Ch.5 Fundamental of Convection

ME203 – HEAT TRANSFER

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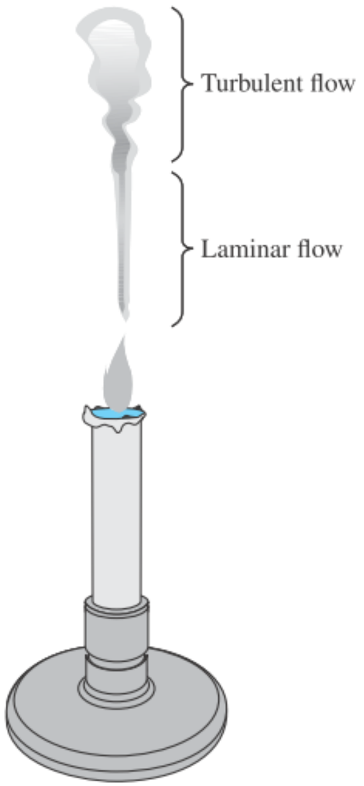
Reynolds Number (Re)

- Noticed that the smoke rises in a smooth plume at the beginning (*laminar flow*) and then starts fluctuating randomly (*turbulent flow*)

- Most flows encountered in practice are turbulent. Laminar flow is encountered when ***highly viscous fluids*** such as oils flow in small pipes or narrow passages.

- The flow of fluid can be laminar or turbulent. The transition from laminar to turbulent flow depends on *the surface geometry, surface roughness, flow velocity, surface temperature, and type of fluid*, among other things



Laminar and turbulent flow regimes of candle smoke.

Reynolds Number (Re)

How to predict if the flow of fluid will be laminar or turbulent?

- To predict the type of flow pattern either laminar or turbulent → ***Reynolds number***

$$Re = \frac{VL_c}{\nu} = \frac{\rho V L_c}{\mu}$$

where :

V : free-stream velocity = u_∞ [m/s]

ν : kinematic viscosity [m²/s]

μ : dynamic viscosity [kg/m.s]

L_c : characteristic length* [m]

$$Re = \frac{\textit{inertial force}}{\textit{viscous force}}$$

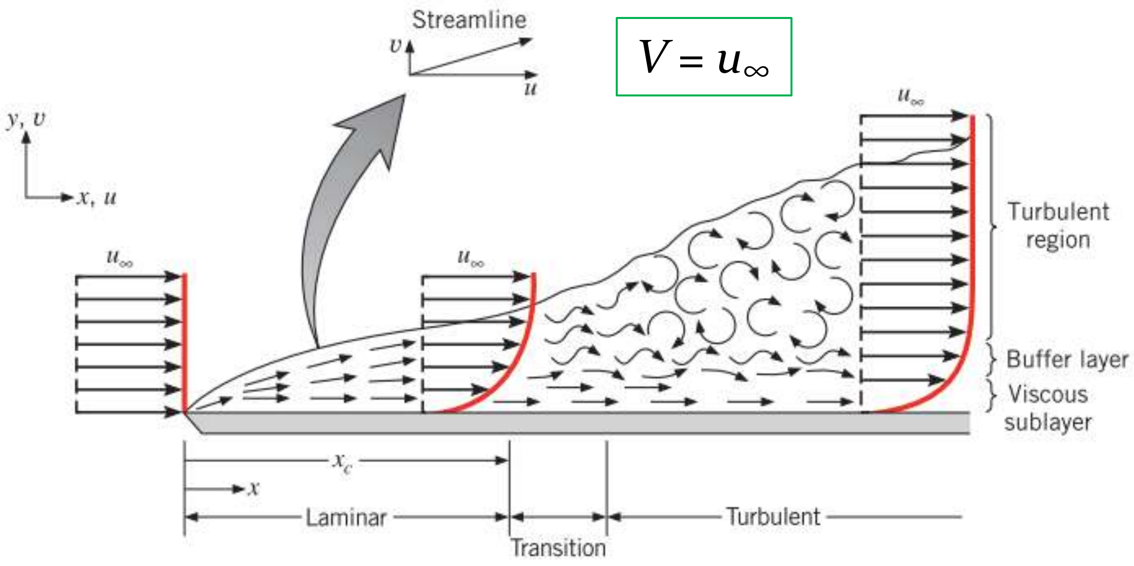
* For a flat plate, the characteristic length is the distance x from the leading edge.

Critical Reynolds Number (Re_{cr})

Low Re < Re_{cr} < High Re

(Laminar flow) *(Turbulent flow)*

For flow over a flat plate, Re_{cr} is vary from $\approx$ **1×10^5 - 30×10^5**



$V = u_\infty$

$$Re_{cr} = Vx_c / \nu$$

* Note that x_c is the distance from the leading edge to the transition regime

Example 1

Consider airflow over a flat plate of length L = 1 m under conditions for which transition occurs at x_c = 0.5 m based on the critical Reynolds number, $Re_{cr} = 5 \times 10^5$. Evaluating the thermophysical properties of air at 350 K, determine the air velocity?

Table A.4 Thermophysical Properties of Gases at Atmospheric Pressure[a]

T (K)	ρ (kg/m^3)	c_p (kJ/kg · K)	$\mu \cdot 10^7$ (N · s/m^2)	$\nu \cdot 10^6$ (m^2/s)	$k \cdot 10^3$ (W/m · K)	$\alpha \cdot 10^6$ (m^2/s)	Pr
Air, $\mathcal{M}$ = 28.97 kg/kmol							
100	3.5562	1.032	71.1	2.00	9.34	2.54	0.786
150	2.3364	1.012	103.4	4.426	13.8	5.84	0.758
200	1.7458	1.007	132.5	7.590	18.1	10.3	0.737
250	1.3947	1.006	159.6	11.44	22.3	15.9	0.720
300	1.1614	1.007	184.6	15.89	26.3	22.5	0.707
350	0.9950	1.009	208.2	20.92	30.0	29.9	0.700
400	0.8711	1.014	230.1	26.41	33.8	38.3	0.690
450	0.7740	1.021	250.7	32.39	37.3	47.2	0.686
500	0.6964	1.030	270.1	38.79	40.7	56.7	0.684
550	0.6329	1.040	288.4	45.57	43.9	66.7	0.683

Example 2

Consider a flat plate positioned inside a wind tunnel, and air at 1 atm and 20°C is flowing with a free stream velocity of 60 m/s.

a) What is the minimum length of the plate necessary for the Reynolds number to reach 2×10^7 ?

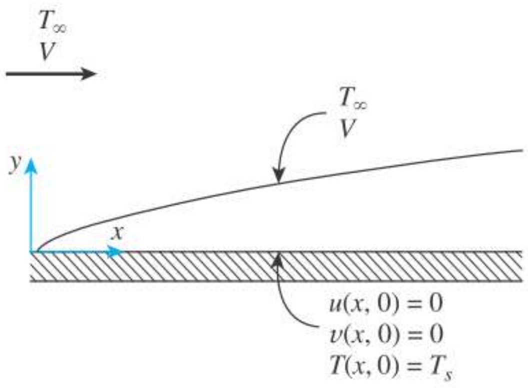
b) If the critical Reynolds number is 5×10^5 , what type of flow regime would the airflow experience at 0.2 m from the leading edge?

Properties of air at 1 atm pressure

Temp. T, °C	Density ρ, kg/m³	Specific Heat c_p, J/kg·K	Thermal Conductivity k, W/m·K	Thermal Diffusivity α, m²/s	Dynamic Viscosity μ, kg/m·s	Kinematic Viscosity ν, m²/s	Prandtl Number Pr
0	1.292	1006	0.02364	1.818×10^{-5}	1.729×10^{-5}	1.338×10^{-5}	0.7362
5	1.269	1006	0.02401	1.880×10^{-5}	1.754×10^{-5}	1.382×10^{-5}	0.7350
10	1.246	1006	0.02439	1.944×10^{-5}	1.778×10^{-5}	1.426×10^{-5}	0.7336
15	1.225	1007	0.02476	2.009×10^{-5}	1.802×10^{-5}	1.470×10^{-5}	0.7323
20	1.204	1007	0.02514	2.074×10^{-5}	1.825×10^{-5}	1.516×10^{-5}	0.7309
25	1.184	1007	0.02551	2.141×10^{-5}	1.849×10^{-5}	1.562×10^{-5}	0.7296
30	1.164	1007	0.02588	2.208×10^{-5}	1.872×10^{-5}	1.608×10^{-5}	0.7282
35	1.145	1007	0.02625	2.277×10^{-5}	1.895×10^{-5}	1.655×10^{-5}	0.7268
40	1.127	1007	0.02662	2.346×10^{-5}	1.918×10^{-5}	1.702×10^{-5}	0.7255

For Incompressible Flow over Flat Surface

Consider *laminar flow of an incompressible fluid over a flat plate :*



Velocity boundary layer thickness: $\delta = \dfrac{4.91}{\sqrt{V/\nu x}} = \dfrac{4.91x}{\sqrt{Re_x}}$

Local friction coefficient: $C_{f,x} = \dfrac{\tau_w}{\rho V^2/2} = 0.664\, Re_x^{-1/2}$

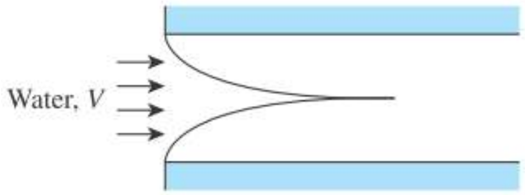
Local Nusselt number: $Nu_x = \dfrac{h_x x}{k} = 0.332\, Pr^{1/3}\, Re_x^{1/2}$

Thermal boundary layer thickness: $\delta_t = \dfrac{\delta}{Pr^{1/3}} = \dfrac{4.91x}{Pr^{1/3}\sqrt{Re_x}}$

* ***Note that*** these relations are valid only for *isothermal plate*

6-69

Water at 20°C is flowing with velocity of 0.5 m/s between two parallel flat plates placed 1 cm apart. Determine the distances from the entrance at which the velocity and thermal boundary layers meet



6-44

Air flows over a flat plate at 40 m/s, 25°C and 1 atm pressure.

(a) What plate length should be used to achieve a Re = 1×10^8 at the end of the plate?

(b) If the critical Reynolds number is 5×10^5, at what distance from the leading edge of the plate would transition occur?

6-78

Consider air flowing over a 1-m-long flat plate at a velocity of 3 m/s. Determine the convection heat transfer coefficients and the Nusselt numbers at x = 0.5 m and 0.75 m. Evaluate the air properties at 40°C and 1 atm.

6–90 Air at 1 atm and 20°C is flowing over the top surface of a 0.2 m × 0.5 m-thin metal foil. The air stream velocity is 100 m/s and the metal foil is heated electrically with a uniform heat flux of 6100 W/m². If the friction force on the metal foil surface is 0.3 N, determine the surface temperature of the metal foil. Evaluate the fluid properties at 100°C.

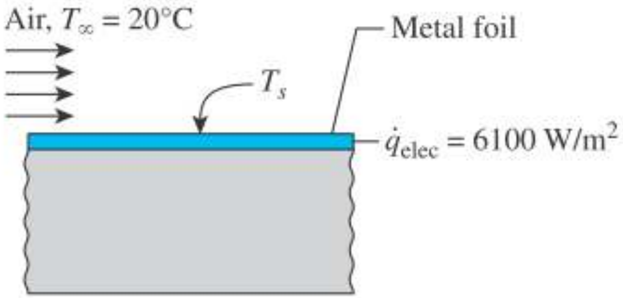


FIGURE P6–90

6–20 A metal plate (k = 180 W/m·K, ρ = 2800 kg/m^3, and c_p = 880 J/kg·K) with a thickness of 1 cm is being cooled by air at 5°C with a convection heat transfer coefficient of 30 W/m^2·K. If the initial temperature of the plate is 300°C, determine the plate temperature gradient at the surface after 2 minutes of cooling. *Hint*: Use the lumped system analysis to calculate the plate surface temperature. Make sure to verify the application of this method to this problem.

END OF THE SLIDES