FLOWCOMAG
April 1–2, 2004

SFB 609

Seawater Flow Transition and Separation Control

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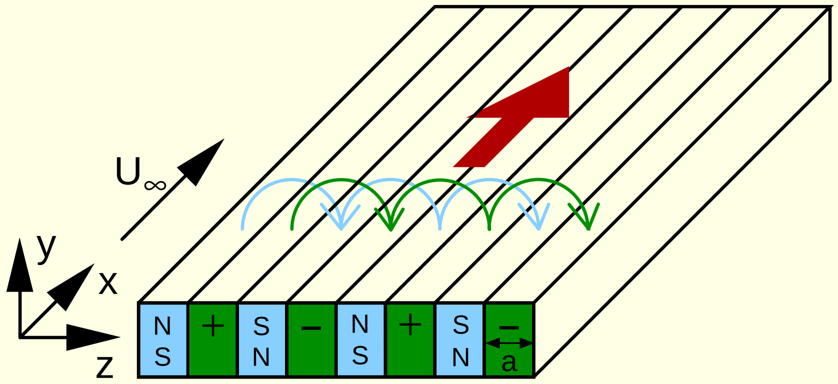
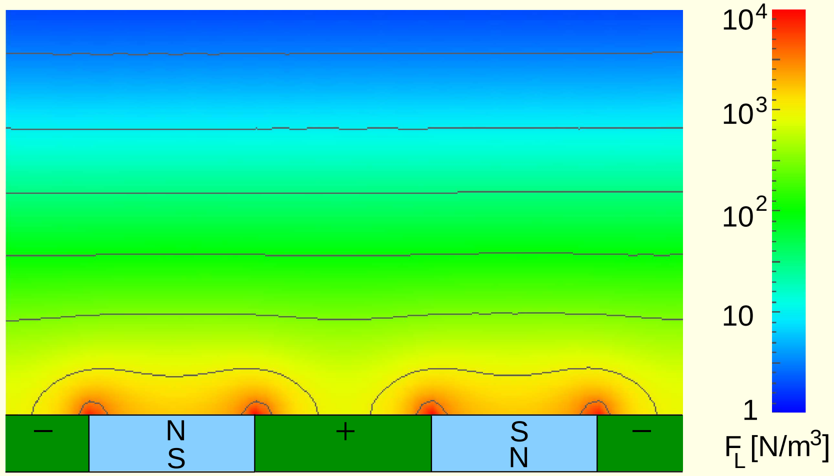
Wall–parallel Lorentz force





Gailitis, Lielausis 1961

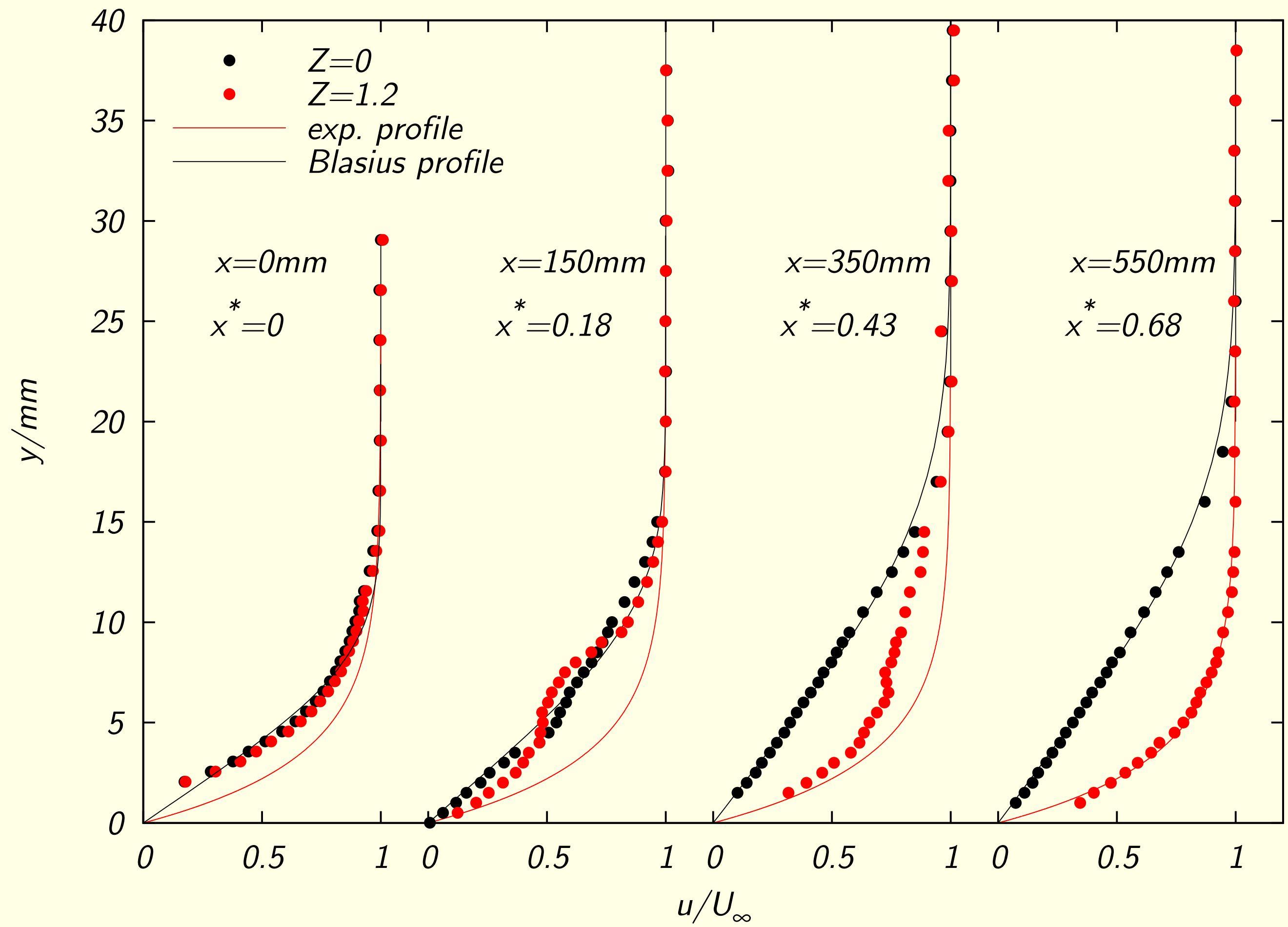
$$u^\star \frac{\partial u^\star}{\partial x^\star} + v^\star \frac{\partial u^\star}{\partial y^\star} = \frac{\partial^2 u^\star}{\partial y^{\star 2}} + Z e^{-y^\star}$$

$$x^\star = \frac{\nu \pi^2 x}{U_\infty a^2}, \; y^\star = \frac{\pi}{a} y, \; u^\star = \frac{u}{U_\infty}, \; v^\star = \frac{va}{\pi \nu}$$

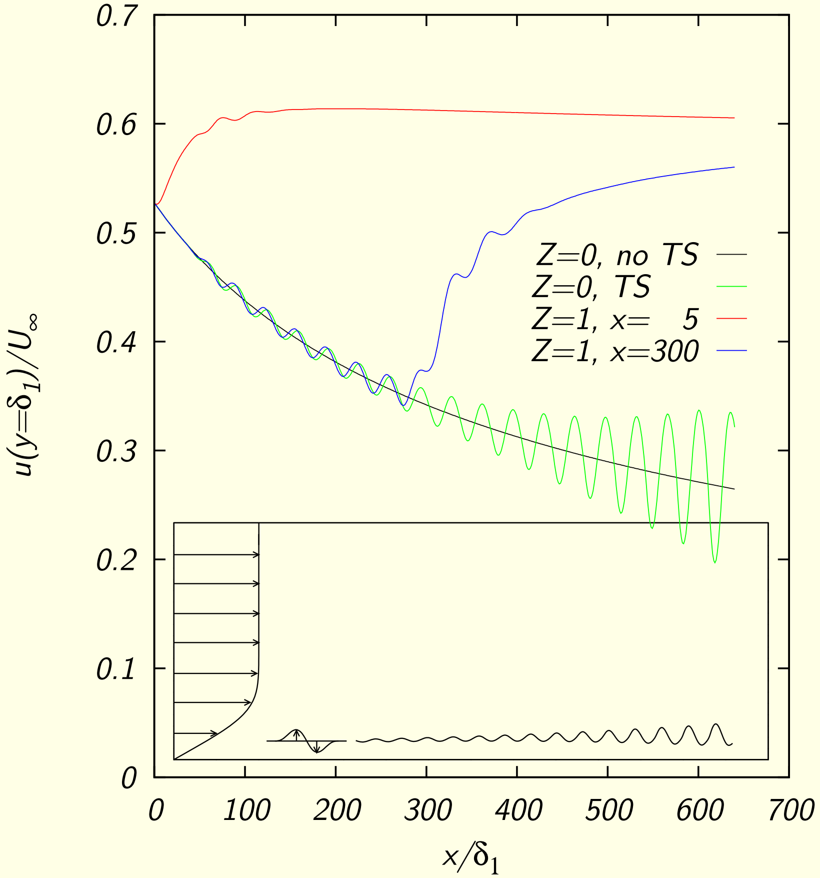
$$Z = \frac{j_0 M_0 a^2}{8 \pi \rho U_\infty \nu} = 1 : \quad \boxed{\frac{u}{U_\infty} = 1 - e^{-\frac{\pi}{a} y}}$$

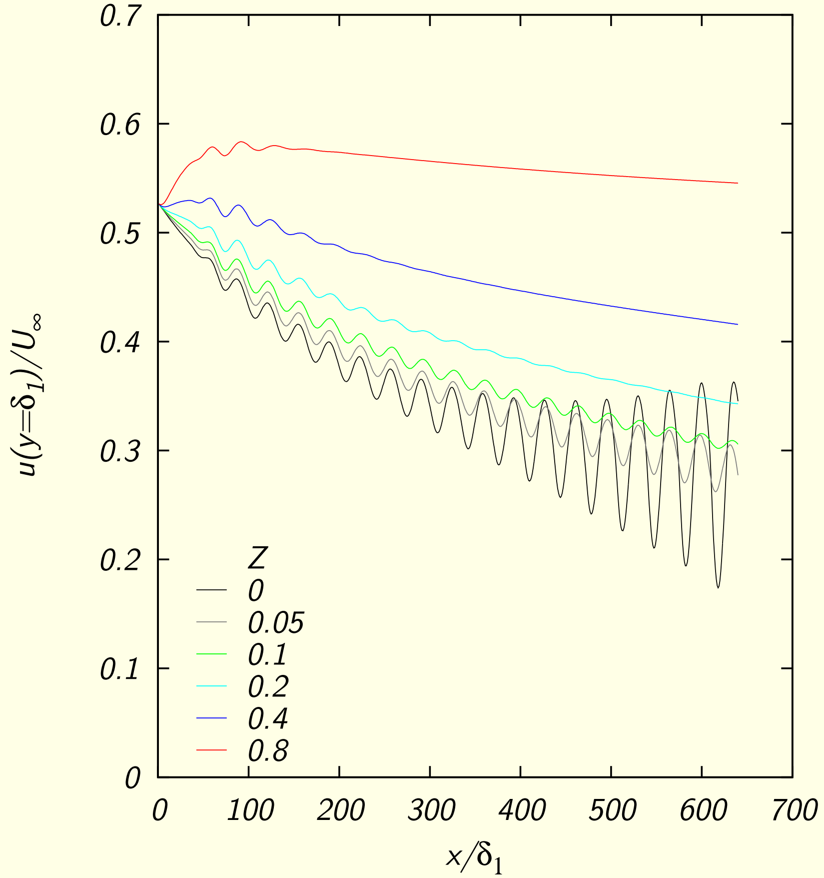
$$\begin{aligned} \mathbf{j} &= \sigma(\mathbf{E} + \mathbf{u} \times \mathbf{B}) \\ \mathbf{F} &= \mathbf{j} \times \mathbf{B} = F \mathbf{e}_x \\ \overline{F} &= \frac{\pi}{8} j_0 M_0 e^{-\frac{\pi}{a} y} \end{aligned}$$

Laminar Boundary Layer with Lorentz force $\mathrm{Re}_{\delta_1} = 290$

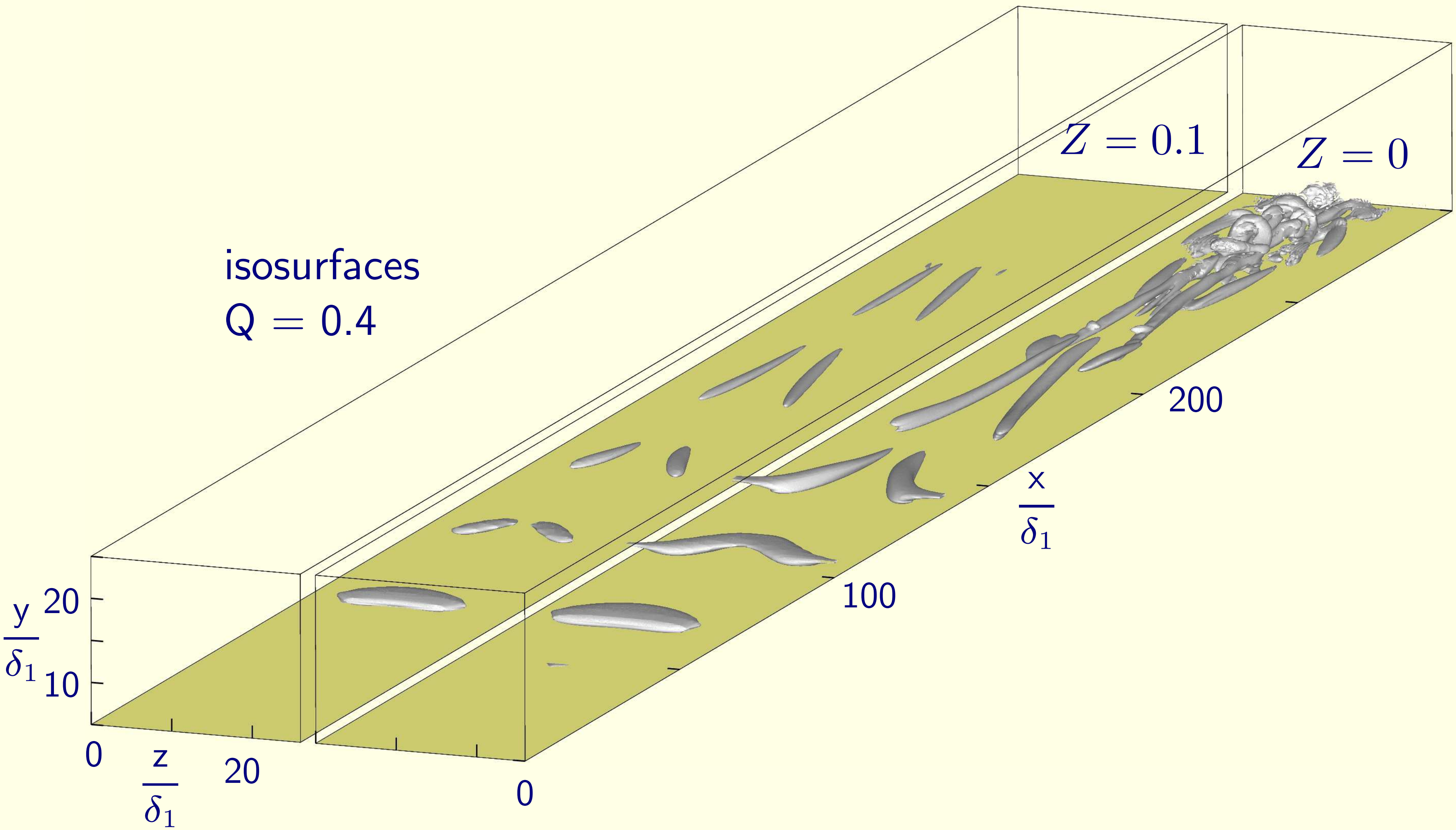


Transition: T–S waves for $\mathrm{Re}_{\delta_1} = 585$, $a = 3.475\delta_1$

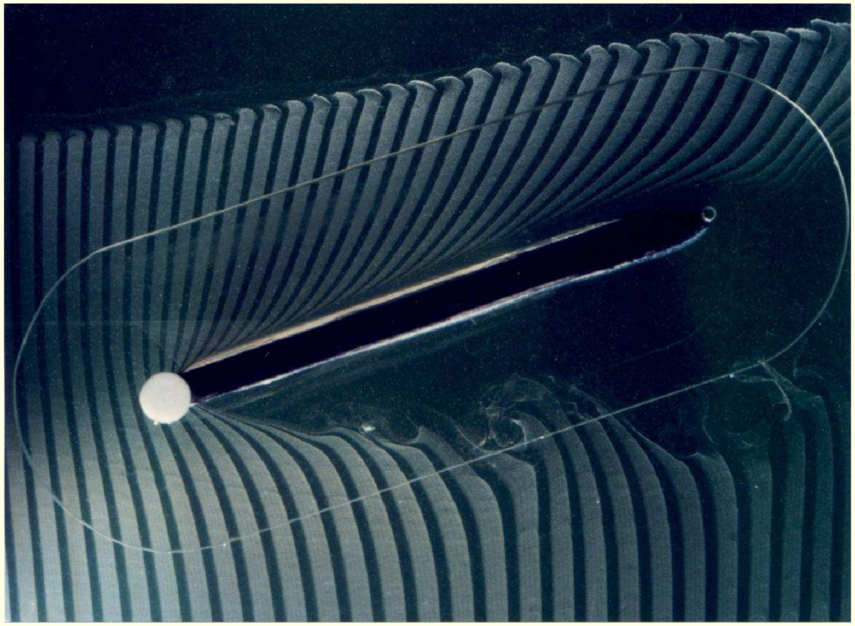


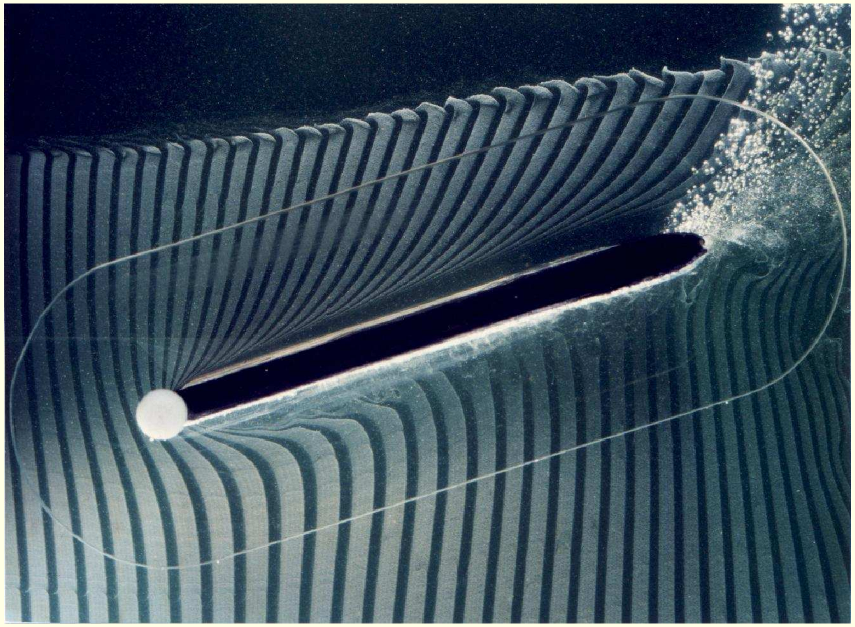


Transition: 3D disturbance for $\mathbf{Re}_{\delta_1} = \mathbf{585}$, $\mathbf{a} = \mathbf{3.475}\delta_1$



Separation suppression at an inclined flat plate



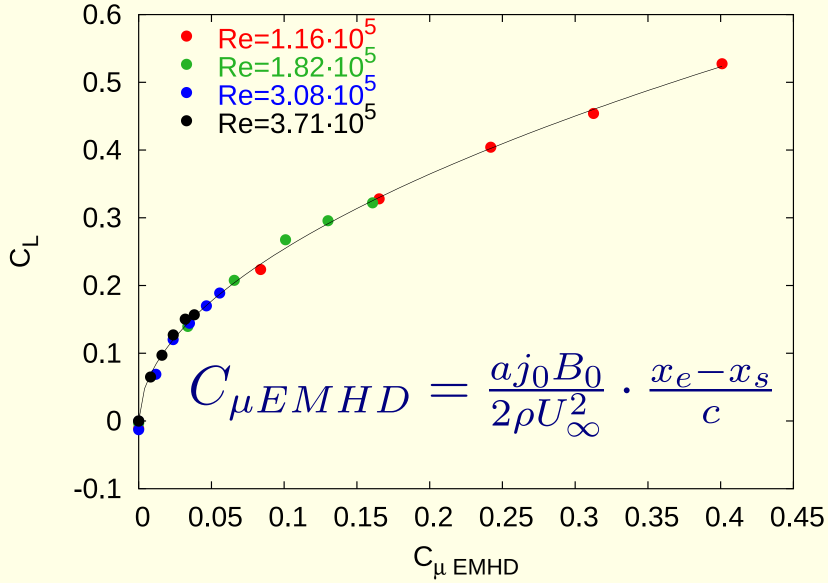


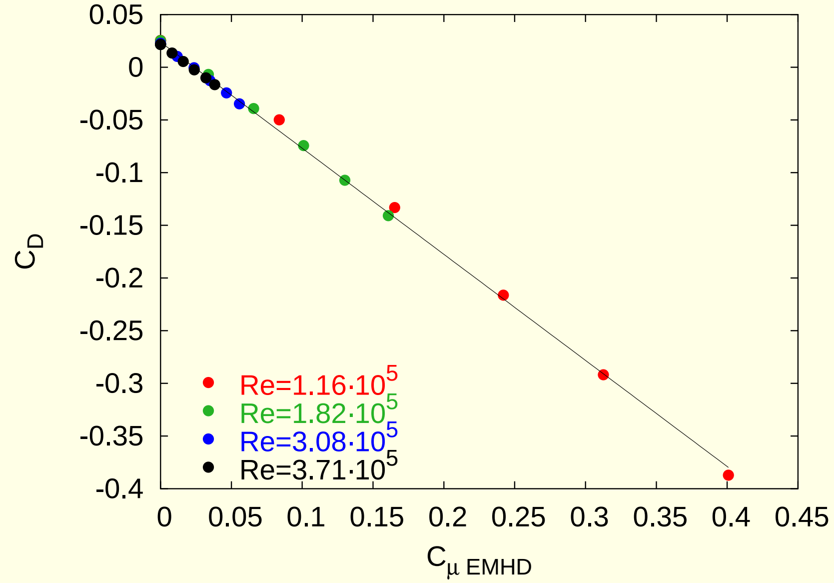
Hydrofoils with electrodes and magnets

NACA 0015 (left):
$c = 0.667\text{m}$
$a/c = 0.015$
$B_0 = 0.58\text{T}$
stainless steel electrodes

PTL IV (right):
$c = 0.158\text{m}$
$a/c = 0.03$
$B_0 = 0.2\text{T}$
Ti with RuO_2/IrO_2 (DSA)

NAACA 0015 in parallel flow

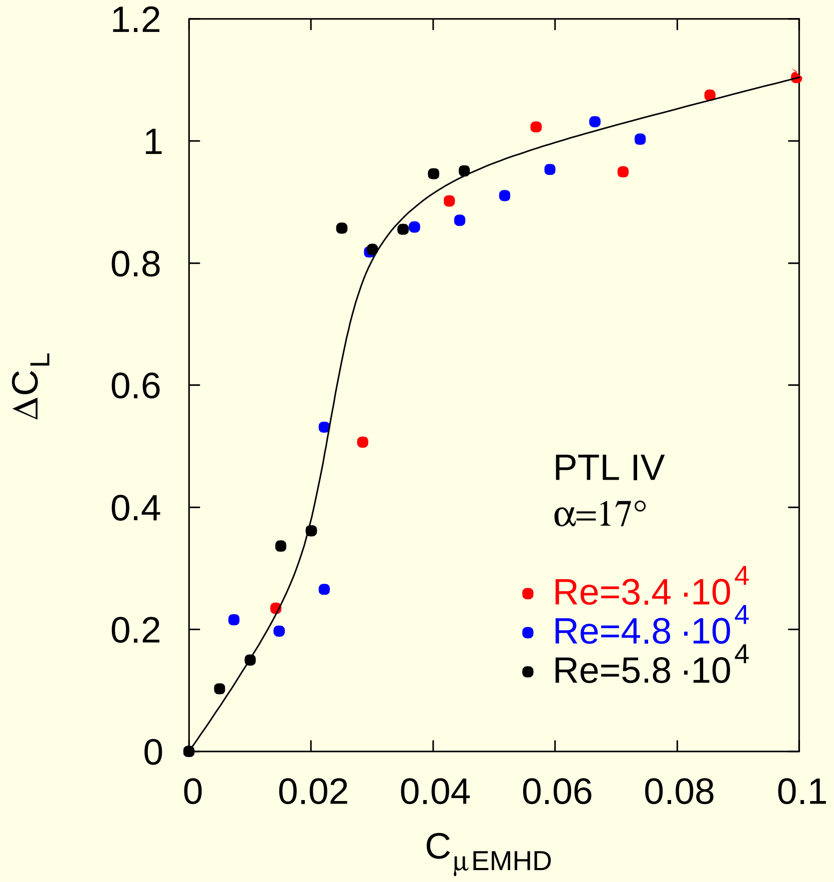


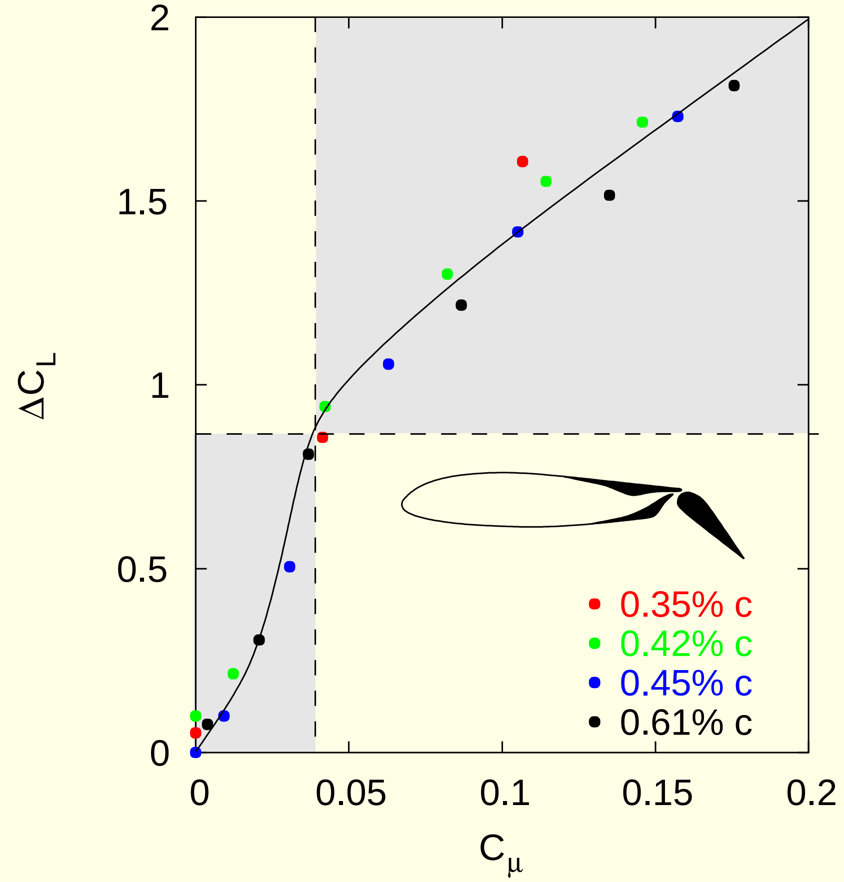


$$C_L = 0.843 \cdot C_{\mu EMHD}^{0.521}$$

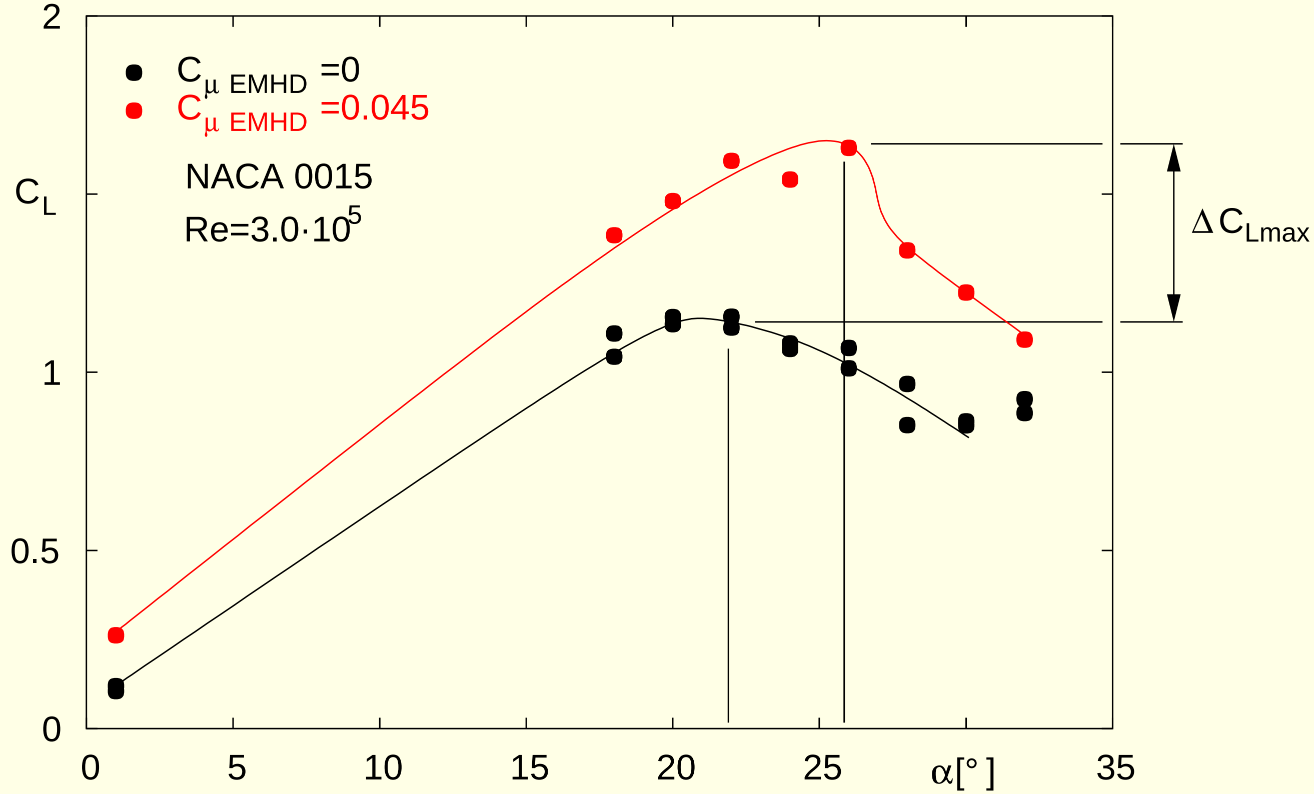
$$C_D = 0.024 - 1.01 \cdot C_{\mu EMHD}$$

Reattachment: Comparison to steady blowing



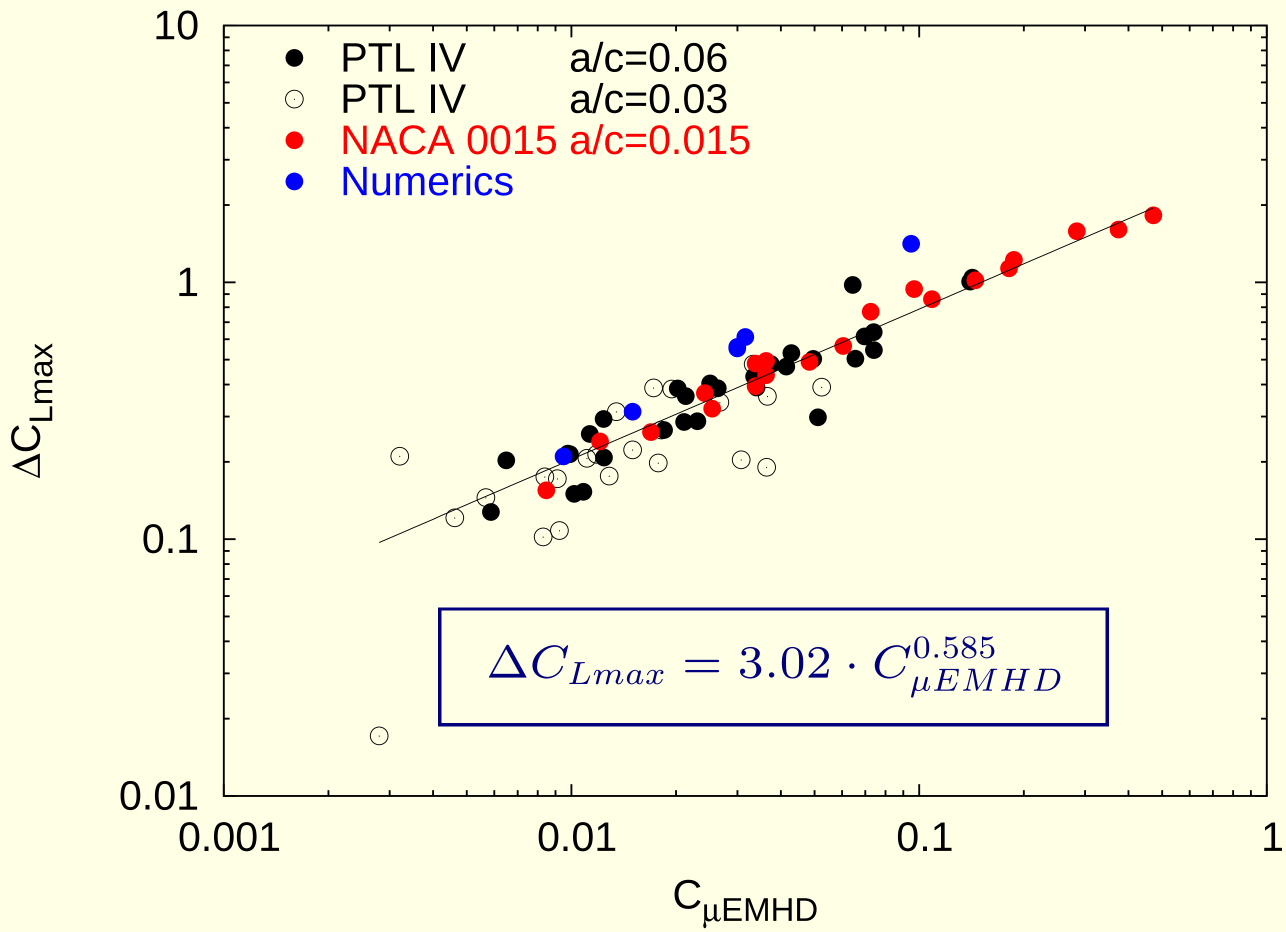


Maximum lift gain

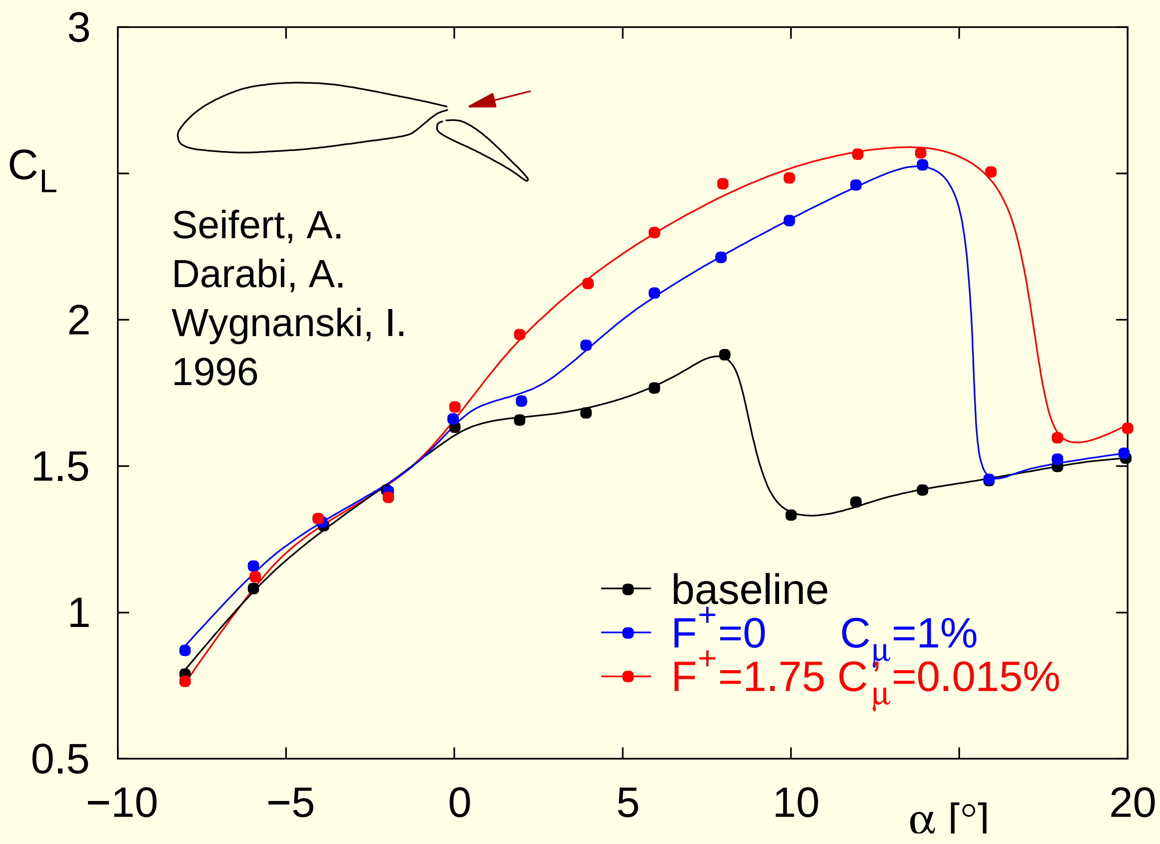


$$\Delta C_{Lmax}(C_\mu, Re) = C_{Lmax}(C_\mu, Re) - C_{Lmax}(C_\mu = 0, Re)$$

Maximum lift gain versus $C_{\mu EMHD}$

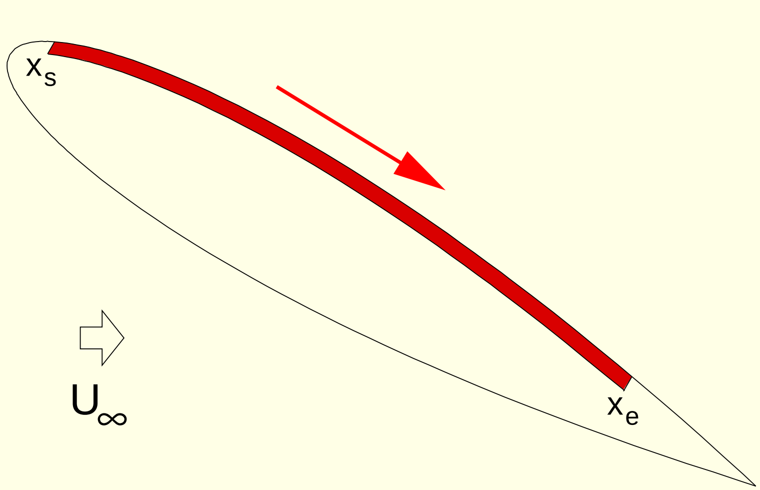


Oscillatory forces: Motivation



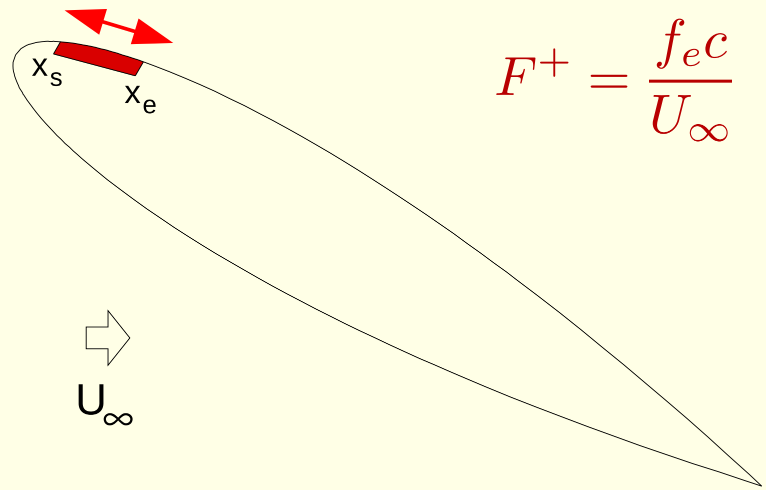
Lorentz force configurations compared

stationary:



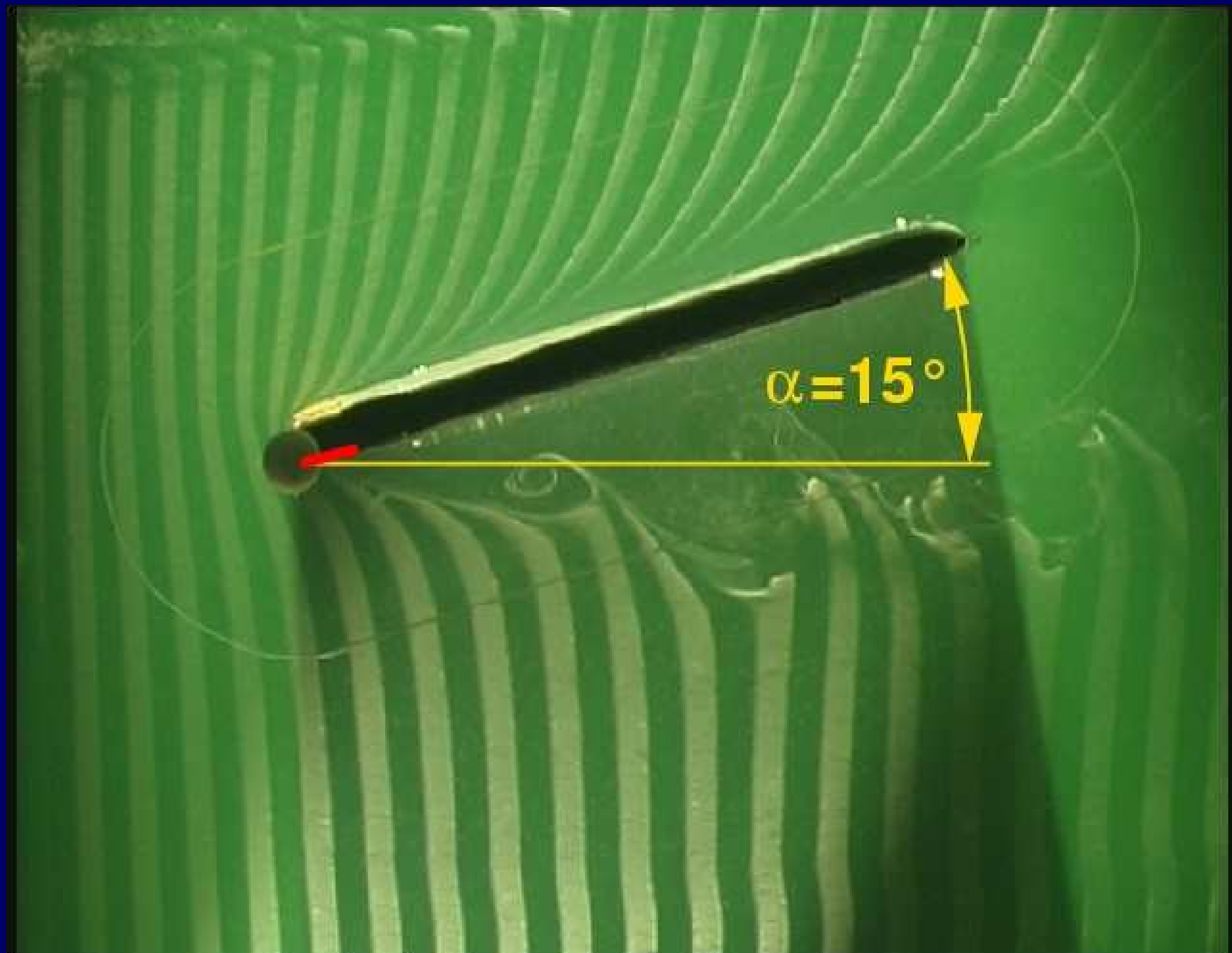
$$C_{\mu EMHD} = \frac{1}{2} \cdot \frac{a j_0 B_0}{\rho U_\infty^2} \cdot \frac{x_e - x_s}{c}$$

oscillatory:

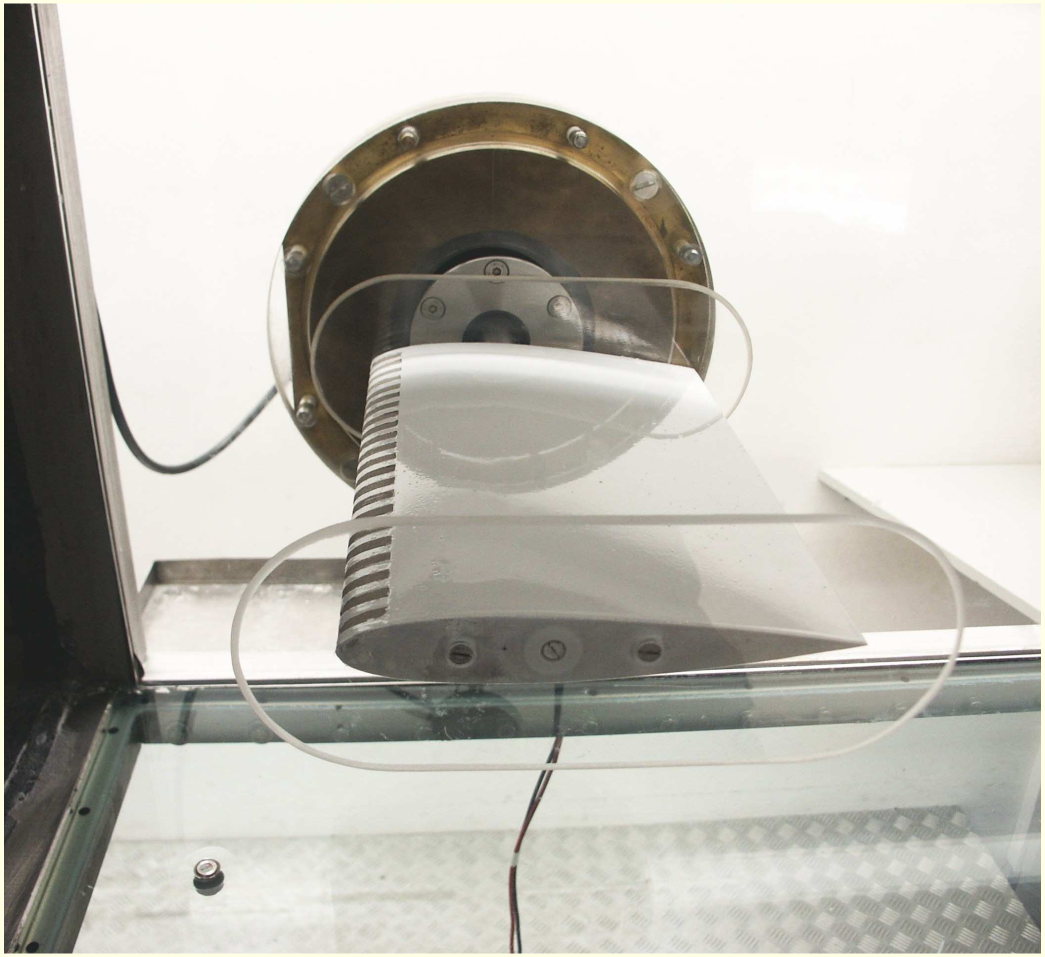


$$F^+ = \frac{f_e c}{U_\infty}$$

$$C'_{\mu eff} = \frac{1}{2} \cdot \frac{a j_{0eff} B_0}{\rho U_\infty^2} \cdot \frac{x_e - x_s}{c}$$

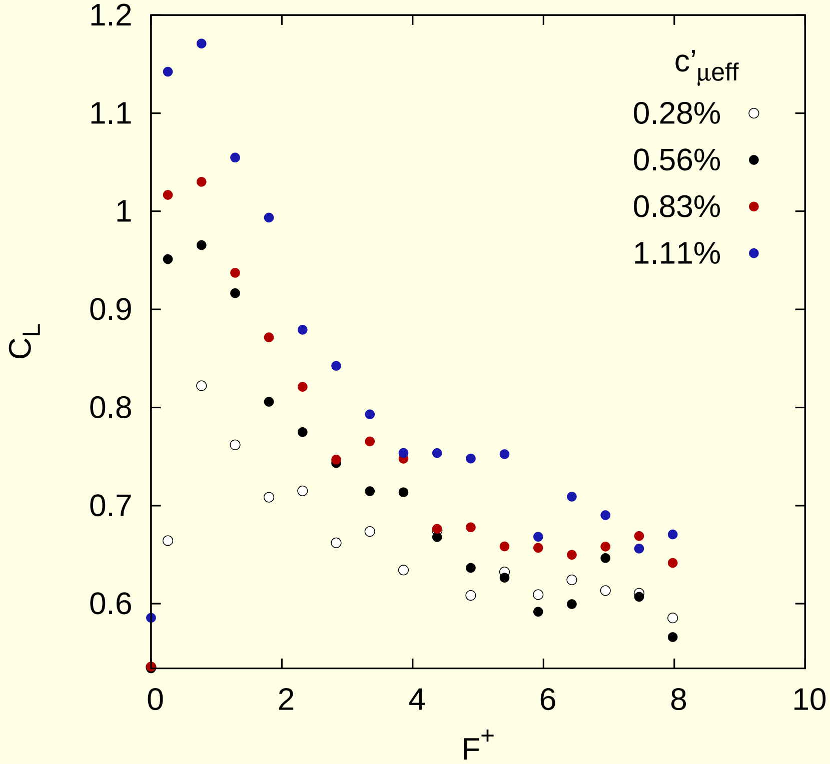

α=15°

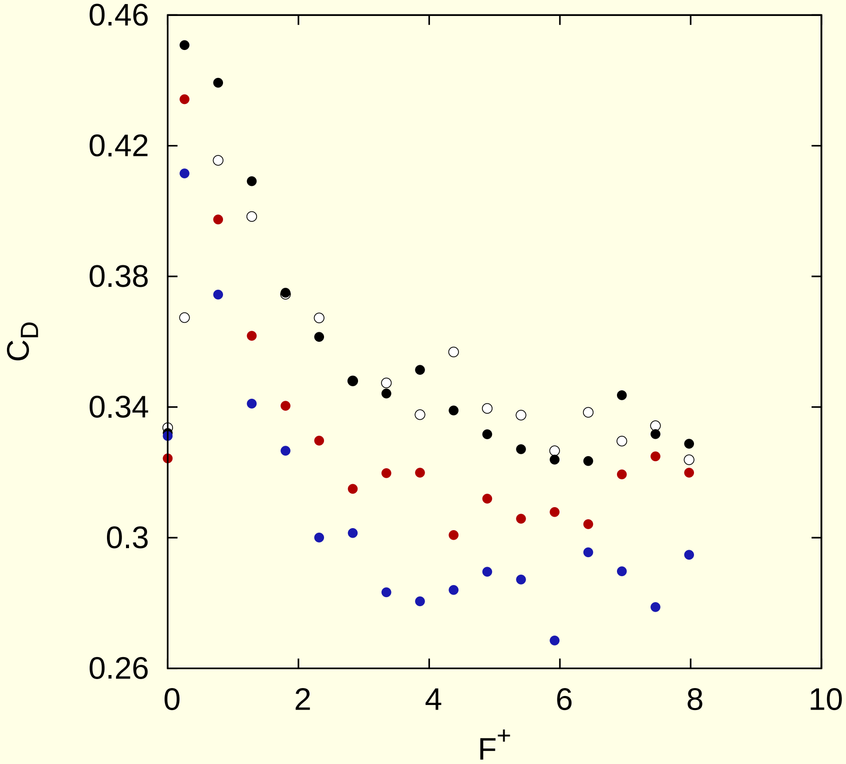
NACA 0015 in the test section



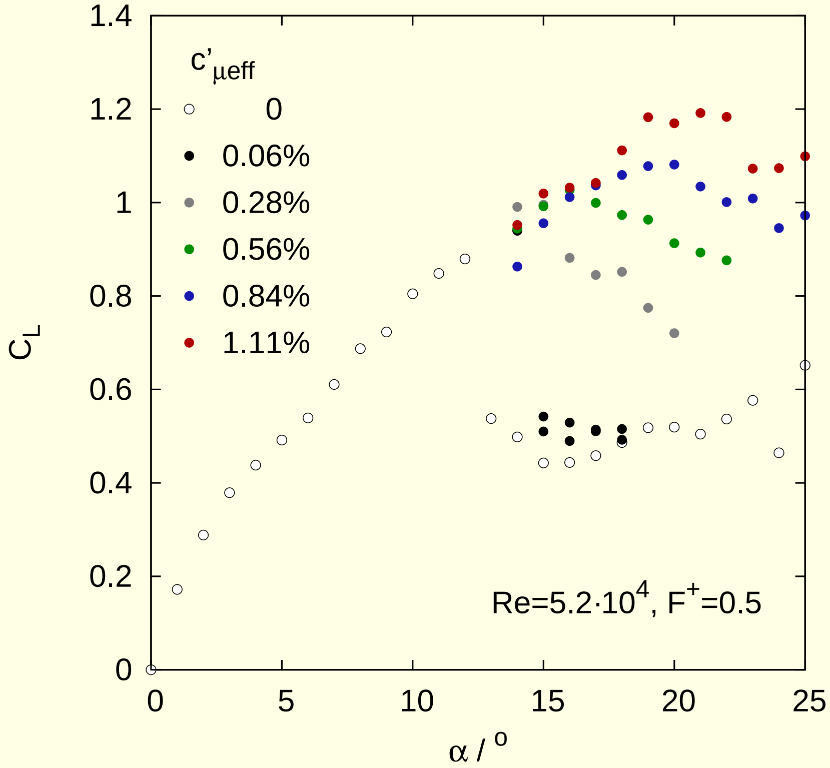
$$
\begin{aligned}
c &= 160 \text{ mm} \\
s &= 240 \text{ mm} \\
x_a &= 15 \text{ mm} \\
a &= 5 \text{ mm} \\
B_0 &= 0.33 \text{ T}
\end{aligned}
$$

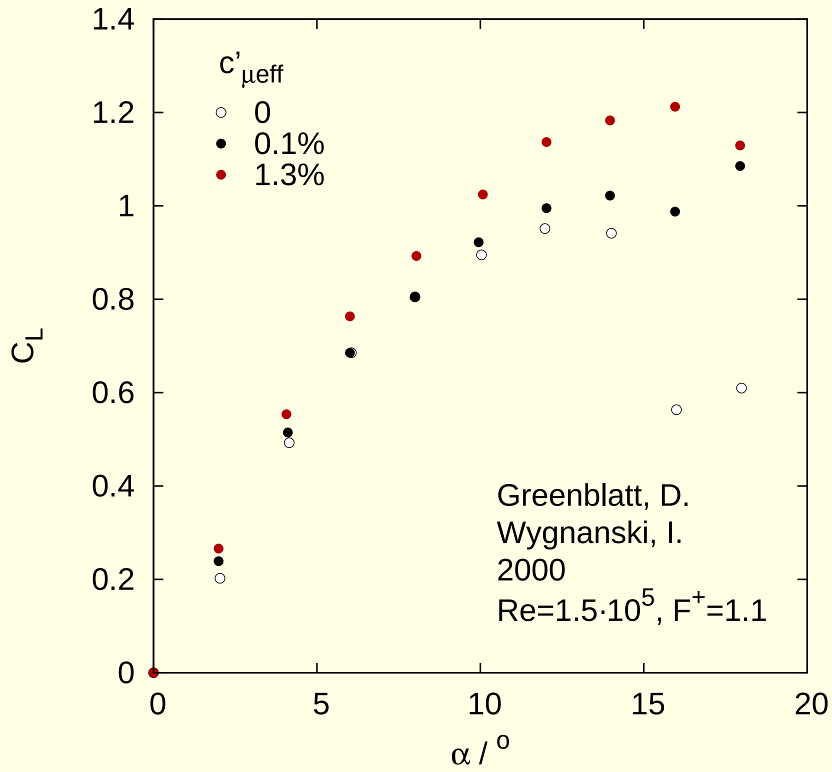
Lift- and drag coefficient versus excitation frequency, $\alpha = 20°$, $Re = 5.2 \cdot 10^4$



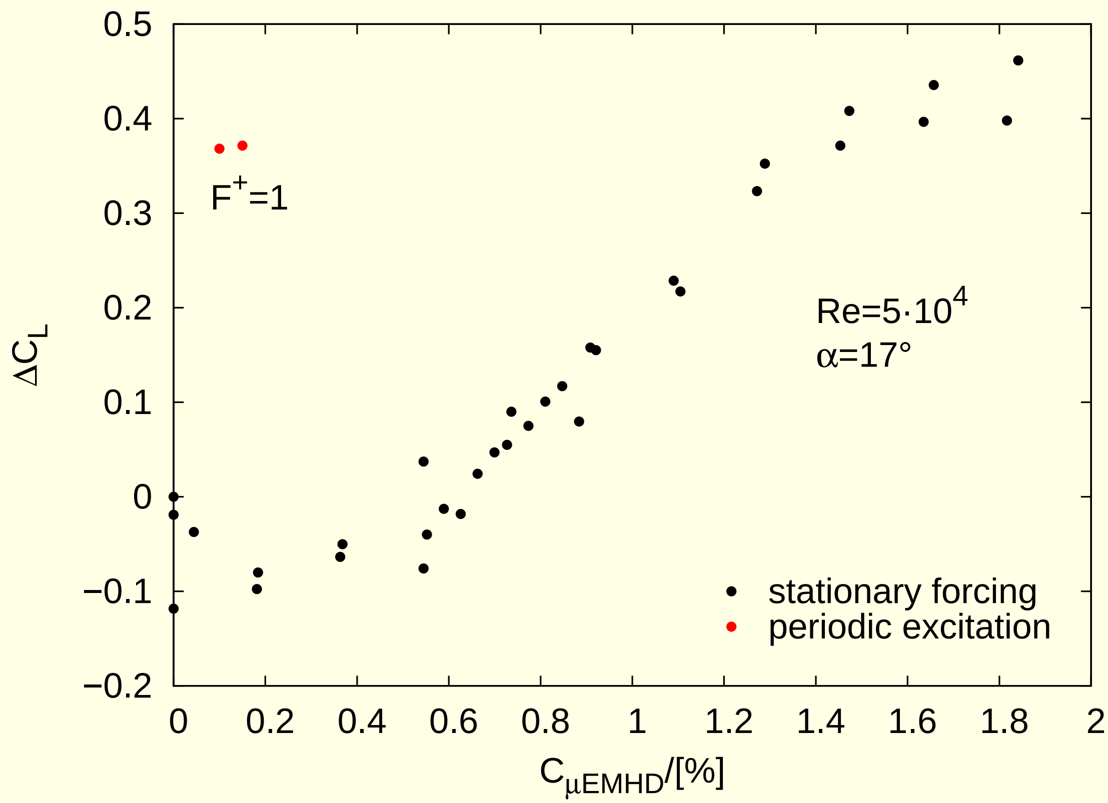


Comparison to oscillatory blowing on a NACA 0015

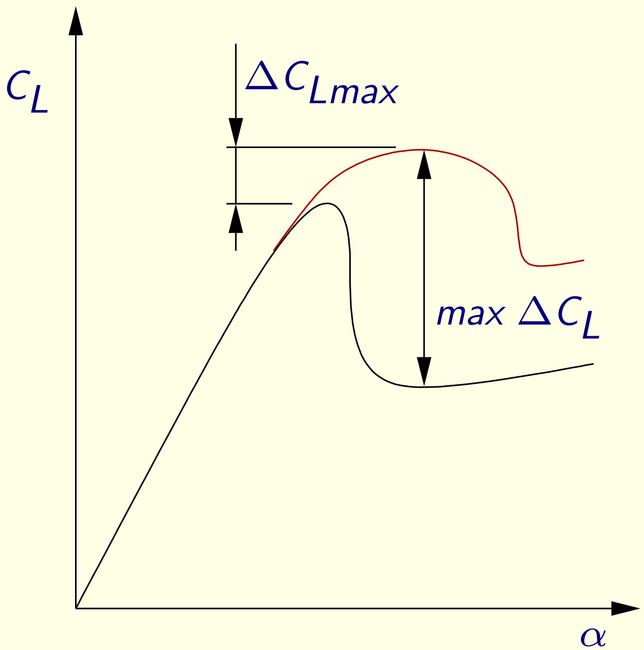


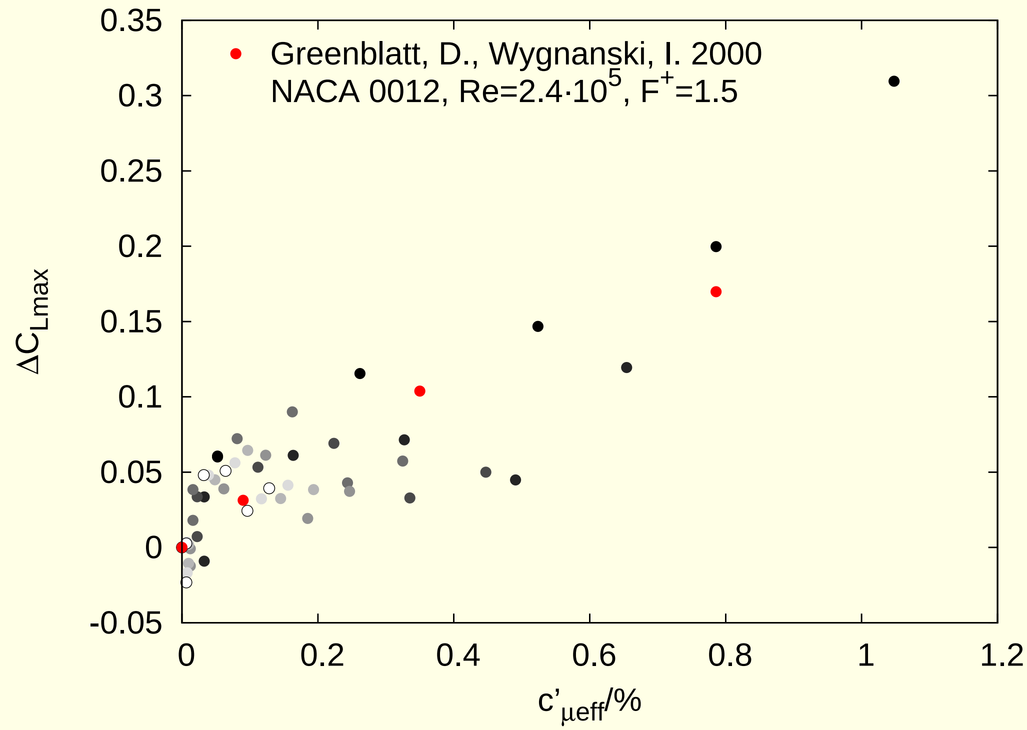


Lift increase at constant angle of attack



Maximum lift gain





Conclusions

Transition delay:

- exponential profile
- T–S waves and 3D disturbances are damped

Separation control by stationary Lorentz force:

- separation & circulation can be controlled
- power consumption (too) high (for applications)

Separation control by oscillatory Lorentz force:

- characteristic phenomena comparable to alternative methods in a quantitative sense

➡ comparable gain in efficiency achievable (?)