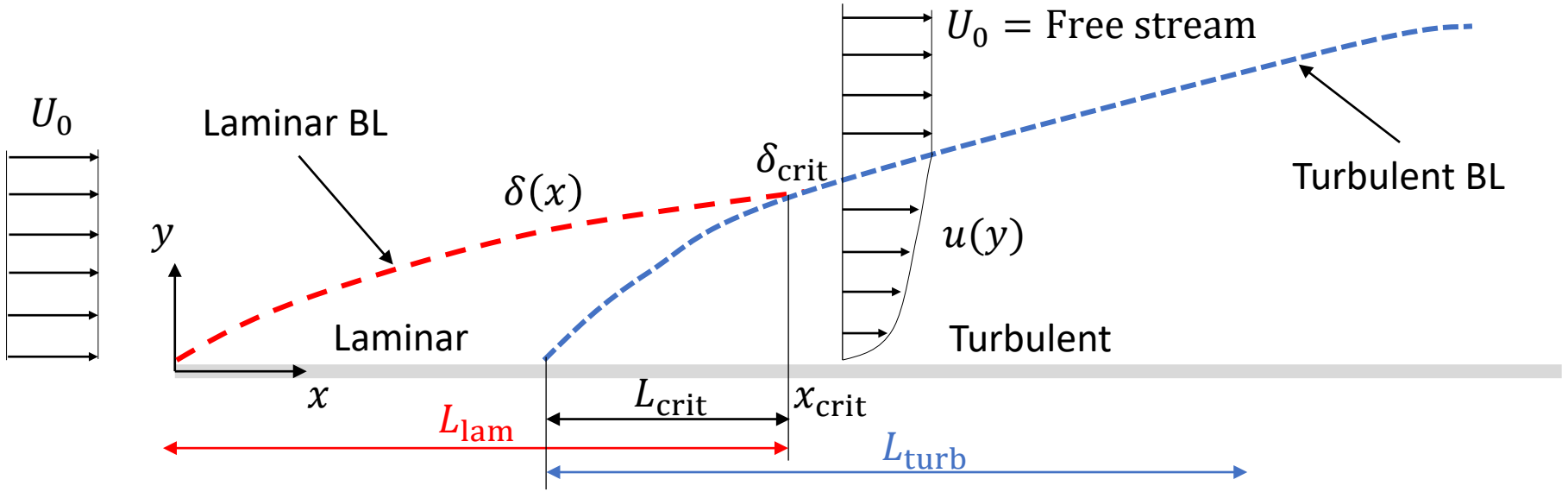
Exercise 11.



- Boundary Layer (BL) thickness $\delta(x) = y(u = 0.99U_0)$

$$\frac{\delta}{x} = \begin{cases} \frac{5}{\text{Re}_x^{1/2}}, \text{Laminar boundary layer}, 10^3 < \text{Re}_x < 10^6 \\ \frac{0.16}{\text{Re}_x^{1/7}}, \text{Turbulent boundary layer}, 10^6 < \text{Re}_x \end{cases}, \quad \text{Eq. (7.1)}$$

$$\text{Re}_x = \frac{\rho U x}{\mu}$$

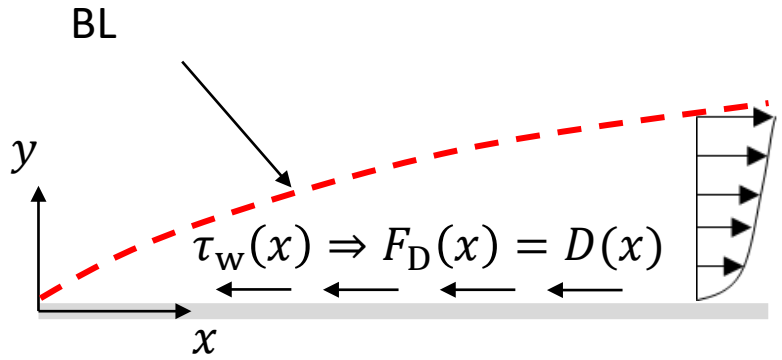
$$L_{\text{tot}}(\delta) = L_{\text{lam}} - L_{\text{crit}} + L_{\text{turb}}$$

Exercise 11.

- Friction coefficient for laminar flow over a flat plate:

$$c_\mathrm{f} = \frac{2\tau_\mathrm{w}}{\rho U^2} = \frac{0.667}{\mathrm{Re}_x^{1/2}} \qquad \text{Eq. (7.25)}$$

  - Dimensionless form of the wall shear stress τ_w
  - Correspond to the friction coefficient f for pipe flow
  - Used to calculate the drag resistance D



- Drag resistance, drag force, D [N]:

$$D(x) = b\int_0^x \tau_\mathrm{w}\mathrm{d}x \qquad \text{Eq. (7.4 or 7.26)}$$

- Total drag force for a plate with the length L (one side of the plate):

$$D(L) = \frac{1}{2}C_\mathrm{D}\rho U^2 bL \qquad \text{Eq. (7.27)}$$

$$C_\mathrm{D} = 2c_\mathrm{f}(L) \qquad \text{Eq. (7.27)}$$

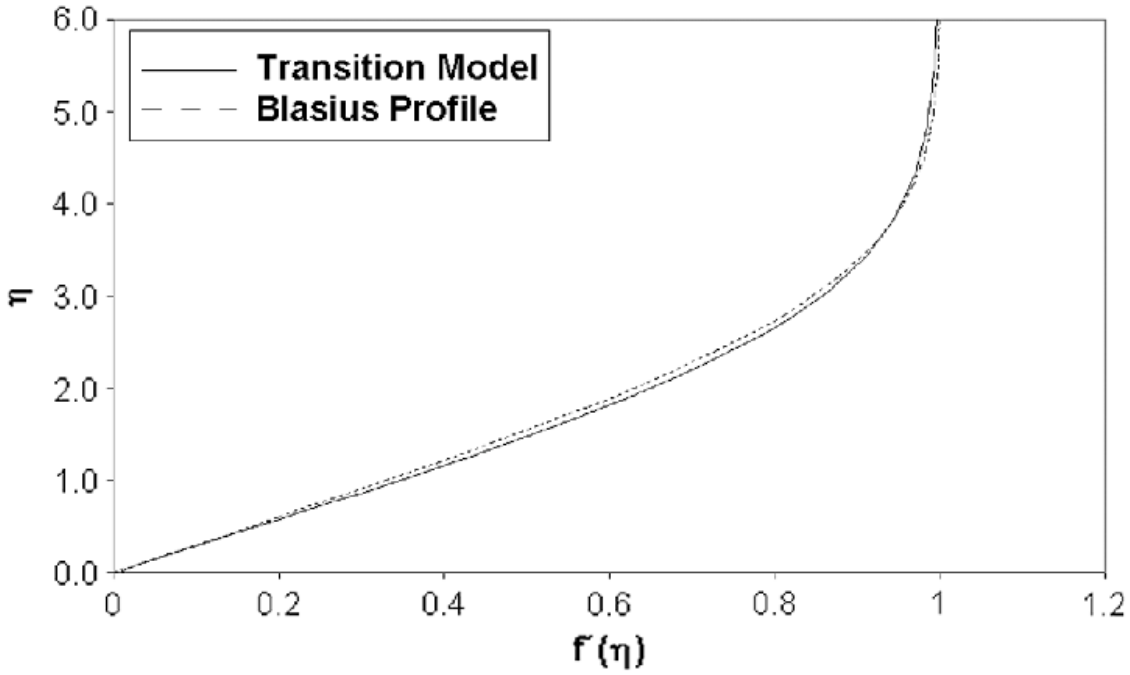
Exercise 11.

- For laminar boundary layer:
  - Analytical solution available by Blasius, Table 7.1

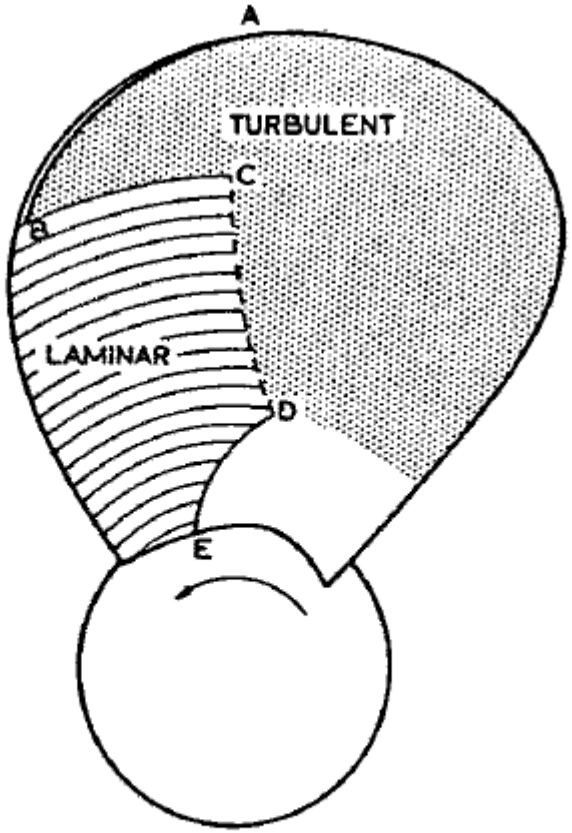
$$f'(\eta) = \frac{u}{U} = \text{Dimensionless velocity}$$

$$\eta = y\left(\frac{U}{\nu x}\right)^{1/2} = \text{Dimensionless coordinate}$$

$$\nu = \frac{\mu}{\rho} \text{ kinematic viscosity}$$



Exercise 11.



AB SHORT LAMINAR SEPARATION BUBBLE
BC CRITICAL RADIUS
CD TRANSITION REGION
DE LAMINAR SEPARATION