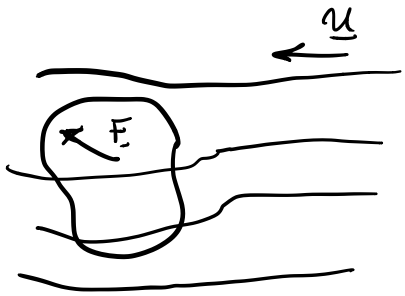
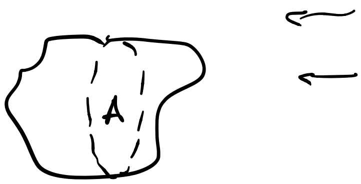
Drag equation





Relevant quantities:

- flow velocity u $\quad m/s$
- density ρ $\quad kg/m^3$
- viscosity ν $\quad \frac{m^2}{s}$
- size of the object
  - → frontal area A $\quad m^2$
- force (drag) F_D $\quad N = kg \cdot \frac{m}{s^2}$

Basic units: m, kg, s

Buckingham π-theorem If an equation is described by n independent physical parameters, it can be expressed by m dimensionless parameters and

$$m = n - k$$

where k is the number of basic dimensions.

Here

$$f_a(F_D, u, \rho, \nu, A) = 0$$

$$k = \{kg, m, s\} = 3$$

$$m = n - k = 2$$

We choose

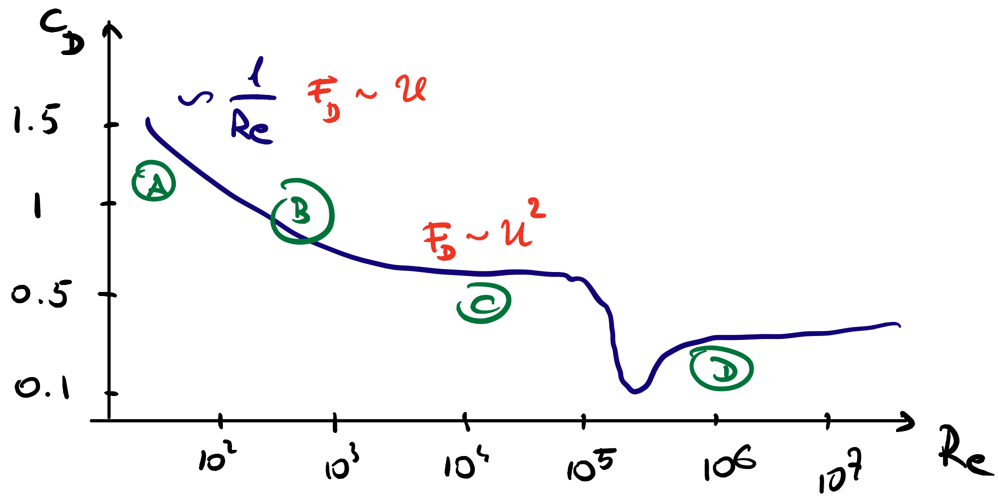
- the Reynolds number $Re = \frac{u\sqrt{A}}{\nu}$
- the drag coefficient $C_D = \frac{F_D}{\frac{1}{2}\rho A u^2}$

$$\Rightarrow \qquad f_b(c_D, Re) = 0$$

So

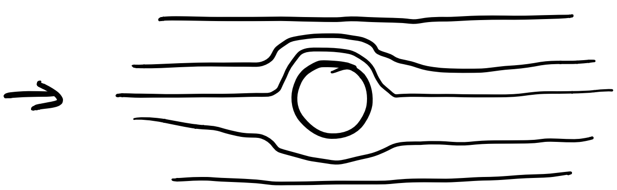
$$F_D = \frac{1}{2} \rho A U^2 f_c(Re) \qquad \text{or} \qquad F_D = \frac{1}{2} C_D(Re) \rho A U^2$$

C_D for a sphere

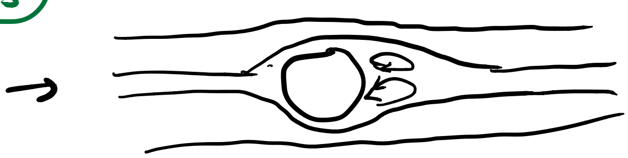


A Stokes flow (attached flow) $\qquad C_D = \frac{24}{Re}$ $\qquad$ 24

$$F_D = 6\pi\eta L U$$



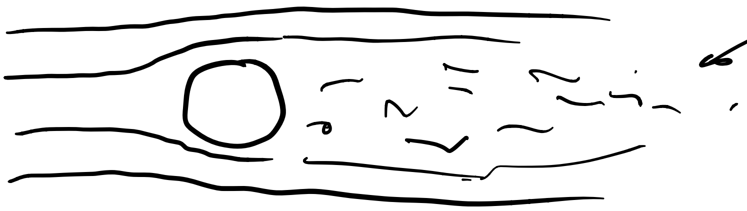
B



Separated flow

Vortex street
(von Karmán)

(C) Separated unsteady flow $F \sim u^2$



turbulent wake

(D) Drag crisis w. turbulent boundary layer