Exercise walk-through

7.6
External flow

University Mechanical Engineering

External flow: the boundary layer

the no-slip layer thickens downstream: δ = 5x/√Re_x (laminar)

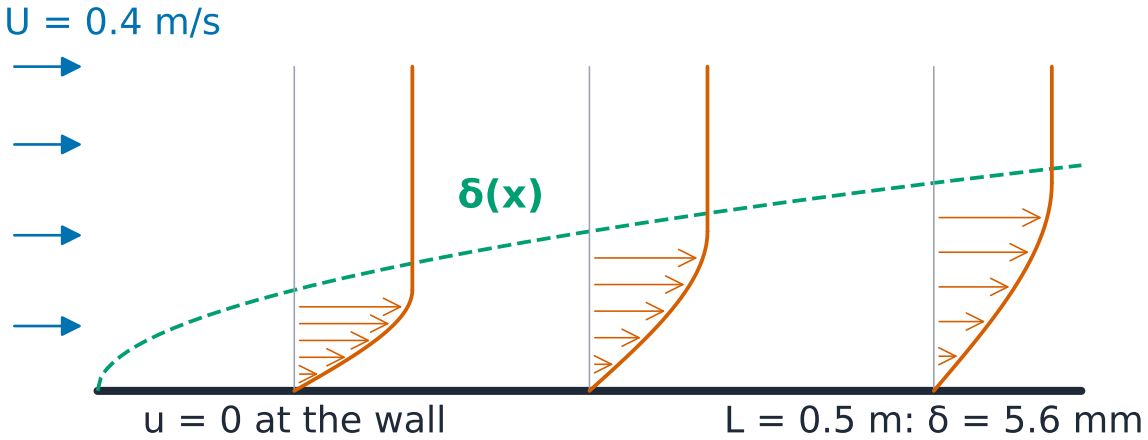


Plate 0.5 m in water at 0.4 m/s: $Re_L = \mathbf{1.99 \times 10^5}$, laminar; $\delta = 5x/\sqrt{Re_x} = \mathbf{5.6}$ mm, $C_f = 1.328/\sqrt{Re_L} = \mathbf{0.00298}$.

Drag on the vent pipe

1. **Plate drag** One side: $0.5 \times 998 \times 0.16 \times 0.00298 \times 0.15 = \mathbf{0.036}$ N; a turbulent layer would more than double it.
2. **Cylinder** Vent pipe $D = 0.1$ m, 3 m tall, 15 m/s wind: $Re = \mathbf{9.89} \times \mathbf{10^4}$, $C_D \approx 1.2$.
3. **Load** $F = 1.2 \times \frac{1}{2} \times 1.204 \times 225 \times 0.3 = \mathbf{48.8}$ N; base moment $\mathbf{73.1}$ N $\cdot$ m.

Check yourself

- The gate and the manometer? (58.7 kN at 2.633 m; 14.8 kPa.)
- The nozzle, the bend, the meters? (534 N; 1107 N; 6.93 L/s; 27.3 m/s.)
- The model and the loop? (2.65 m/s, 8.25 N; 16.8 L/s at 13.0 m, 3.06 kW shaft.)
- The plate and the pipe? (5.6 mm, $C_f = 0.00298$; 48.8 N, 73.1 N $\cdot$ m.)

Exercises 2.1·2.2

2.1 Air at 3 m/s flows along a plate 0.8 m long. Find Re_L (three significant figures), say whether the layer stays laminar, and find its thickness at the trailing edge (one decimal, mm). [4]

2.2 The plate of 2.1 is 0.5 m wide and the air flows over both sides. Find the skin-friction drag (three significant figures, N). [4]

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2.1

- $Re_L = UL/\nu = 3 \times 0.8/(1.516 \times 10^{-5}) = \mathbf{1.58 \times 10^5}$, below 5×10^5: **laminar**.
- $\delta = 5L/\sqrt{Re_L} = 5 \times 0.8/\sqrt{1.58 \times 10^5} = \mathbf{10.1}$ mm.

2.2 The plate of 2.1 is 0.5 m wide and the air flows over both sides. Find the skin-friction drag (three significant figures, N). [4]

2.2

- $C_f = 1.328/\sqrt{Re_L} = 1.328/\sqrt{1.583 \times 10^5} = 0.00334$.
- One side: $F = C_f \tfrac{1}{2}\rho U^2 A = 0.00334 \times 0.5 \times 1.204 \times 3^2 \times 0.4 = 0.00723$ N.
- Both sides: $F = 2 \times 0.00723 = \mathbf{0.0145}$ N.

Exercises 2.3·3.1

2.3 A flagpole 0.08 m in diameter and 6 m tall stands in a 20 m/s wind. Check Re, then find the drag with $C_D = 1.2$ (one decimal, N) and the bending moment at its base (nearest N · m). [5]

3.1 A car has $C_D = 0.30$ and frontal area 2.2 m^2. Find its drag and the power to overcome it at 30 m/s (nearest newton, one decimal kW). By what factor does that power rise at 35 m/s, and what is it then? [5]

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2.3

- $Re = UD/\nu = 20 \times 0.08/(1.516 \times 10^{-5}) = 1.06 \times 10^5$, below the drag crisis, so $C_D = 1.2$ holds.
- $F_D = C_D \tfrac{1}{2} \rho U^2 A = 1.2 \times 0.5 \times 1.204 \times 20^2 \times (0.08 \times 6) = \mathbf{138.7}$ N.
- Uniform wind acts at mid-height: $M = F_D \times 3 = \mathbf{416}$ N · m.

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3.1

- $F_D = C_D \tfrac{1}{2} \rho U^2 A = 0.30 \times 0.5 \times 1.204 \times 30^2 \times 2.2 = \mathbf{358}$ N.
- $P = F_D U = 357.6 \times 30 = \mathbf{10.7}$ kW.
- $P \propto U^3$: factor $(35/30)^3 = \mathbf{1.59}$, so $P = 1.59 \times 10.7 = \mathbf{17.0}$ kW.