# Turbulent Flow

$$C_{fx} = 0.0592\, Re_x^{-1/5} \qquad Re_{x,c} < Re_x < 10^8$$

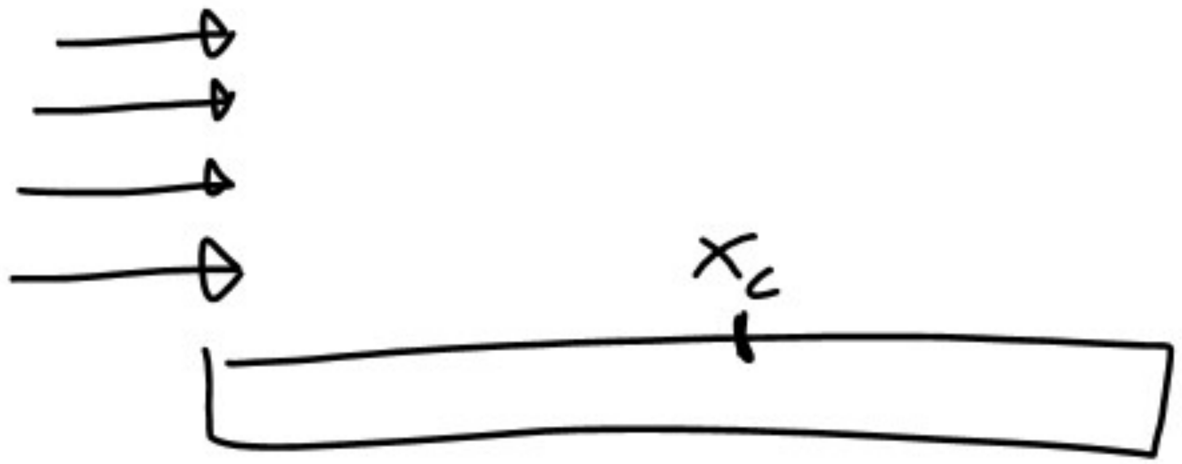
$$\delta = 0.37\, x\, Re_x^{-1/5}$$

$$Nu_x = St\, Re_x\, Pr = 0.0296\, Re_x^{4/5}\, Pr^{1/3} \qquad 0.6 < Pr < 60$$

Stanton Number

$$St = \frac{h}{\rho V c_p} = \frac{Nu}{Re\, Pr}$$

# Mixed Boundary Layer




$$\overline{h}_L = \frac{1}{L}\left(\int_0^{x_c} h_{Lam}\,dx + \int_{x_c}^{L} h_{turb}\,dx\right)$$

$$\overline{h}_L = \frac{k}{L}\left(0.332\left(\frac{u_\infty}{\nu}\right)^{1/2}\int_0^{x_c}\frac{dx}{x^{1/2}} + 0.0296\left(\frac{u_\infty}{\nu}\right)^{4/5}\int_{x_c}^{L}\frac{dx}{x^{1/5}}\right) Pr^{1/3}$$

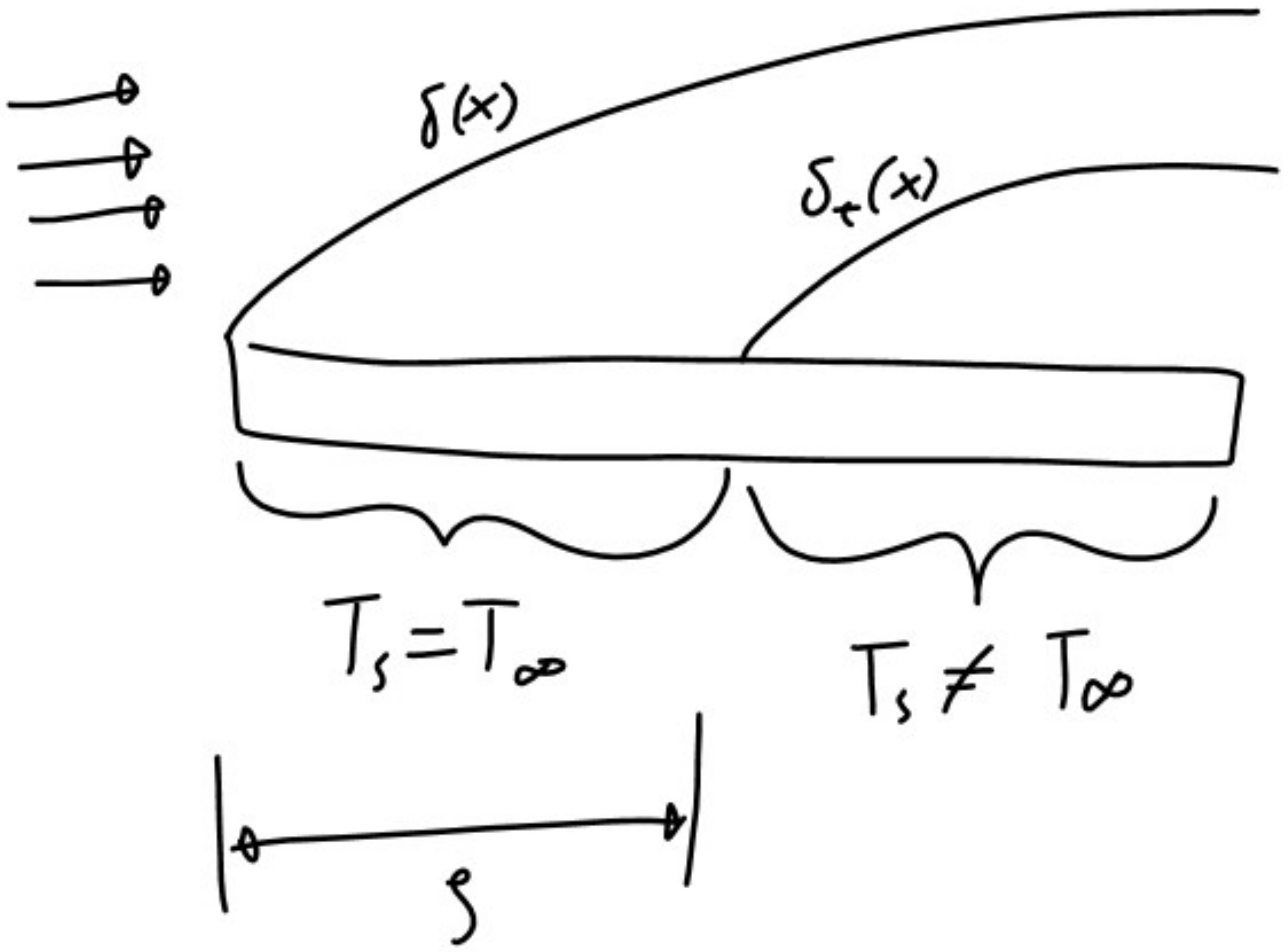
$$\overline{Nu}_L = \left(0.037\, Re_L^{4/5} - A\right) Pr^{1/3}$$

$0.6 < Pr < 60$

$Re_{x_c} < Re_L < 10^8$

$$A = 0.037\, Re_{x_c}^{4/5} - 0.664\, Re_{x_c}^{1/2}$$

# Unheated Starting Length




## Laminar Flow

$$Nu_x = \frac{Nu_x|_{\xi=0}}{\left(1-\left(\xi/x\right)^{3/4}\right)^{1/3}}$$

## Turbulent Flow

$$Nu_x = \frac{Nu_x|_{\xi=0}}{\left(1-\left(\xi/x\right)^{9/10}\right)^{1/9}}$$

$$\overline{Nu}_L = \overline{Nu}_L\Big|_{\xi=0} \frac{L}{L-\xi}\left(1-\left(\xi/L\right)^{\frac{p+1}{p+2}}\right)^{\frac{p}{p+1}}$$

Laminar $p=2$

Fully turbulent $p=8$

$\xi > x_c$

**7.2** Engine oil at 100°C and a velocity of 0.1 m/s flows over both surfaces of a 1-m-long flat plate maintained at 20°C. Determine:

(a) The velocity and thermal boundary layer thicknesses at the trailing edge.

(b) The local heat flux and surface shear stress at the trailing edge.

(c) The total drag force and rate of heat transfer per unit width of the plate.

(d) Plot the boundary layer thicknesses and local values of the surface shear stress, convection coefficient, and heat flux as a function of $x$ for $0 \le x \le 1$ m.

$$\delta = \frac{5x}{\sqrt{Re_x}} \qquad x = L = 1\ m$$

$$Re_x = \frac{\rho V L}{\mu}$$

$$T_f = \frac{T_s + T_\infty}{2} = \frac{20+100}{2} = 60\ °C$$

$$= 273 + 60 = 333\ K$$

$$\rho = 865.8\ \frac{Kg}{m^3}$$

$$\mu\, 10^2 = 8.36\ \frac{Ns}{m^2} \Rightarrow \mu = 8.36 \times 10^{-2}\ \frac{Ns}{m^2}$$

$$\frac{\delta}{\delta_t} = Pr^{1/3}$$

$$\frac{\delta}{Pr^{1/3}} = \delta_t$$

$Pr = 1205$

$$Nu_L = \frac{h_L L}{K} = 0.332 \ Re_L^{1/2} \ Pr^{1/3}$$