6.15 Liquid at 23°C flows at 2 m/s over a smooth, sharp-edged, flat surface 12 cm in length which is kept at 57°C. Calculate h at the trailing edge (a) if the fluid is water; (b) if the fluid is glycerin ($h = 346\ \mathrm{W/m^2K}$). (c) Compare the drag forces in the two cases. [There is 23.4 times as much drag in the glycerin.]

$T_{film} = 40\ °C$

Table A.3: saturated liquids...*continued*

Temperature K	°C	ρ (kg/m³)	c_p (J/kg·K)	k (W/m·K)	α (m²/s)	ν (m²/s)	Pr	β (K⁻¹)
				Water				
310	37	993.3	4179	0.6260	1.508×10^{-7}	6.982×10^{-7}	4.63	0.000361

Table A.3: saturated liquids...*continued*

Temperature K	°C	ρ (kg/m³)	c_p (J/kg·K)	k (W/m·K)	α (m²/s)	ν (m²/s)	Pr	β (K⁻¹)
				Glycerin (or glycerol)				
313	40	1249	2460	0.285	0.928×10^{-7}	0.000227	2,451	0.00049

Water

Re = 3.4374e+05 < Re_{crit} = 5e5

Laminar flow

$$Nu_x = 0.332\, Re_x^{1/2}\, Pr^{1/3} \qquad 0.6 \leqslant Pr \leqslant 50$$

Nu_x = 324.42, h = 1692.4 W/m^2K

$$\overline{C}_f = \frac{1.328}{\sqrt{Re_L}} \qquad C_f \equiv \frac{\tau_w}{\rho u_\infty^2/2}$$

C_f = 0.0022651, τ = 4.4998 Pa

Glycerin

Re = 1057.3 < Re_{crit} = 5e5

Laminar flow

$$Nu_x = 0.332\, Re_x^{1/2}\, Pr^{1/3} \qquad 0.6 \leqslant Pr \leqslant 50$$

Nu_x = 145.55, h = 345.68 W/m^2K

$$\overline{C}_f = \frac{1.328}{\sqrt{Re_L}} \qquad C_f \equiv \frac{\tau_w}{\rho u_\infty^2/2}$$

C_f = 0.040841, τ = 102.02 Pa

$\tau_{glycerin}/\tau_{water}$ = 22.672

Consider atmospheric air at 25°C and a velocity of 25 m/s flowing over both surfaces of a 1-m-long flat plate that is maintained at 125°C. Determine the rate of heat transfer per unit width from the plate for values of the critical Reynolds number corresponding to 10^5, 5×10^5, and 10^6.

$T_{film} = 75°C$

Table A.6 Thermophysical properties of gases at atmospheric pressure (101325 Pa)

T (K)	ρ (kg/m^3)	c_p (J/kg·K)	μ (kg/m·s)	ν (m^2/s)	k (W/m·K)	α (m^2/s)	Pr
			Air				
350	1.008	1009	2.090×10^{-5}	2.073×10^{-5}	0.02984	2.931×10^{-5}	0.707

$Re_L = 1.2060e+06$

$$\overline{Nu}_L = 0.037\, Pr^{0.43} \left\{ Re_L^{0.8} - \left[Re_{trans}^{0.8} - 17.95\, Pr^{-0.097} (Re_{trans})^{1/2} \right] \right\}$$

$$0.6 \leqslant Pr \leqslant 50,$$

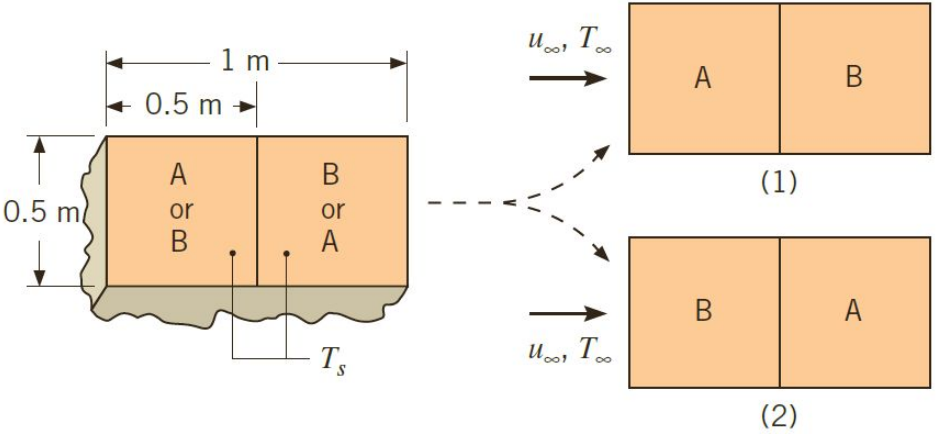
$Q = h*2*A*(T_{wall}-T_{fluid})$

	Nu	h [W/m^{2}K]	Q [W/m]
Re_{trans} = 1e+05	2204.7	65.788	1.3158e+04
Re_{trans} = 5e+05	1599.6	47.732	9546.4
Re_{trans} = 1e+06	916.85	27.359	5471.8

The top surface of a heated compartment consists of very smooth (A) and highly roughened (B) portions, and the surface is placed in an atmospheric airstream.

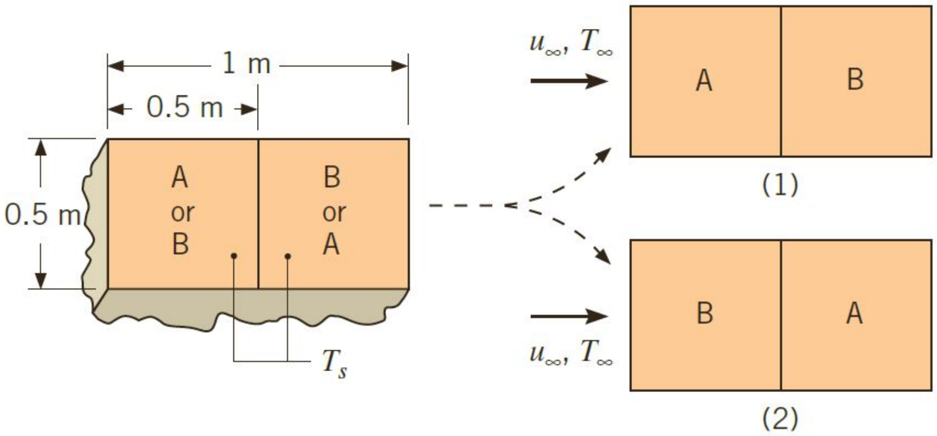
In the interest of minimizing total convection heat transfer from the surface, which orientation, (1) or (2), is preferred? If $T_s = 100°C$, $T_\infty = 20°C$, and $u_\infty = 20$ m/s, what is the convection heat transfer from the entire surface for this orientation?

A highly roughened surface is one which triggers a turbulent flow.



T (K)	ρ (kg/m³)	c_p (J/kg·K)	μ (kg/m·s)	ν (m²/s)	k (W/m·K)	α (m²/s)	Pr
Air							
330	1.070	1008	1.981×10^{-5}	1.851×10^{-5}	0.02821	2.616×10^{-5}	0.708

Configuration 1



$$\overline{Nu}_L = 0.037\, Pr^{0.43} \left\{ Re_L^{0.8} - \left[Re_{trans}^{0.8} - 17.95\, Pr^{-0.097} (Re_{trans})^{1/2} \right] \right\}$$

$$0.6 \leqslant Pr \leqslant 50,$$

Re at x = 0.5 m

$Re_{0.5}$ = 5.4025e+05 > Re_{crit}

The turbulent flow is triggered by the shear stress of the smooth surface (A), before 0.5 m.

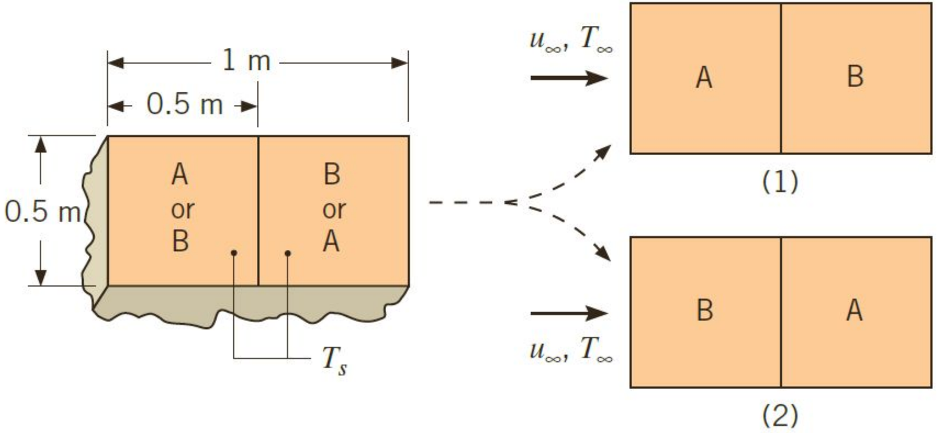
Re at x = 1 m

Re_1 = 1.0805e+06

Nu_L = 1403

h_L = Nu*k/L = 39.6 W/m^2K

Configuration 2



$Re_{crit} = 0$

The turbulent flow is triggered by the shear stress of the roughened surface (B).

Re at x = 1 m

$Re_1 = 1.0805e+06$

$$\overline{Nu}_L = 0.037\,Pr^{0.43}\left\{Re_L^{0.8} - \left[Re_{trans}^{0.8} - 17.95\,Pr^{-0.097}\,(Re_{trans})^{1/2}\right]\right\}$$

$$0.6 \leqslant Pr \leqslant 50,$$

$Nu_L = 2141$

$h_L = Nu*k/L = 60.398\ W/m^2K$

The boundary layer associated with parallel flow over an isothermal plate may be tripped at any x-location by using a fine wire that is stretched across the width of the plate. Determine the value of the critical Reynolds number $Re_{x,c,\text{op}}$ that is associated with the optimal location of the trip wire from the leading edge that will result in maximum heat transfer from the warm plate to the cool fluid.

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