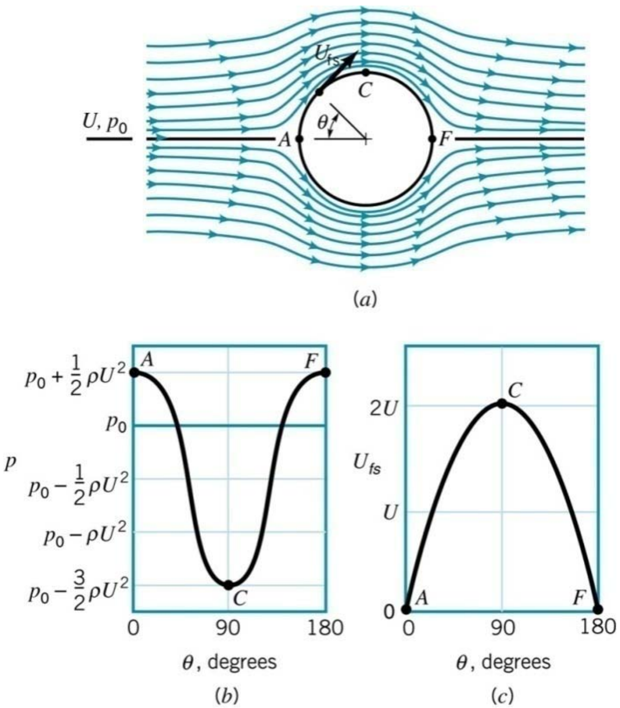
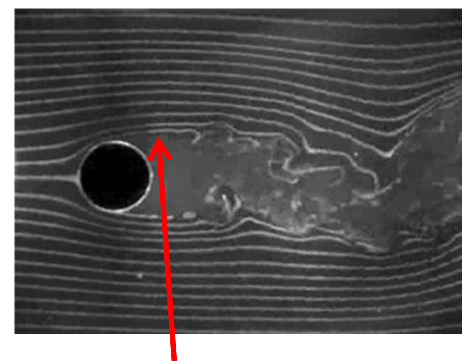
Viscous effects

Boundary layer

Inviscid flow



Viscous flow



Boundary layer separation in the wake region

Streamlined bodies are design to reduce the effects of this separation, thus the drag.

Drag

Friction drag

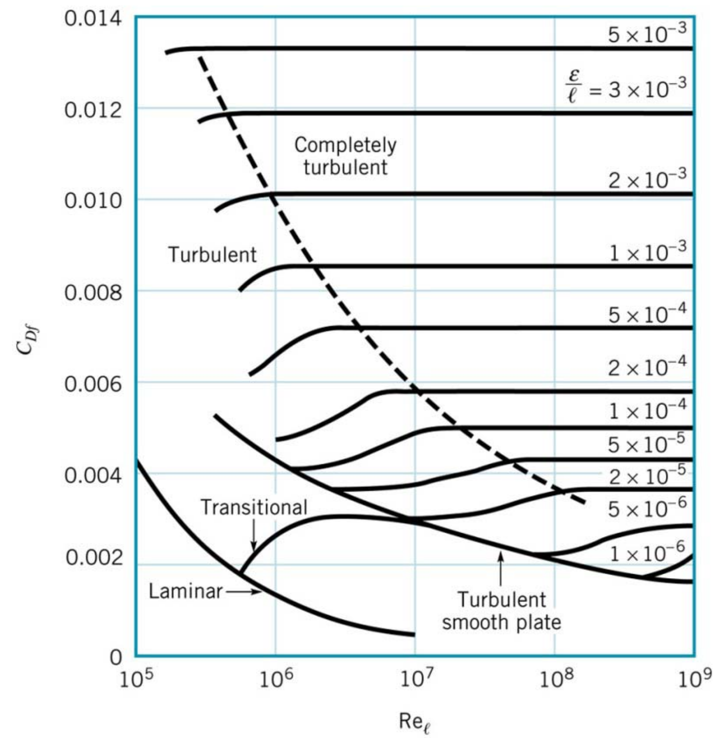
$$C_{Df} = \frac{F_{Df}}{\frac{1}{2}\rho U^2 A_0}$$

For example for a flat plate with dimensions $\ell \times b$:

$$A_0 = \ell \times b$$

$$\mathrm{Re}_\ell = \frac{\rho U \ell}{\mu}$$

See Table 9.3 for empirical equations



Drag

Pressure drag

$$C_{Dp} = \frac{F_{Dp}}{\frac{1}{2}\rho U^2 A_0}$$ Eq (9.37)

- Due to the pressure on an object
- Strongly depends on the shape of the object

•Much larger than the friction drag for turbulent flow over blunt objects

Overall drag coefficient

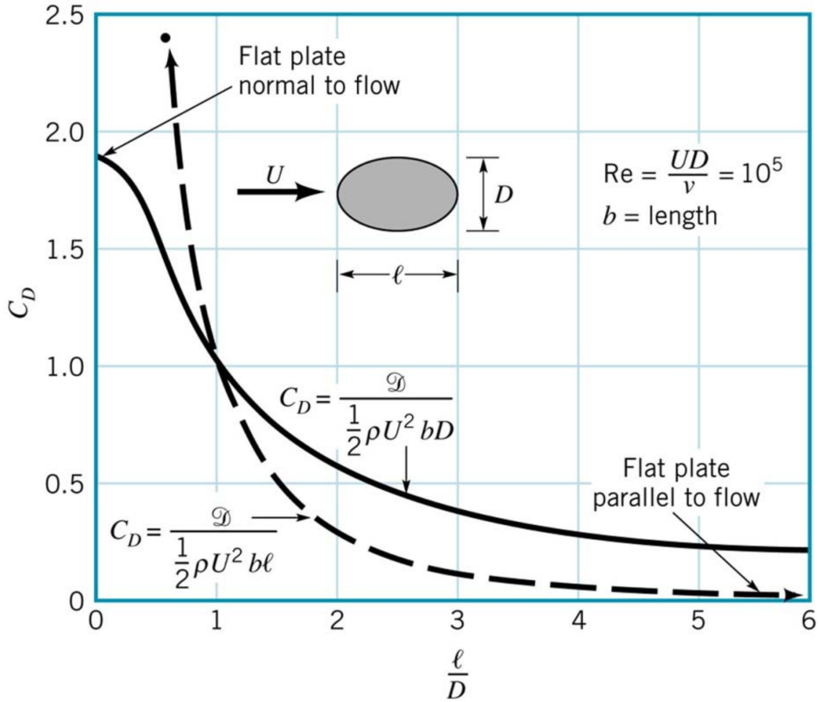
$$C_D = C_{Df} + C_{Dp}$$

In general: $$C_D = \phi\left(\text{shape}, \text{Re}, \text{Ma}, \text{Fr}, \frac{\varepsilon}{\ell}\right)$$

Drag

Overall drag coefficient

Shape dependence



(a) Circular cylinder, $C_D = 1.2$
(b) Streamlined strut, $C_D = 0.12$