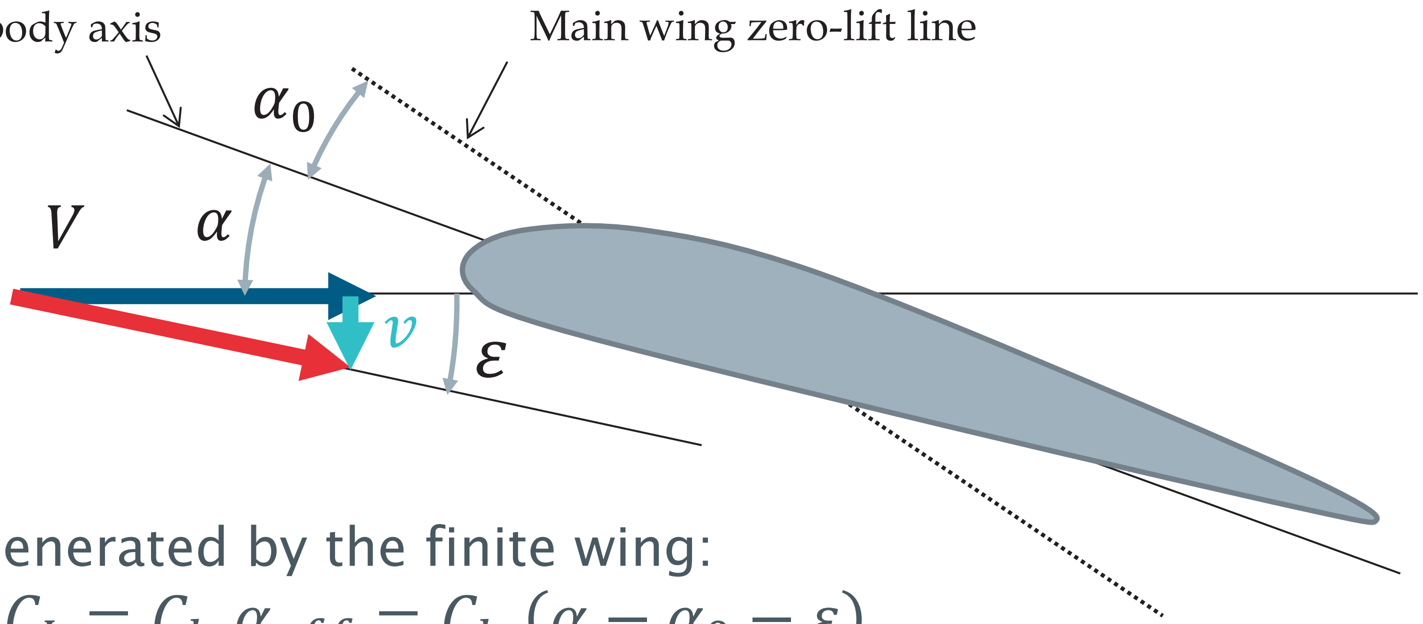
(3D case)

Finite wing influence

Downwash effect on lift

For a finite wing, the (average) downwash changes the effective angle of attack:

$$\alpha_{eff} = \alpha - \alpha_0 - \varepsilon$$



which in turn affects the lift generated by the finite wing:

$$C_L = C_{l_\alpha}\alpha_{eff} = C_{l_\alpha}(\alpha - \alpha_0 - \varepsilon)$$


e > 1
UNITED
N23707
e > 1

Finite wing influence

Downwash effect on lift I

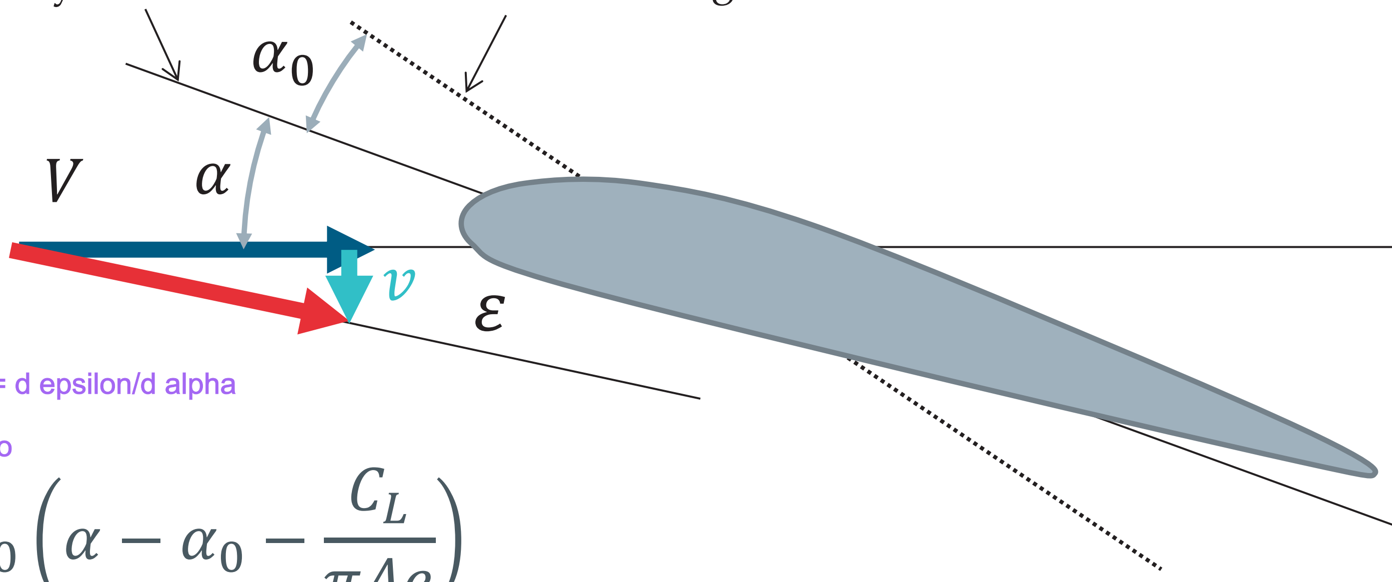
e is the oswold thingy

e could be larger than one if you account for the effect of winglets

Given the downwash angle:

$$\varepsilon = \varepsilon_\alpha(\alpha - \alpha_0) = \frac{C_L}{\pi A e}$$

Since downwash is caused by lift (conservation of momentum) we can tell (using small angle approxiamtions) that epsilon will be somewhat proportional to C_L



epselon_alpha = d epsilon/d alpha

The wing lift coefficient is:

Plug ^ into lift equation to get V

$$C_L = C_{l_\alpha}\alpha_{eff} = a_0(\alpha - \alpha_0 - \varepsilon) = a_0\left(\alpha - \alpha_0 - \frac{C_L}{\pi A e}\right)$$

Rearranging for C_L ^ becomes V

Therefore:

$$C_L = a_0\frac{\pi A e}{\pi A e + a_0}(\alpha - \alpha_0) = C_{L_\alpha}(\alpha - \alpha_0)$$

$$\boxed{C_{L_\alpha} = \frac{\mathrm{d}C_L}{\mathrm{d}\alpha}}$$

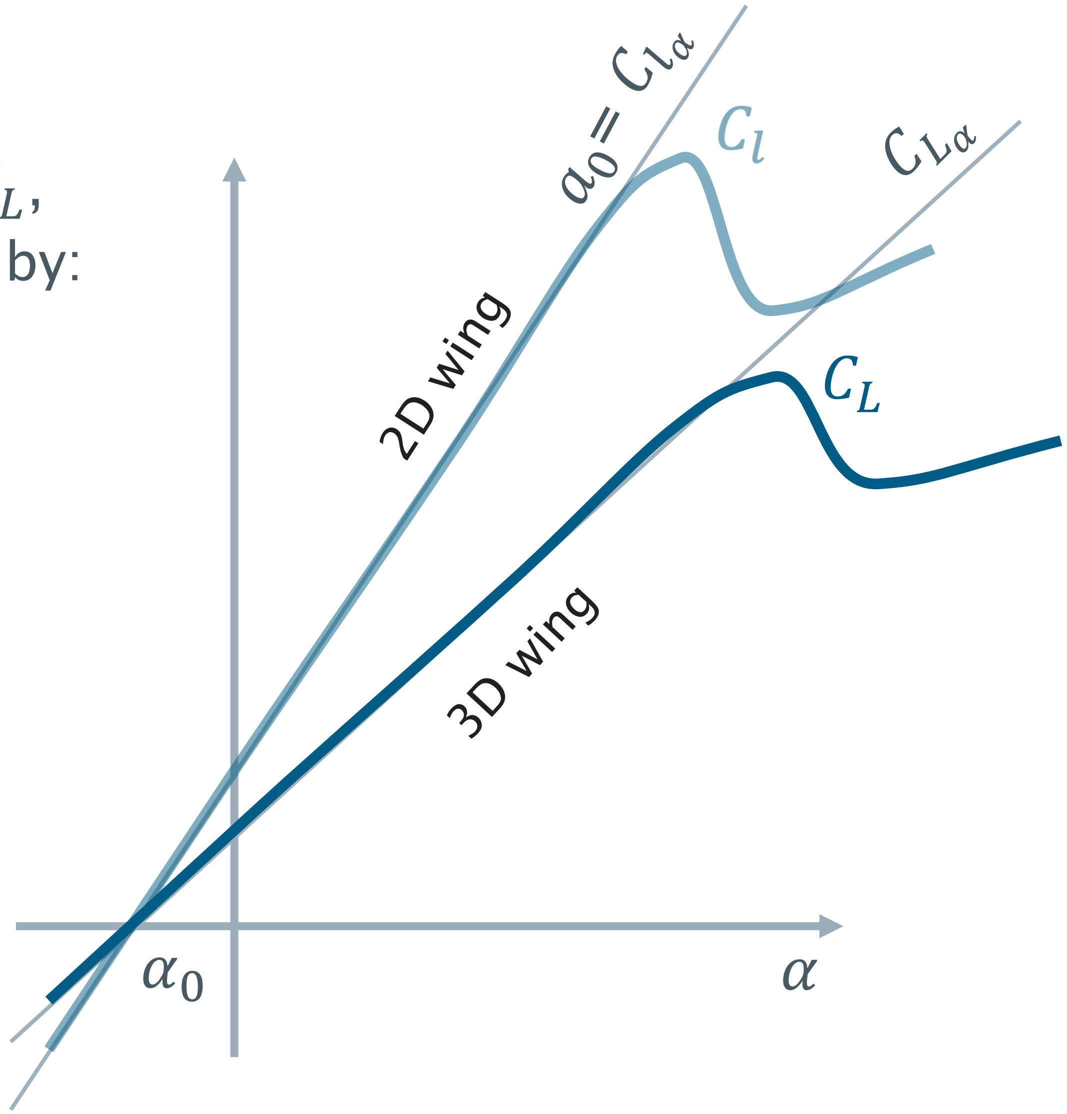
Finite wing influence

Downwash effect on lift II

Due to downwash, a finite (3D) wing's lift, C_L, is related to that of an infinite (2D) wing C_l, by:

$$C_l = a_0(\alpha - \alpha_0)$$

$$C_L = a_0 \frac{\pi A e}{\pi A e + a_0}(\alpha - \alpha_0)$$



Finite wing influence

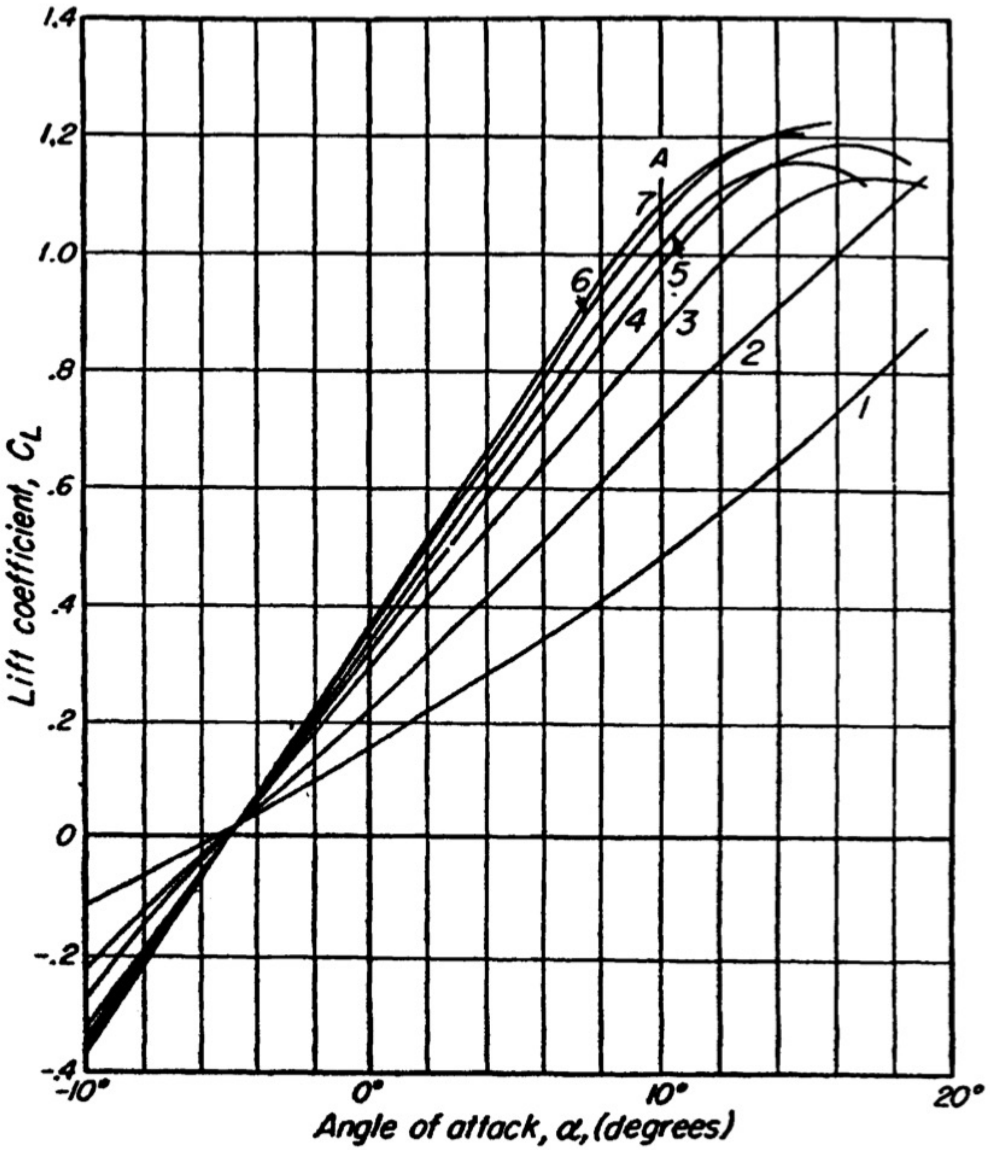
Downwash effect on lift II

Due to downwash, a finite (3D) wing's lift, C_L, is related to that of an infinite (2D) wing C_l, by:

$$C_l = a_0(\alpha - \alpha_0)$$

As predicted by theory, increasing aspect ratio tends closed to a_0

$$C_L = a_0 \frac{\pi A e}{\pi A e + a_0}(\alpha - \alpha_0)$$

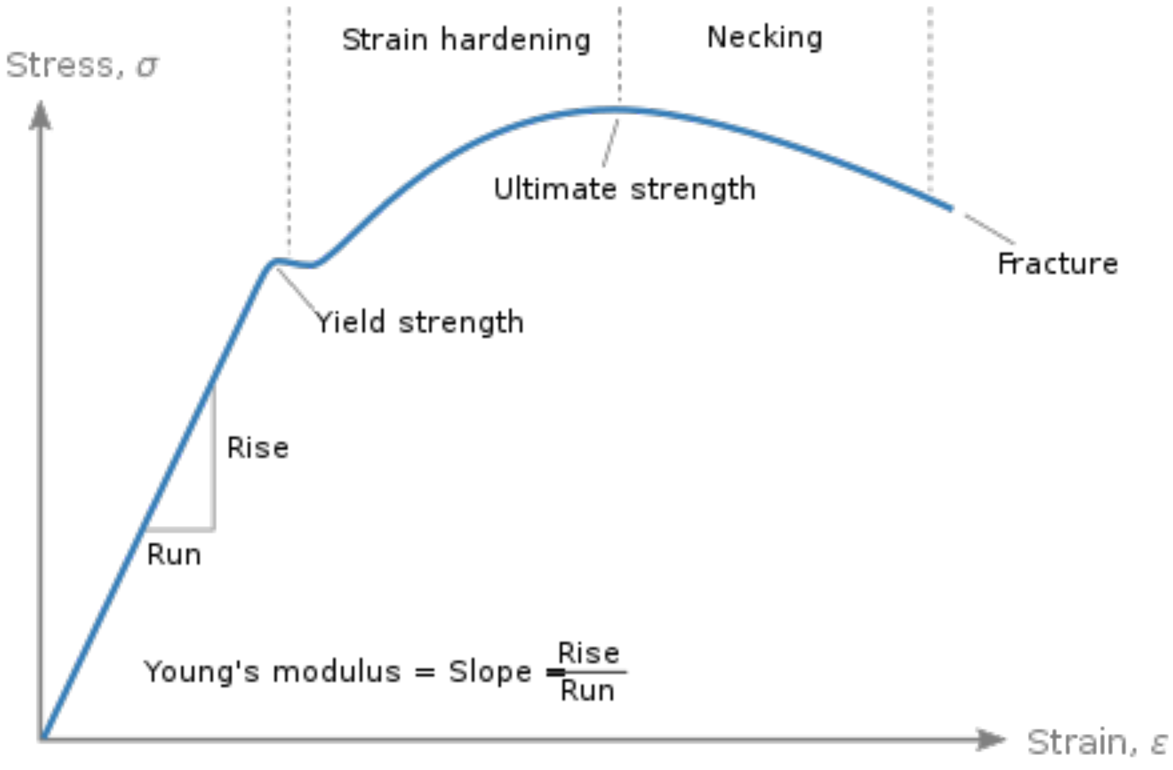


Theory of Wing Sections (Abbott 1949)

Analogy with materials

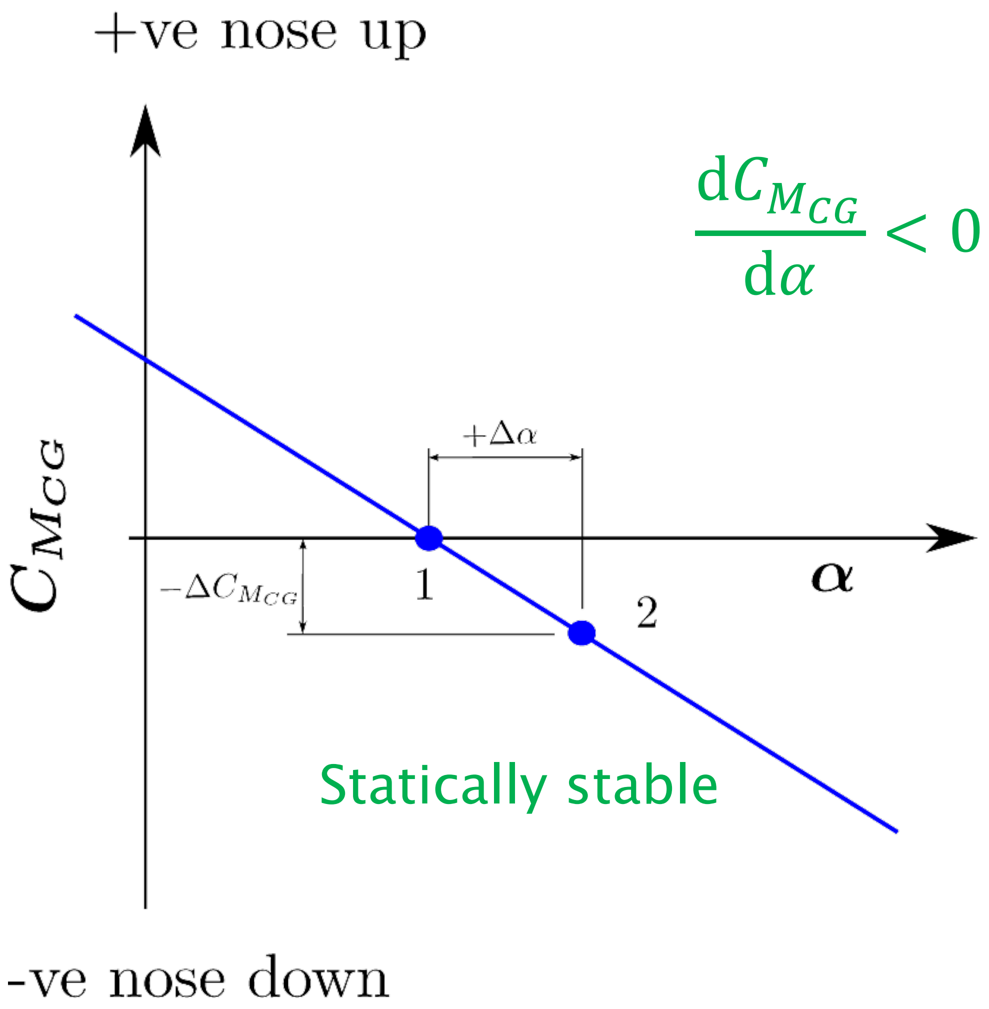
C_{L_α} analogy with Young's modulus

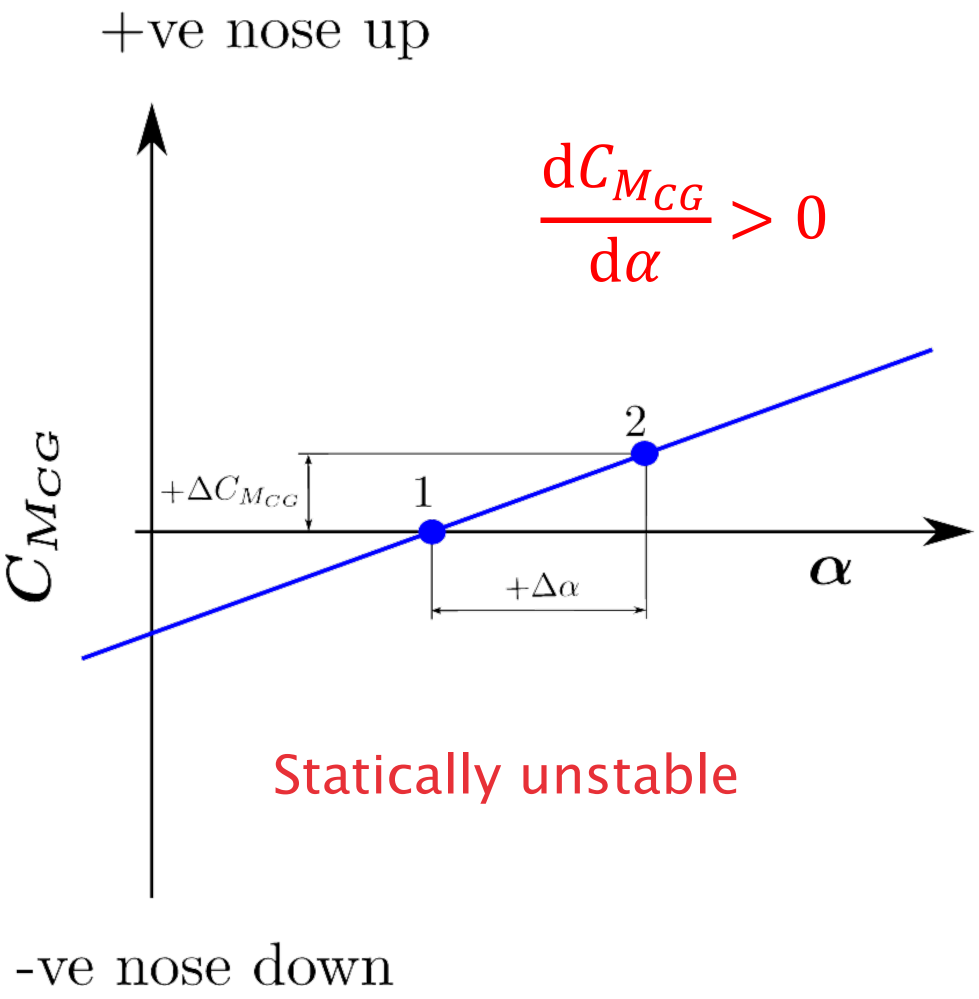
just an analogy



Impact on longitudinal static stability

Look at changes of net pitching moment with changes in angle of attack (from lecture 0.1)





Impact on longitudinal static stability

Effect of the aspect ratio

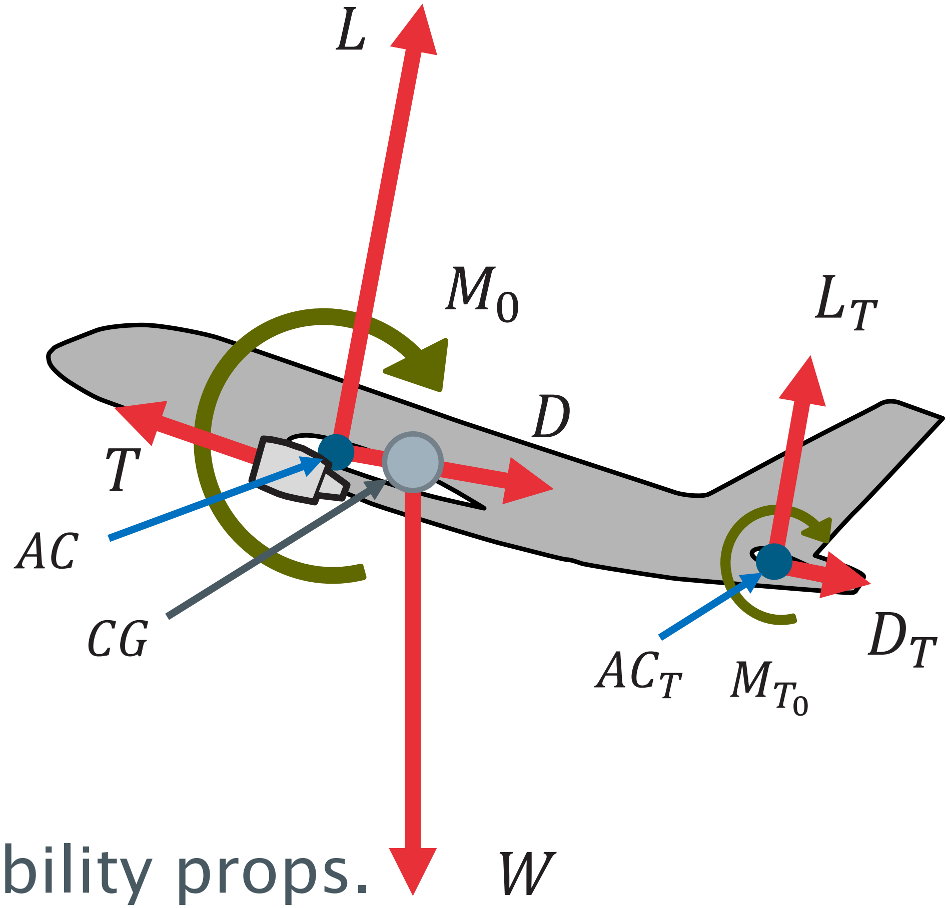
- Pitching moment around CG

$$M_{CG} = L \times (x_{AC} - x_{CG}) + M_0 + \ldots$$

- Differentiate w.r.t. α

$$\frac{dM_{CG}}{d\alpha} = \frac{dL}{d\alpha} \times (x_{AC} - x_{CG}) + \ldots$$

proportional to C_{L_α}



- Aspect ratio has direct implications on stability props.
- Tail plane contribution is also affected by downwash!

Finite wing influence

Downwash effect on drag I

Given the downwash angle due to the trailing vortices:

$$\varepsilon = \varepsilon_\alpha(\alpha - \alpha_0) = \frac{C_L}{\pi A e}$$

The effective lift force gets tilted backwards and this induces additional drag; for small angles: $\sin\varepsilon \approx \varepsilon$, therefore this vortex-induced drag is:

$$C_{D_i} = C_L \varepsilon = \frac{C_L^2}{\pi A e}$$

combineing equations, with some basic use of geometry