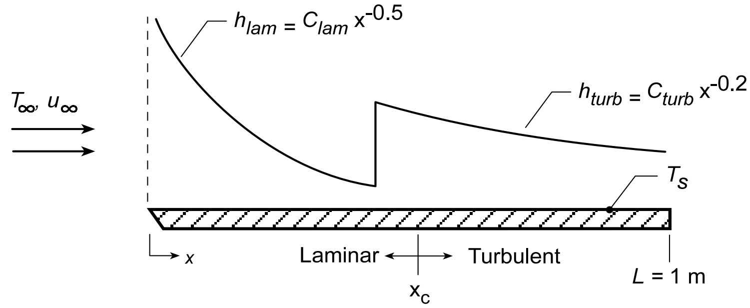
PROBLEM 6.13

KNOWN: Air flow over a flat plate of length L = 1 m under conditions for which transition from laminar to turbulent flow occurs at x_c = 0.5m based upon the critical Reynolds number, $Re_{x,c} = 5\times 10^5$. Forms for the local convection coefficients in the laminar and turbulent regions.

FIND: (a) Velocity of the air flow using thermophysical properties evaluated at 350 K, (b) An expression for the average coefficient $\overline{h}_{lan}(x)$, as a function of distance from the leading edge, x, for the laminar region, $0 \le x \le x_c$, (c) An expression for the average coefficient $\overline{h}_{turb}(x)$, as a function of distance from the leading edge, x, for the turbulent region, $x_c \le x \le L$, and (d) Compute and plot the local and average convection coefficients, h_x and $\overline{h}_x$, respectively, as a function of x for $0 \le x \le L$.

SCHEMATIC:



ASSUMPTIONS: (1) Forms for the local coefficients in the laminar and turbulent regions, $h_{lam} = C_{lam}x^{-0.5}$ and $h_{tirb} = C_{turb}x^{-0.2}$ where C_{lam} = 8.845 W/m$^{3/2}\cdot$K, C_{turb} = 49.75 W/m$^2\cdot$K$^{0.8}$, and x has units (m).

PROPERTIES: *Table A.4*, Air (T = 350 K): k = 0.030 W/m·K, $\nu = 20.92 \times 10^{-6}$ m^2/s, Pr = 0.700.

ANALYSIS: (a) Using air properties evaluated at 350 K with x_c = 0.5 m,

$$Re_{x,c} = \frac{u_\infty x_c}{\nu} = 5\times10^5 \qquad u_\infty = 5\times10^5\,\nu/x_c = 5\times10^5\times20.92\times10^{-6}\,\text{m}^2/\text{s}/0.5\,\text{m} = 20.9\,\text{m/s} \quad <$$

(b) From Eq. 6.5, the average coefficient in the laminar region, $0 \le x \le x_c$, is

$$\overline{h}_{lam}(x) = \frac{1}{x}\int_0^x h_{lam}(x)dx = \frac{1}{x}C_{lam}\int_o^x x^{-0.5}dx = \frac{1}{x}C_{lam}x^{0.5} = 2C_{lam}x^{-0.5} = 2h_{lam}(x) \qquad (1) \quad <$$

(c) The average coefficient in the turbulent region, $x_c \le x \le L$, is

$$\overline{h}_{turb}(x) = \frac{1}{x}\left[\int_0^{x_c} h_{lam}(x)dx + \int_{x_c}^{x} h_{turb}(x)dx\right] = \left[C_{lam}\left.\frac{x^{0.5}}{0.5}\right|_0^{x_c} + C_{turb}\left.\frac{x^{0.8}}{0.8}\right|_{x_c}^{x}\right]$$

$$\overline{h}_{turb}(x) = \frac{1}{x}\left[2C_{lam}x_c^{0.5} + 1.25C_{turb}\left(x^{0.8} - x_c^{0.8}\right)\right] \qquad (2) \quad <$$

(d) The local and average coefficients, Eqs. (1) and (2) are plotted below as a function of x for the range $0 \le x \le L$.