CHAPTER (11)

DRAG & LIFT

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SUMMARY

1. Drag Force on Body:

$$F_D = C_D A_p \rho \frac{V_0^2}{2} \qquad (11.5)$$

2. Drag force on body is a combination of **Form Drag** (Pressure Forces) and **Skin Friction Drag** (Shear Stress Forces).

3. Coefficient of a Drag of a Sphere For Re<0.5 (Stokes Drag):

$$C_D = \frac{24}{\mathrm{Re}} \qquad (11.9)$$

4. Frequency of vortex Shedding is Given by (St = Strouhal) Number:

$$\mathrm{St} = \frac{nd}{V_0} \qquad (11.7)$$

5. Lift Force on Body:

$$F_L = \frac{1}{2}\rho V_0^2 C_L A_p$$

$$A_p = S = bc$$

6. Lift Coefficient For a Symmetric Two – Dimensional Wing (No tip effect):

$$C_L = 2\pi\alpha$$

7. Drag Coefficient Corresponding to the <u>Minimum Induced Drag:</u>

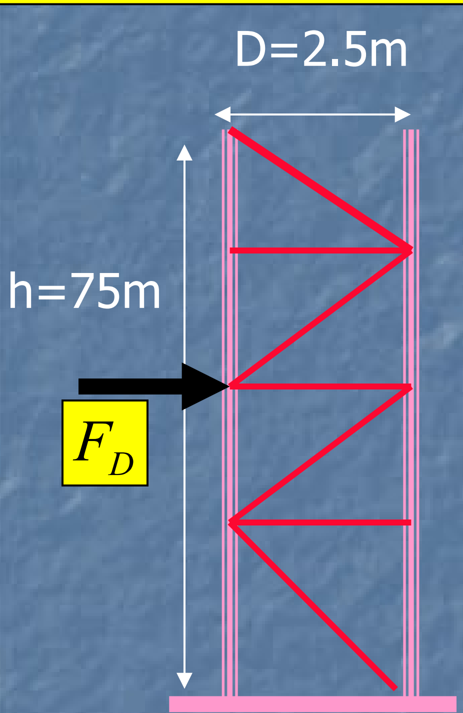
$$C_{Di} = \frac{C_L^{\,2}}{\pi(b^2/S)}$$

8. <u>Streamlining at high Re</u> reduces the drag due to pressure and increase the viscous drag.

9. <u>Streamlining at Low Re</u> increases the drag due to viscous forces.

Problem (11.7)

Find Over Turning Moment at the Base



Cylinder shape

Long smokestack

PROBLEM 11.7

Situation: Wind ($V_o = 35$ m/s) acts on a tall smokestack.
Height is $h = 75$ m. Diameter is $D = 2.5$ m.

Find: Overturning moment at the base.

Assumptions: Neglect end effects–that is the coefficient of drag from a cylin
infinite length is applicable.

Properties: Air at 20 °C from Table A.3: $\rho = 1.2 \times 99/101.3 = 1.17$ kg/m
1.51×10^{-5} m²/s.

$$M_{Turning} = F_D \times \frac{h}{2}$$

$$\frac{L}{D} = \frac{75}{2.5} =$$

2-dimensio

ANALYSIS

Reynolds number

$$\begin{aligned} \text{Re} &= \frac{V_o D}{\nu} \\ &= \frac{(35\text{ m/s}) \times (2.5\text{ m})}{1.51 \times 10^{-5}\text{ m}^2/\text{s}} \\ &= 5.79 \times 10^6 \end{aligned}$$

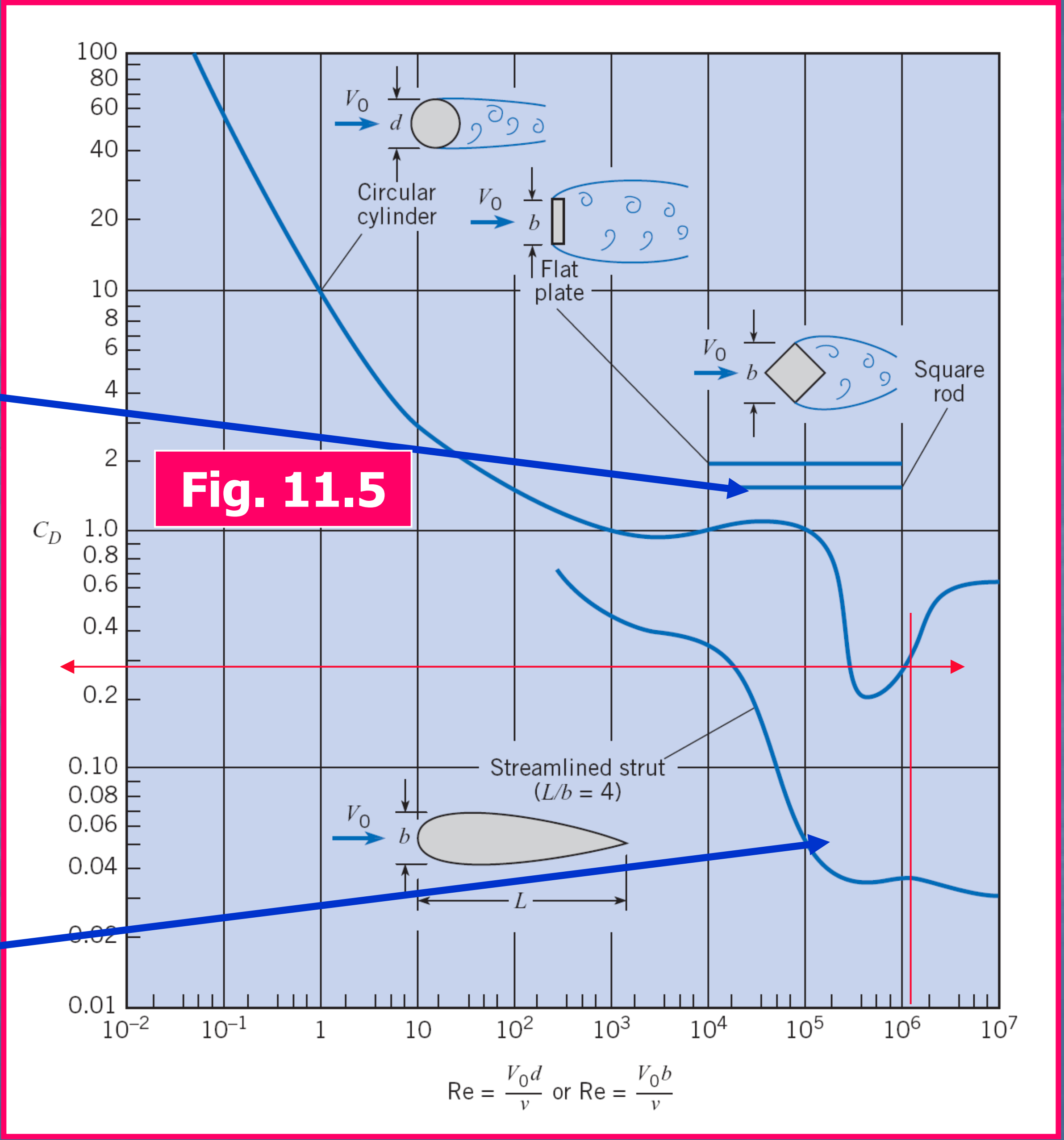
Drag force
From Fig. 11.5 $C_D \approx 0.62$ so

$$\begin{aligned} F_D &= C_D A_p \frac{\rho V_0^2}{2} \\ &= 0.62 \times (2.5 \times 75\text{ m}^2) \times \frac{(1.17\text{ kg/m}^3) \times (35\text{ m/s})^2}{2} \\ &= 83.31\text{ kN} \end{aligned}$$

Equilibrium. Sketch a free-body diagram of the stack–the overturning mome
is

$$\begin{aligned} M_o &= h/2 \times F_D \\ M_o &= (75/2)\text{ m} \times (83.31\text{ kN}) \\ &= \boxed{3.12\text{ MN}\cdot\text{m}} \end{aligned}$$

C_D For Various Two – Dimensional Bodies

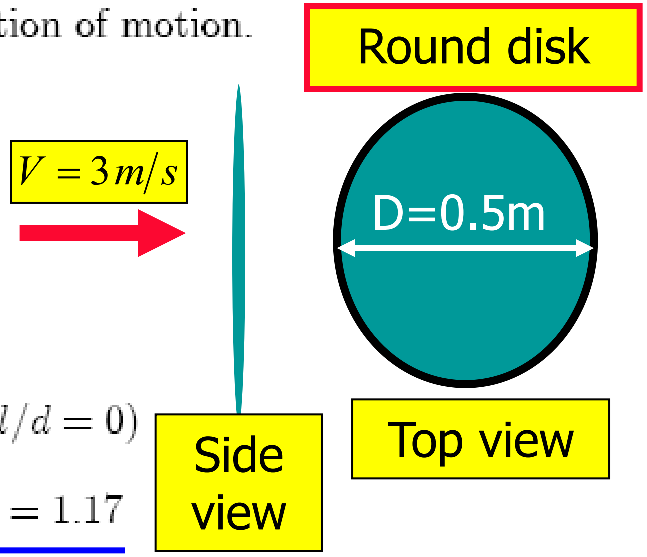


Problem (11.17)

PROBLEM 11.17

Situation: A round disk ($D = 0.5$ m) is towed in water ($V = 3$ m/s). The disk is oriented normal to the direction of motion.

Find: Drag force.



APPROACH

Apply the drag force equation.

ANALYSIS

From Table 11.1 (circular cylinder with $l/d = 0$)

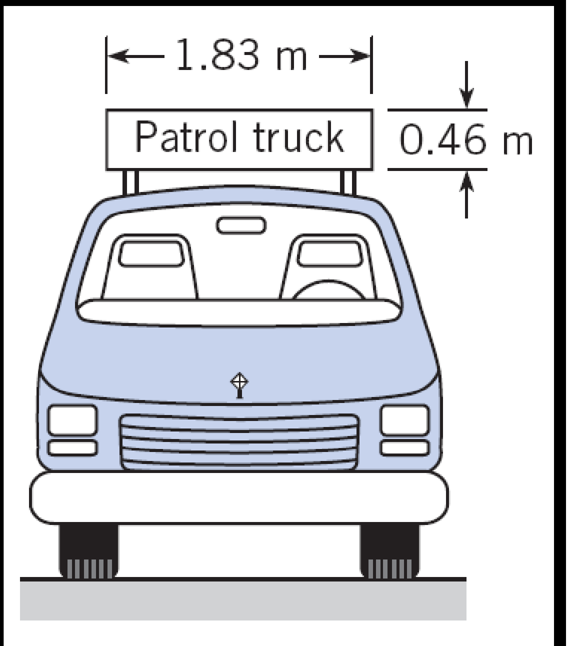
$$C_D = 1.17$$

Drag force **3-dimensional**

$$\begin{aligned} F_D &= C_D A_p \left(\frac{\rho V_0^2}{2}\right) \\ &= 1.17 \left(\frac{\pi \times 0.5^2}{4}\right) \left(\frac{1000 \times 3^2}{2}\right) \\ &= 1033.8 \text{ N} \end{aligned}$$

$$\boxed{F_D = 1030 \text{ N}}$$

Problem (11.20)



PROBLEM 11.20

Situation: A truck carries a rectangular sign.
Dimensions of the sign are 1.83 m by 0.46 m.
Truck speed is $V = 25$ m/s.

Find: Additional power required to carry the sign.

$$Power = P = F \times V$$

Assumptions: Density of air $\rho = 1.2$ kg/m^3.

APPROACH

Apply the drag force equation. Then, calculate power as the product of force and speed.

ANALYSIS

Drag force
From Table 11-1 for a rectangular plate with an aspect ratio of $l/d = 3.98$:

$$C_D \approx 1.20$$

Drag Force

$$\begin{aligned} F_D &= C_D A_p \rho V^2/2 \\ &= 1.2 \times 1.83 \times 0.46 \times 1.2 \times 25^2/2 \\ &= 379 \text{ N} \end{aligned}$$

Power

$$\begin{aligned} P &= F_D \times V \\ &= 379 \times 25 \end{aligned}$$

$$\boxed{P = 9.47 \text{ kW}}$$

Problem (11.27)

$$V_{Wind} = ?$$

PROBLEM 11.27

Situation: A boxcar is described in the problem statement.

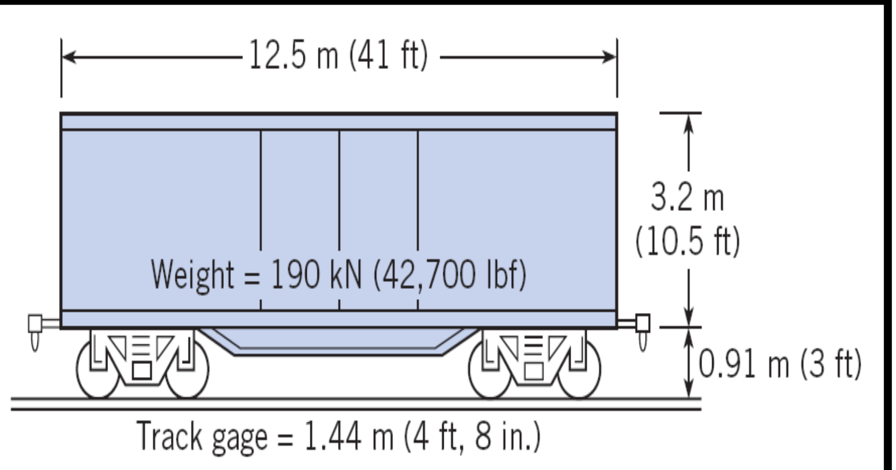
Find: Speed of wind required to blow boxcar over.

Assumptions: $T = 10°C$; $\rho = 1.25\ \mathrm{kg/m^3}$.

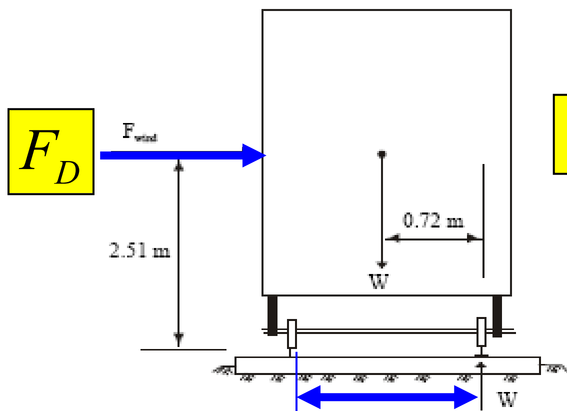
ANALYSIS

Take moments about one wheel for impending tipping.

$$\sum M = 0$$



Side View



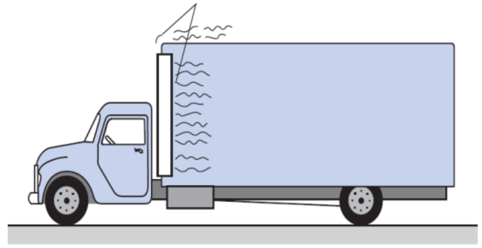
$$W \times 0.72 - F_D \times 2.51 = 0$$

$$F_D = (190,000 \times 1.44/2)/2.51 = 54,500\ \mathrm{N} = C_D A_p \rho V^2/2$$

From Table 11-1, assume $C_D = 1.20$. Then

$$V^2 = 54,500 \times 2/(1.2 \times 12.5 \times 3.2 \times 1.25)$$

$$\boxed{V = 42.6\ \mathrm{m/s}}$$



Problem (11.33)

Situation: To reduce drag, vanes are added to truck—additional details are provided in the problem statement.

Find: Reduction in drag force due to the vanes.

Assumptions: Density, $\rho = 1.2\ \mathrm{kg/m^3}$.

C_D without vanes = 0.78

25% reduction in drag when vanes introduced

V=100 km/hr

Given projected area (A_p)=8.36 m2

APPROACH

Apply drag force equation.

ANALYSIS

$$F_D = C_D A_p \rho V^2/2$$

$$F_{D_{reduction}} = 0.25 \times 0.78 \times 8.36 \times 1.2(100,000/3,600)^2/2$$

$$F_{D_{reduction}} = \boxed{755\ \mathrm{N}}$$

Problem (11.49)

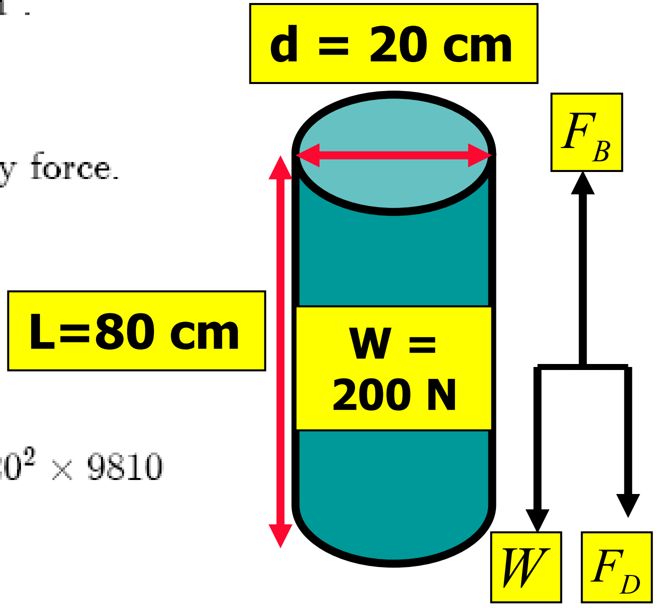
PROBLEM 11.49

Situation: A weighted wood cylinder falls through a lake (see the problem statement for all the details).

Find: Terminal velocity of the cylinder.

$$V_{Terminal} = ?$$

Assumptions: For the water density, $\rho = 1000 \text{ kg/m}^3$.



APPROACH

Apply equilibrium with the drag force and buoyancy force.

ANALYSIS

Buoyancy force

$$\begin{aligned} F_{\text{buoy}} &= V\gamma_{\text{water}} \\ &= 0.80 \times (\pi/4) \times 0.20^2 \times 9810 \\ &= 246.5 \text{ N} \end{aligned}$$

Then the drag force is

$$\begin{aligned} F_D &= F_{\text{buoy}} - W \\ &= 246.5 - 200 \\ &= 46.5 \text{ N} \end{aligned}$$

The cylinder is released at a depth of 100 m in a lake

Problem (11.49)

From Table 11-1 $C_D = 0.87$. Then

$$\frac{l}{d} = \frac{80\,cm}{20\,cm} = 4$$

$$46.5 = \frac{C_D A_p \rho V_0^2}{2}$$

or

$$V_0 = \sqrt{\frac{2 \times 46.5}{C_D A_p \rho}}$$

$$V_0 = \sqrt{\frac{2 \times 46.5}{0.87 \times (\pi/4) \times 0.2^2 \times 1000}}$$

$$= \boxed{1.84 \text{ m/s}}$$

Problem (11.73)

PROBLEM 11.73

Situation: The problem statement provides data describing aircraft takeoff and landing.

Find: (a)Landing speed.
(b) Stall speed.

Landing speed is 8 m/s faster than stalling speed

$$(C_L)_{Landing} = 1.2$$

$$(C_L)_{Stalling} = 1.4$$

ANALYSIS

$$Given: V_{landing} = V_{stall} + 8$$

$C_{L\,max} = 1.40$ which is the C_L at stall. Thus, for stall

$$\begin{aligned} W &= C_{L\,max} S \rho V_s^2/2 \\ &= 1.4 S \rho V_s^2/2 \end{aligned}$$

For landing

$$W = 1.2 S \rho V_L^2/2$$

But

$$V_L = V_s + 8$$

so

$$W = 1.2 A \rho (V_s + 8)^2/2$$

Therefore

$$1.2(V_s + 8)^2 = 1.4 V_s^2$$

$$\boxed{V_s = 99.8 \text{ m/s}}$$

$$V_L = V_s + 8$$

$$\boxed{V_L = 107.8 \text{ m/s}}$$

END OF SOLVED PROBLEMS