Name :_____ **Quiz: No. 12** **Time: 15 minutes**

Student ID# : _____ **Course: ME 5160, Fall 2023**

The exam is closed book and closed notes.

A thin flat plate 20 by 90 cm is immersed in a 1-m/s stream of water at 20°C (ρ = 998 kg/m^3, μ = 0.001 kg/m.s.). Assume that the flow is laminar for Re_x < 5E5 and turbulent for larger Re_x. If the stream is parallel to the long side, compute the wall shear stress at the end of the plate (in stream-wise direction), and the total friction drag considering both front and back sides of the plate.

Equations:

- Laminar Boundary Layer: $c_f = \frac{2\tau_w}{\rho U^2} = \frac{0.664}{Re_x^{1/2}}$; $C_D = \frac{D}{\frac{1}{2}\rho A U^2} = \frac{1.328}{Re_L^{1/2}}$; $\frac{\delta}{x} \approx \frac{5.0}{Re_x^{1/2}}$; velocity profile given in the Table below:

$y[U/(\nu x)]^{1/2}$	u/U	$y[U/(\nu x)]^{1/2}$	u/U
0.0	0.0	2.8	0.81152
0.2	0.06641	3.0	0.84605
0.4	0.13277	3.2	0.87609
0.6	0.19894	3.4	0.90177
0.8	0.26471	3.6	0.92333
1.0	0.32979	3.8	0.94112
1.2	0.39378	4.0	0.95552
1.4	0.45627	4.2	0.96696
1.6	0.51676	4.4	0.97587
1.8	0.57477	4.6	0.98269
2.0	0.62977	4.8	0.98779
2.2	0.68132	5.0	0.99155
2.4	0.72899	∞	1.00000
2.6	0.77246		

- Turbulent Boundary Layer: $c_f = \frac{2\tau_w}{\rho U^2} \approx \frac{0.027}{Re_x^{1/7}}$; $C_D = \frac{D}{\frac{1}{2}\rho A U^2} = \frac{0.031}{Re_L^{1/7}}$; velocity profile: $\frac{u}{U} \approx \left(\frac{y}{\delta}\right)^{\frac{1}{7}}$ where $\frac{\delta}{x} \approx \frac{0.16}{Re_x^{1/7}}$

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Solution:

KNOWN: U, L, b,

(1) FIND: τ_w, D, δ, $u(y)$

ASSUMPTIONS: boundary layer flow with zero pressure gradient

ANALYSIS:

$$Re_{x=L} = \frac{\rho U L}{\mu} = \frac{(998)(1)(0.9)}{(0.001)} = 8.982E5 > 5E5 \quad \rightarrow \quad Turbulent$$ (1)

$$c_{f\,x=L} = \frac{0.027}{Re_L^{1/7}} = \frac{(0.027)}{(8.982E5)^{1/7}} = 0.00381$$ (1)

$$c_f = \frac{2\tau_w}{\rho U^2} \quad \rightarrow \quad \tau_w = \frac{c_f \rho U^2}{2} = \frac{(0.00381)(998)(1)^2}{2} = 1.9\ Pa$$ (1) (1)

$$C_D = \frac{0.031}{Re_L^{1/7}} = \frac{(0.031)}{(8.982E5)^{1/7}} = 0.004374$$ (1)

$$C_D = \frac{D}{\frac{1}{2}\rho A U^2}$$ (1)

Find drag force considering $A = bL$ and multiplying by 2 for both sides:

$$D = 2 \times \left[C_D \frac{1}{2}\rho (bL) U^2\right] = 2\,(0.004374)\left(\frac{1}{2}\right)(998)(0.2)(0.9)(1)^2 = 0.79\ N$$ (0.5) (0.5)