MAE 158 Lecture 8
Fall 2024

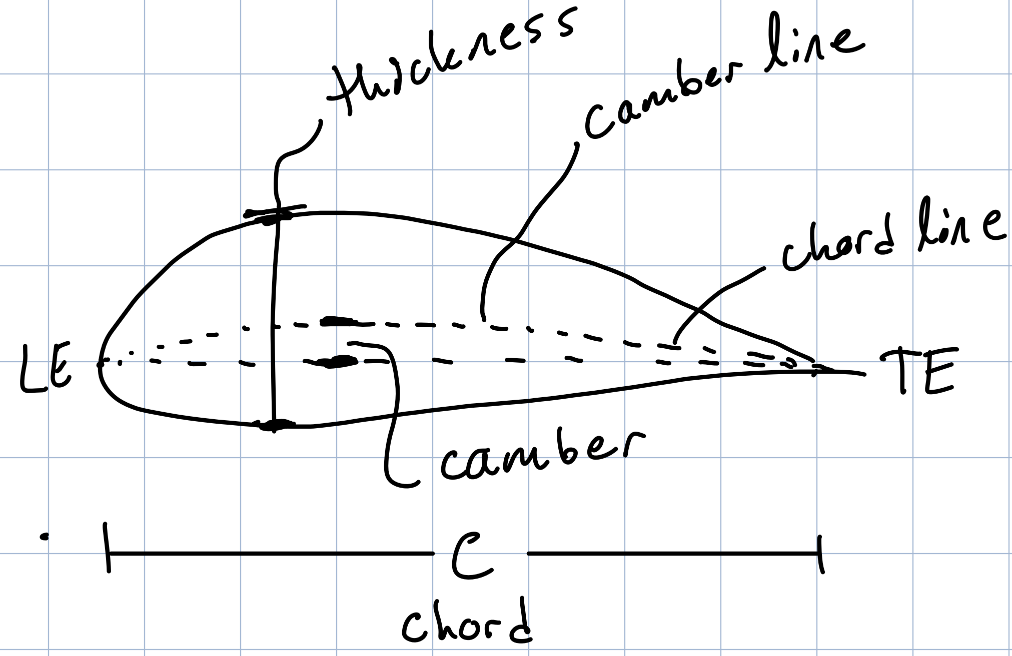
Announcements: HW 5 posted

Today's Objectives: Airfoils

last time:

$$\text{Drag} = \underbrace{f \cdot q}_{\text{profile}} + \underbrace{\left(\frac{L}{b}\right)^2 \frac{1}{\pi q e}}_{\text{induced}} + \text{compressibility}$$

Airfoils
↓
cross sections of wings, tails, pylons ...



<u>thickness</u> - distance between top &

Bottom of Airfoil $\perp$
to the chordline
- t/c → thickness to chord
Ratio → max thickness

<u>camber</u> - distance between camberline & chord line
- camber line is the midpoint between the top & Bottom of Airfoil

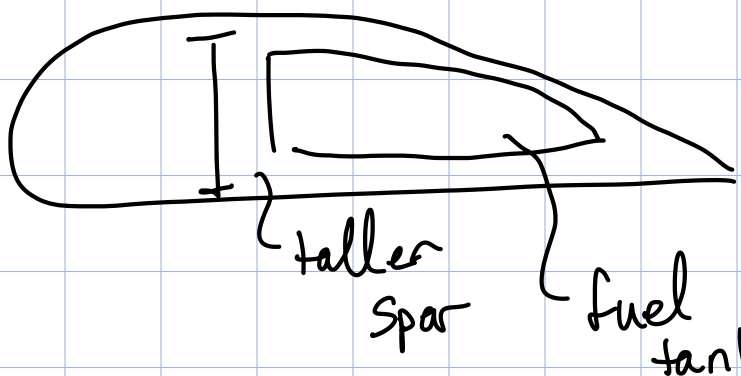
- Rounded LE → keep attached flow for different α

- sharp TE → established Kutta condition

camber → effect of changing lift curve

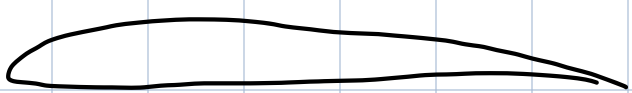
↳ increase C_l @ a given α

thickness →



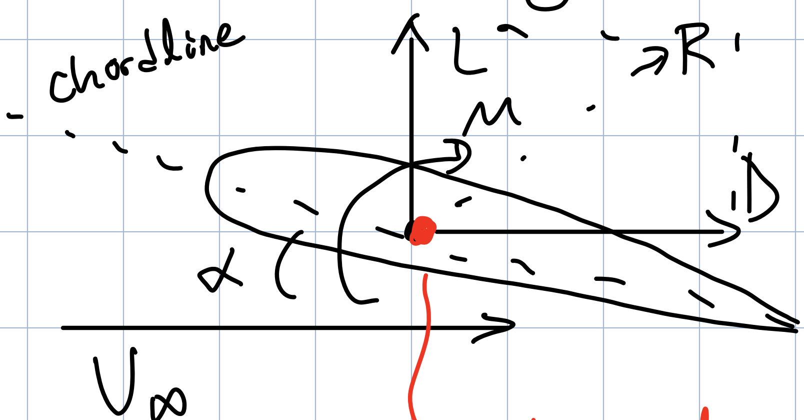
thicker → structures → more efficient for bending loads

thinner airfoil



better for compressibility drag

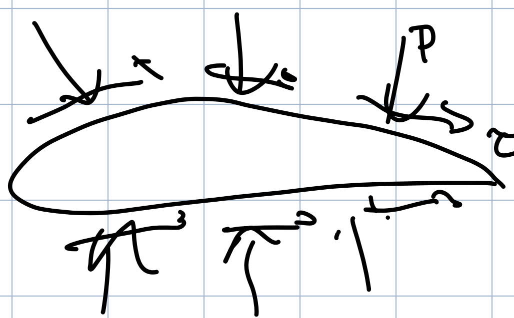
Lift, Drag, Moment

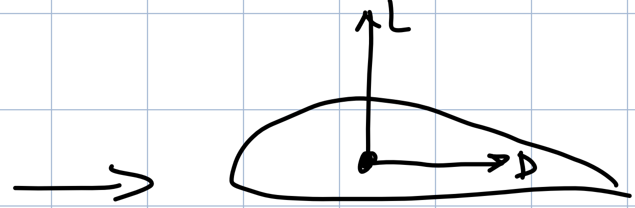


Moment (M) is + if it serves to increase α

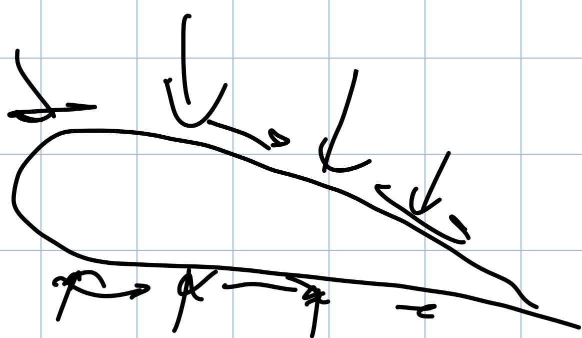
where do you put the resulting forces?

One option:



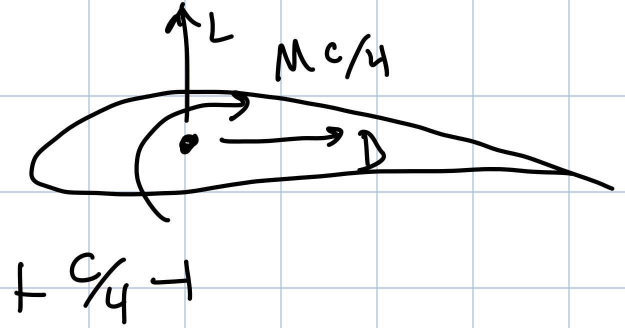


if sum, the p & τ distribution the centroid is <u>center of pressure</u>



as α changes, then the location of center of pressure changes → not convenient

Option 2 (typically used)



put forces & Resulting moment @ c/4 point

~> because $M_{c/4}$ stays *Relatively* constant with α

c/4 point is near <u>aerodynamic center</u> for most Airfoils

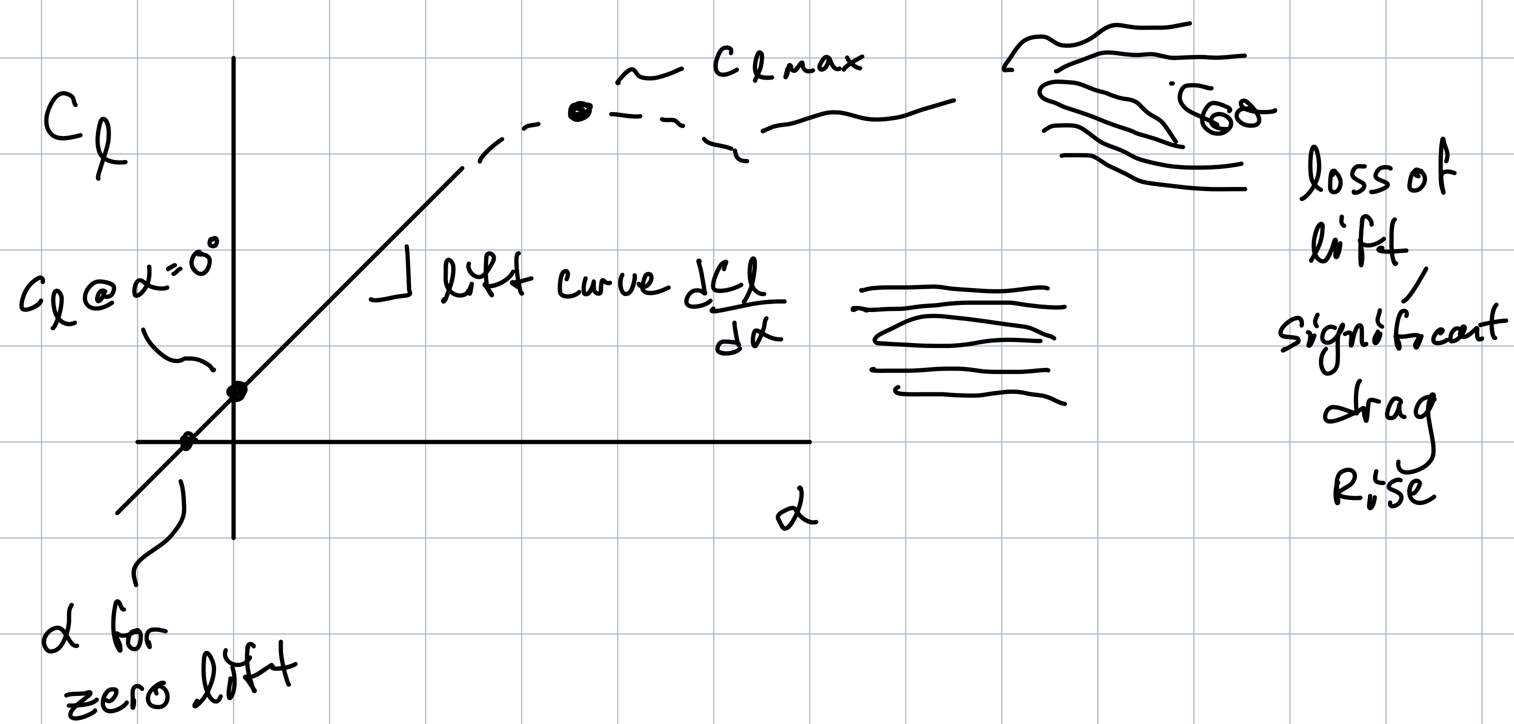
aerodynamic center: location where moment is constant with α

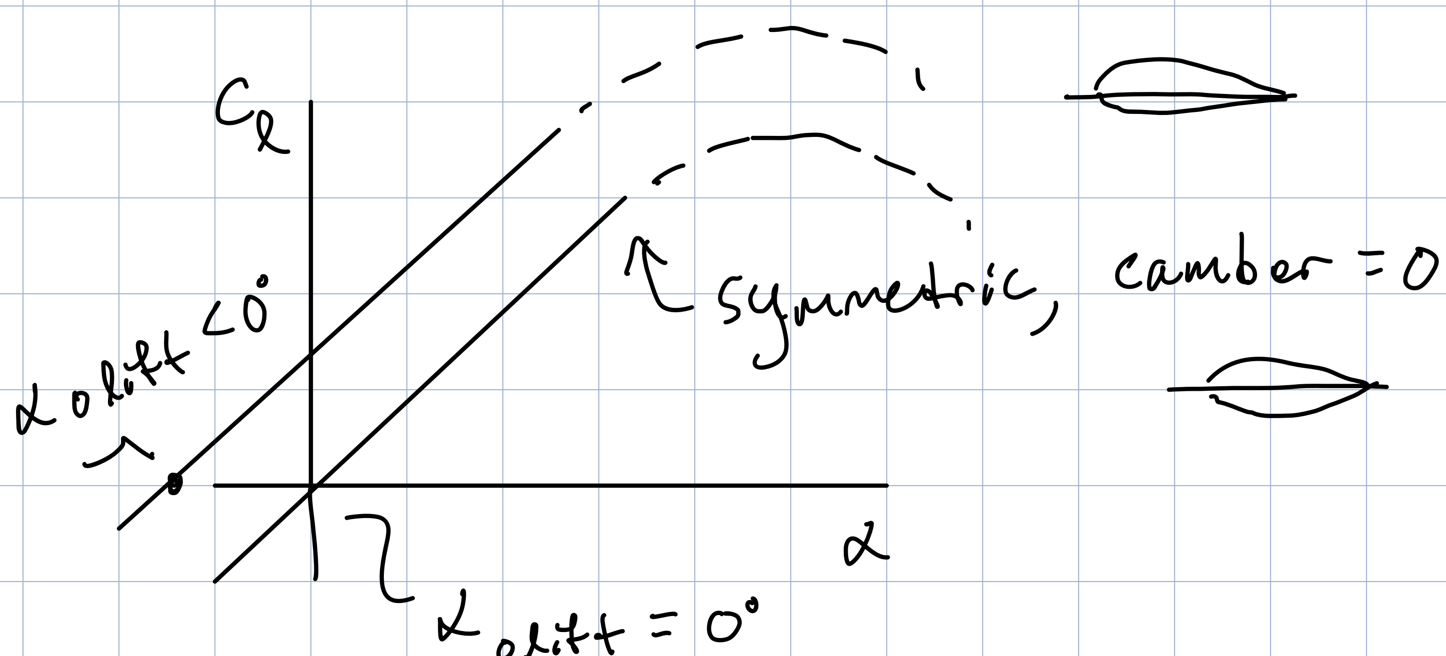
2d airfoils airfoiltools.com

$$C_l = f(\alpha, Re, M)$$
$$C_d = f(\alpha, Re, M)$$
$$C_m = f(\alpha, Re, M)$$

Re, M are <u>similarity parameters</u>

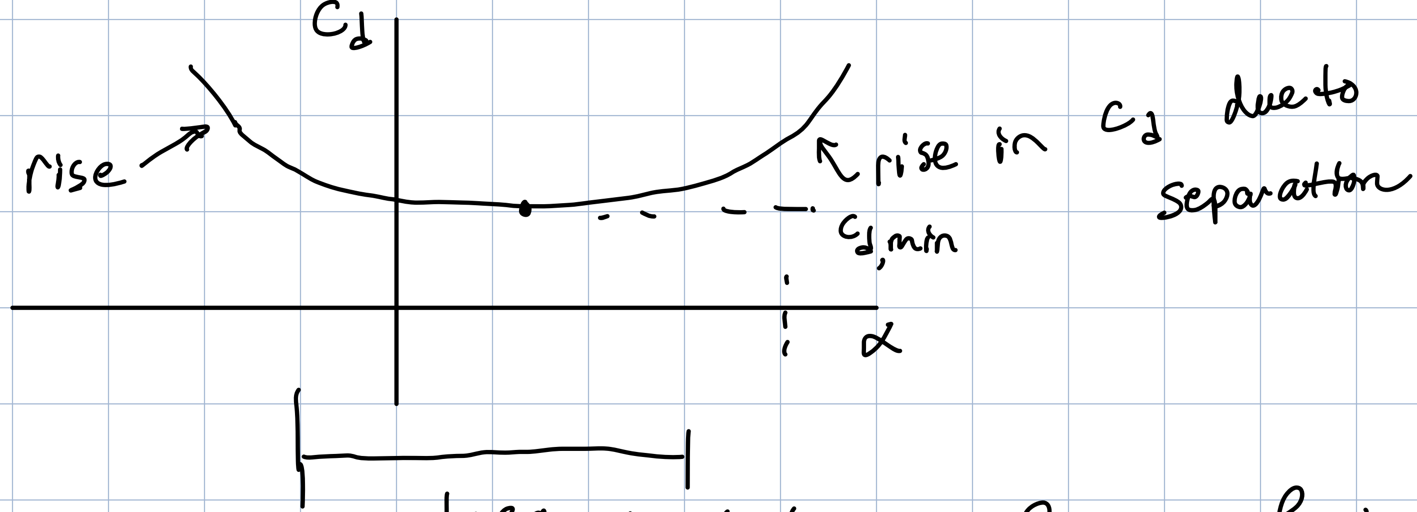
if operate in conditions where Re & M are the same for 2 airfoils of the same shape but different c, V, ρ .... then the coefficients will be the same





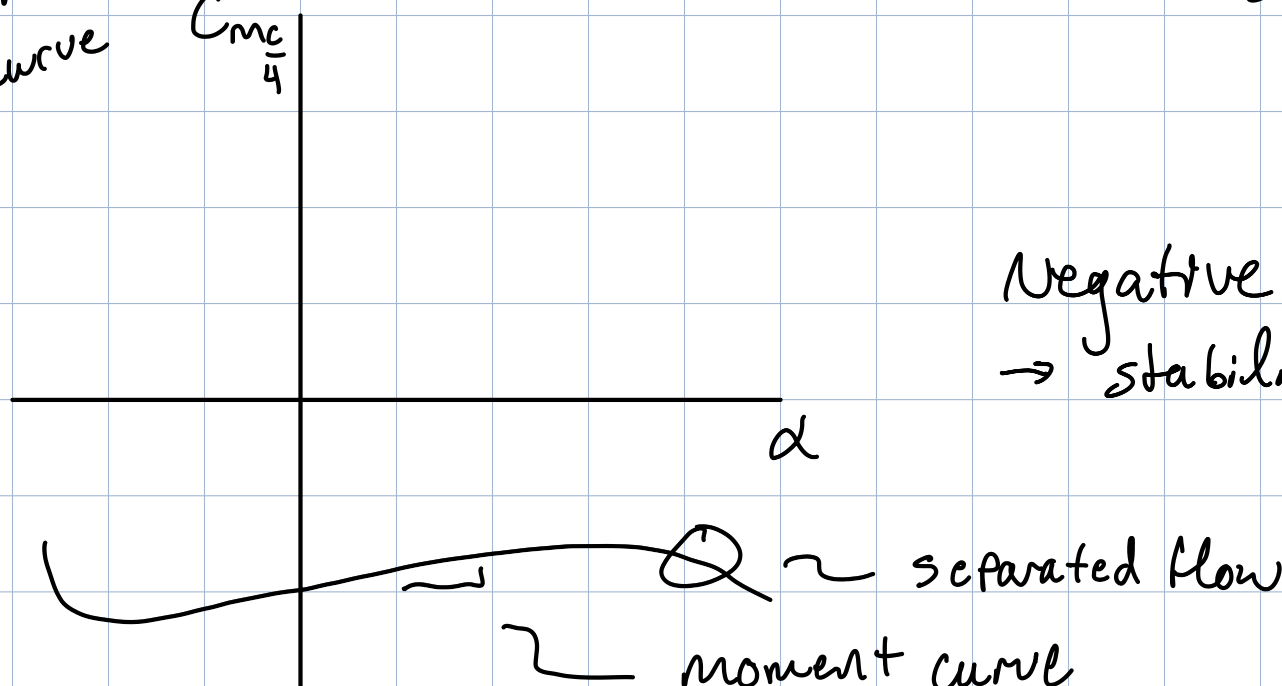
↳ 2D c_l → convert to 3D C_L if you want to get C_{D_i}

drag curve



drag bucket ~> Range of α where c_d is low

moment curve

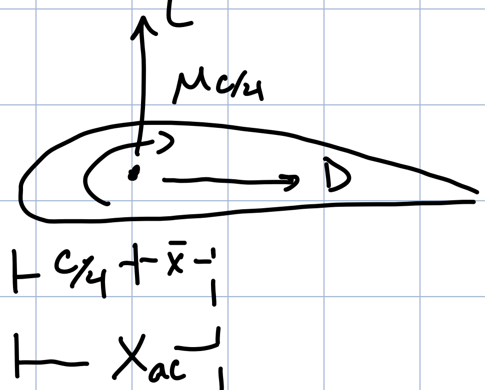


Negative C_m → stability

Slope $\frac{d C_{m_{c/4}}}{d\alpha} = m_0$

~ constant over a Reasonable α Range

Aerodynamic Center: can find it knowing m_0, a_0



$$M = C_m \cdot q \cdot S_{REF} \cdot C$$

$$\frac{M_{ac}}{q S_{REF} c} = \frac{L \bar{x}}{q S_{REF} c} + \frac{M_{c/4}}{q S_{REF} C}$$

$$\rightarrow \quad C_{m_{ac}} = C_l \cdot \frac{\bar{x}}{c} + C_{m_{c/4}}$$

if you want location of AC $\rightarrow$ find where $C_{m_{ac}}$ is a const with α

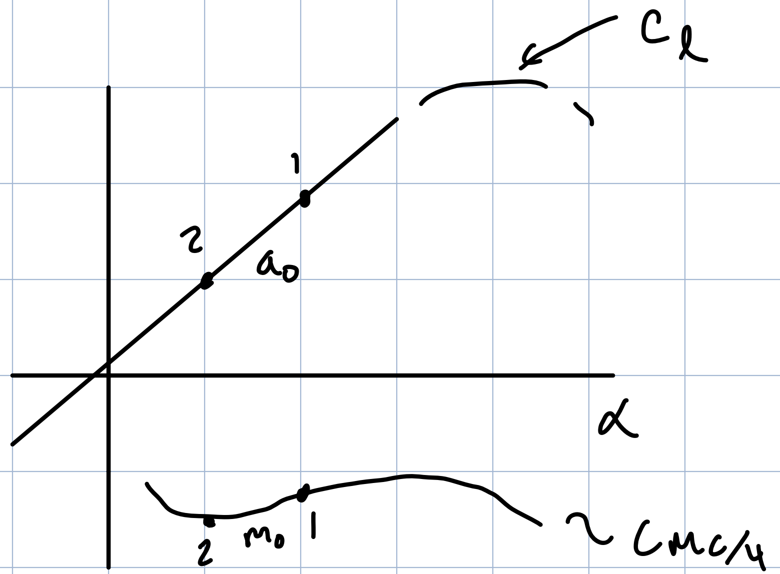
$\hookrightarrow \quad \frac{dc_{m_{ac}}}{d\alpha} = 0$

differentiate with α

$$\frac{dC_{m_{ac}}}{d\alpha} = \frac{dc_l}{d\alpha}\frac{\bar{x}}{c} + \frac{dC_{m_{c/4}}}{d\alpha} = 0$$

thus:

$$\frac{\bar{x}}{c} = -\frac{dC_{m_{c/4}}/d\alpha}{dC_l/d\alpha} = \frac{-m_0}{a_0}$$



$$a_0 = \frac{C_{l_1} - C_{l_2}}{\alpha_1 - \alpha_2}$$

$$m_0 = \frac{C_{m_{c/4},1} - C_{m_{c/4},2}}{\alpha_1 - \alpha_2}$$

$C_L \rightsquigarrow$ $a_0 = 2\pi\eta$

↳ for $\frac{dc_l}{d\alpha}$

then $\frac{dC_L}{d\alpha} = \frac{a_0}{1 + \frac{a_0}{\pi A\!\!\!R}}$ ← in 3D

include M & Λ affect

$$\frac{dC_L}{d\alpha} = \frac{2\pi AR}{\left[2+\sqrt{\left(\frac{AR}{\eta}\right)^2\left(1+\tan^2\Lambda - M_\infty^2\right)}\right]}$$

$C_d \rightsquigarrow$ pressure + shear stress distribution

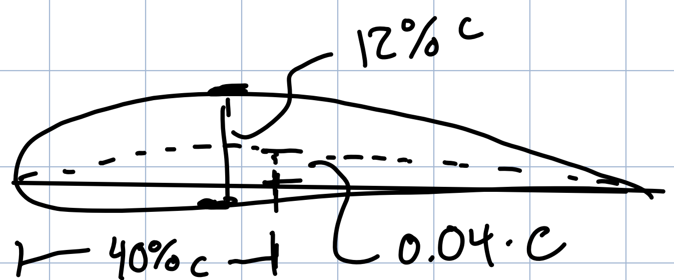
$C_D \rightsquigarrow C_{D_p} + C_{D_i} + \Delta C_{D,c}$

$\uparrow$ C_L

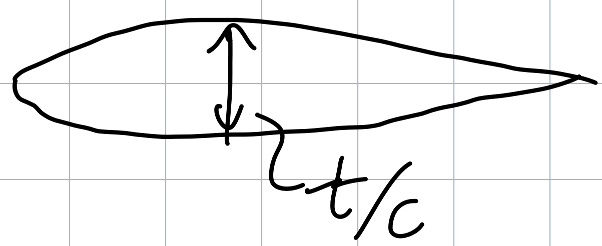
NACA 4 series (Naming Convention)

NACA 4412

- 4 — max camber in % of chord ($0.04 \cdot c$)
- 4 → location of max camber in 1/10th of chord. (40% chord)
- 12 — max t/c in % chord (12% t/c)



- NACA 00 12
  - 12 → max t/c
  - 00 → symmetric, camber = 0



- NACA 5 Series

ex: NACA 2 30 15

- 2 → $\frac{20}{3}$ of the design c_l
- 30 → 2x position of max camber, %c
- 15 → t/c

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thrust Required

If you are steady, level,

$\gamma = 0°$, $\Delta V = 0$

$\hookrightarrow W = L$
$T = D$

thrust Required = Drag

$$\underline{N_{eng}} \cdot \frac{\text{Thrust}}{\text{eng}} = \text{Drag}$$

How do we get T_R?

if you know W, AR, S_{REF}

if compressible $C_D = C_{D_p} + \underset{\uparrow \frac{C_L^2}{\pi AR e}}{C_{D_i}} + \Delta C_{D,c}$

if incompressible $C_D = C_{D_p} + \frac{C_L^2}{\pi AR}$

$$\frac{1}{\pi AR e} = K$$

$$= C_{D_p} + K C_L^2$$

$$L = W = \tfrac{1}{2}\rho V^2 S C_L \rightarrow C_L = \frac{2W}{\rho V^2 S}$$

$$D = \tfrac{1}{2}\rho V^2 S C_D = \tfrac{1}{2}\rho V^2 S \left(C_{D_p} + K C_L^2\right)$$

$$= T_R \qquad \underbrace{\quad}_{V^2} \qquad \underbrace{\quad}_{1/V^2}$$