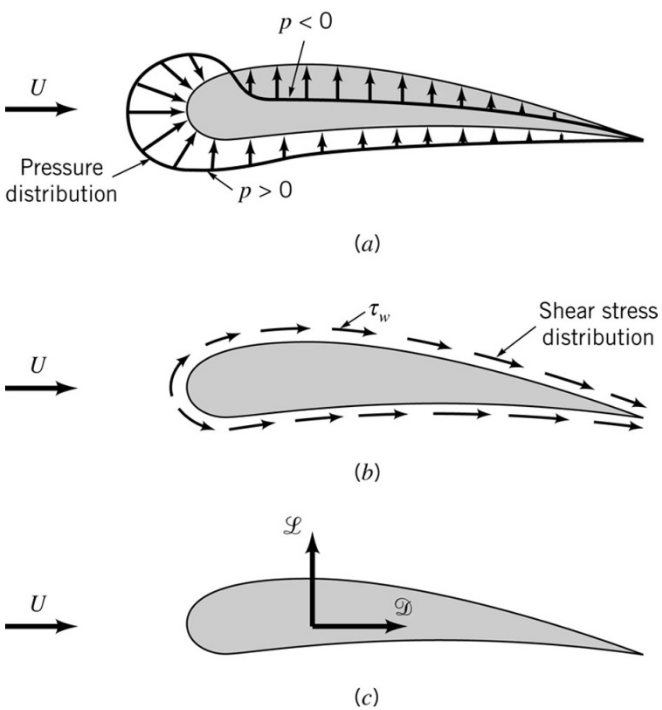
Flow over Immersed Bodies

- We have external flows
- It is termed aerodynamics if involving air
- The fluid exerts forces (lift and drag) on surfaces of the bodies
- These forces depend heavily on the geometry of the bodies, e.g., streamlined bodies usually move more easily in fluids than the blunt bodies do
- Similar situations for cases where the bodies are stationary in moving fluids and cases where the bodies are moving in the fluids
- The flow in the vicinity of bodies are unsteady, e.g., turbulent fluctuations in the wake regions behind the bodies
- Usually unsteadiness and non-uniformity are of minor importance

Flow over Immersed Bodies

Interaction between the object and the fluid:



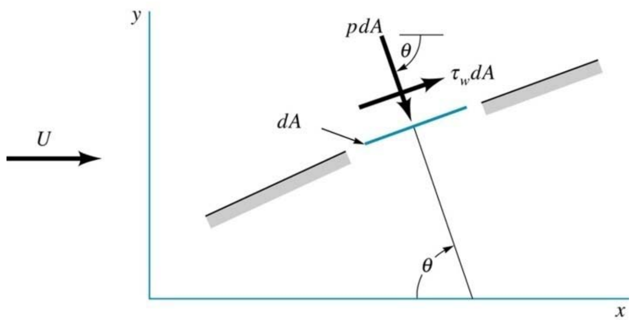
- *Normal stresses*: due to the static pressure
- *Shear stresses* on the fluid-body interface: due to viscous effects

Resultant force components:

- Along U: Drag (F_D)
- Perpendicular to U: Lift (F_L)

Flow over Immersed Bodies

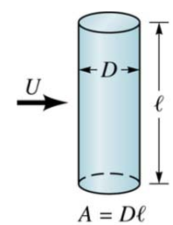
If the distribution of pressure and shear stress is known, then:



$$F_D = \int_{\text{interface}} dF_{//} = \int_{\text{interface}} \left(p\cos\theta + \tau_w \sin\theta\right) dA$$

$$F_L = \int_{\text{interface}} dF_{\perp} = \int_{\text{interface}} \left(-p\sin\theta + \tau_w \cos\theta\right) dA$$

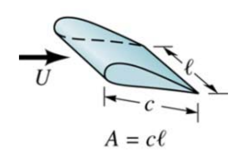
If the distribution of pressure and shear stress is unknown, which is common, then:



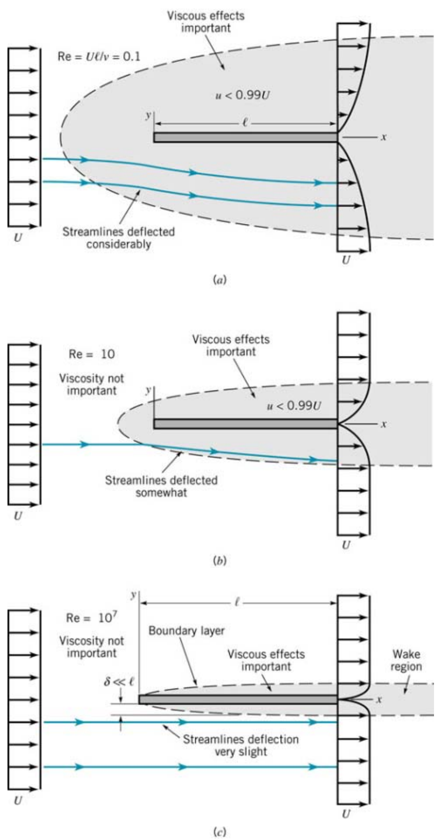
$$C_L = \frac{F_L}{\frac{1}{2}\rho U^2 A_0}$$

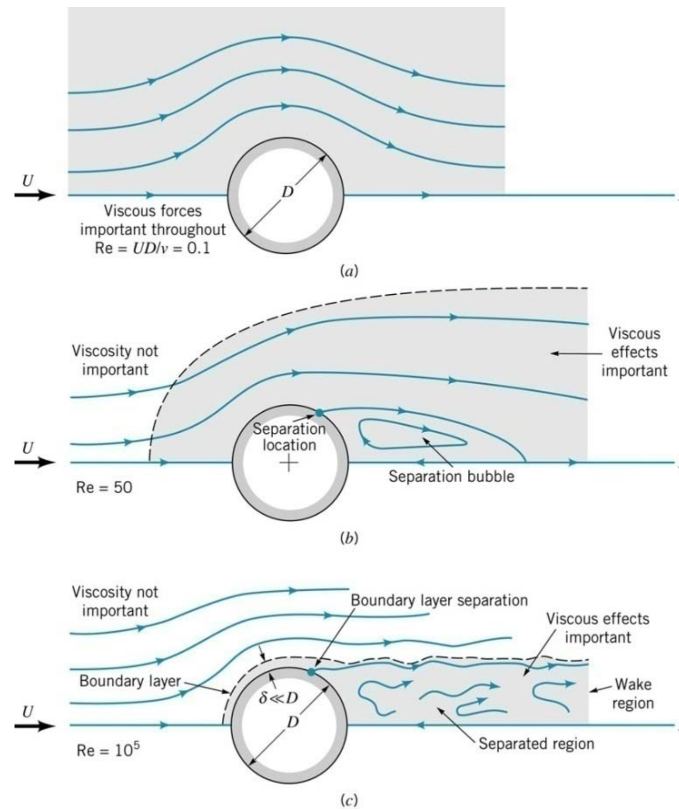
$$C_D = \frac{F_D}{\frac{1}{2}\rho U^2 A_0}$$

A_0 is the reference surface area



Viscous effects

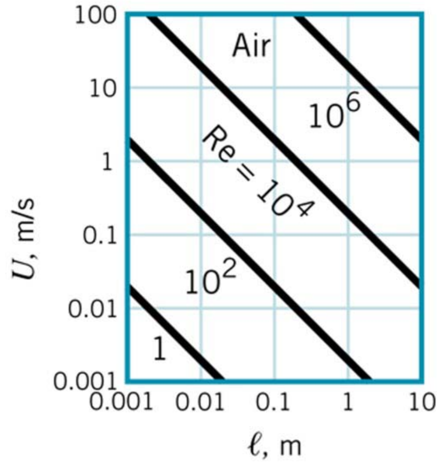




Viscous effects

Reynolds number:

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



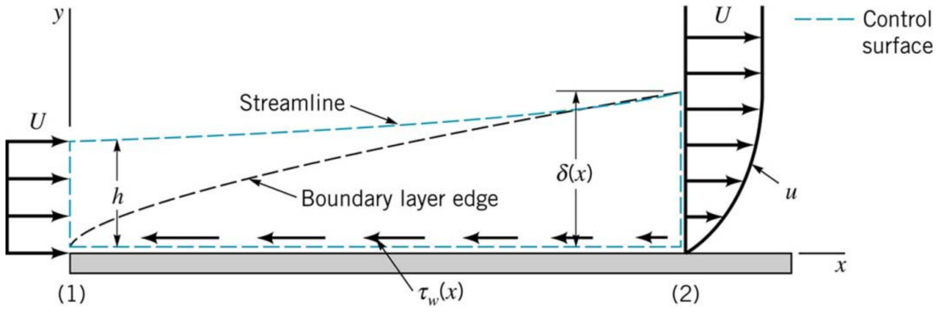
Rule of thumb:

- Re < 1: viscous effects are dominant
- Re > 100: inertial effects are dominant

Critical value of Reynolds number at which the transition from a laminar boundary layer to a turbulent boundary layer: $2 \times 10^5 - 3 \times 10^6$

Viscous effects

Boundary layer



$$F_D = b \int_{\text{plate}} \tau_w dx$$

Eq (9.19)

Linear momentum equation:

$$-F_D = \rho \int_{(1)} U \mathbf{v} \bullet \hat{\mathbf{n}} dA + \rho \int_{(2)} u(y) \mathbf{v} \bullet \hat{\mathbf{n}} dA$$

$$F_D = \rho U^2 bh - \rho b \int_0^{\delta} u^2 dy$$ Eq (9.20)

$$= \rho b \int_0^{\delta} u(U - u) dy$$ Eq (9.22)