Example 1

The drag coefficient of a car at the design conditions of 1 atm, 25°C, and 90 km/h is to be determined experimentally in a large wind tunnel in a full-scale test. The height and width of the car are 1.40 m and 1.65 m, respectively. If the horizontal force acting on the car is measured to be 300 N, determine the total drag coefficient of this car.

Solution of Example 1:

The density of air at 1atm and 25°C is ρ=1.164kg/m^3.

The drag force acting on a body is given by $F_D = C_D A \frac{\rho V^2}{2}$

The drag coefficient is given by $C_D = \frac{2F_D}{A\rho V^2}$

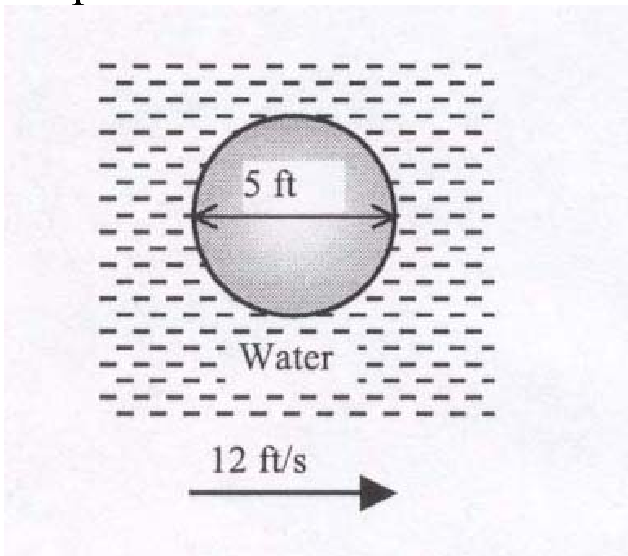
Note A is the frontal area $A = 1.40 \times 1.65 m^2$
and $1 m/s = 3.6 km/h$. Then

$$C_D = \frac{2F_D}{A\rho V^2} = \frac{2 \times 350}{(1.40 \times 1.65) \times 1.164 \times (90/3.6)^2} = 0.42$$

Example 2

A 5-ft-diameter spherical tank completely submerged in freshwater is being towed by a ship at 12 ft/s. Assuming turbulent flow, determine the required towing power.

Solution of Example 2:



The density of water: 62.4lbm/ft^3.

Drag coefficient for a sphere:

$C_D = 0.2$ for turbulent flow

$C_D = 0.5$ for laminar flow

The frontal area of a sphere is $A = \frac{\pi D^2}{4}$

Then the drag force acting on the spherical tank is

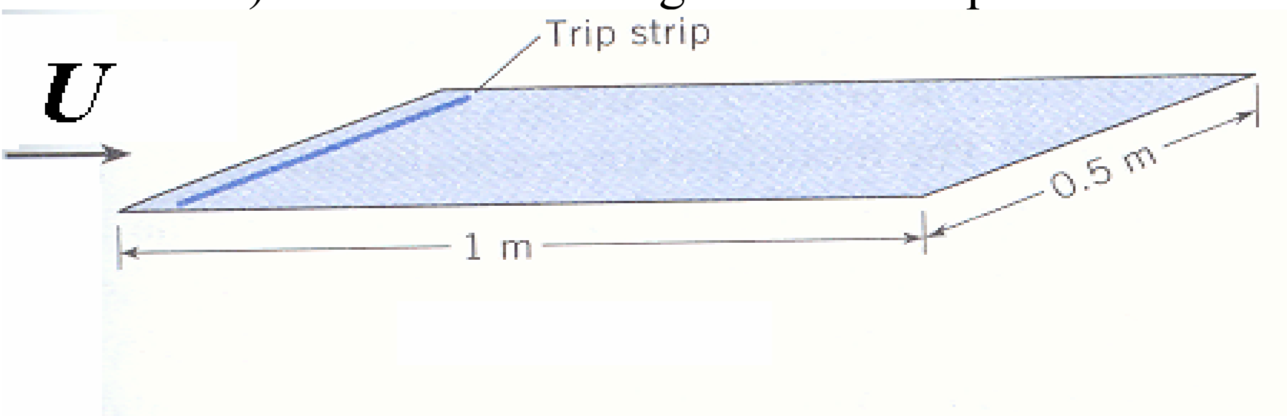
$$F_D = C_D A \frac{\rho V^2}{2} = (0.2)\left(\frac{\pi \times 5^2}{4}\right)\left(\frac{62.4 \times 12^2}{2}\right)\left(\frac{1lbf}{32.2lbm \cdot ft/s^2}\right) = 548lbf$$

Note the power is force times velocity, so the power needed to overcome this drag during towing is

$$\dot{W}_{Towing} = \dot{W}_{Drag} = F_D V = (548)(12)\left(\frac{1kW}{737.56lbf \cdot ft/s}\right) = 8.92kW = 12.0hp$$

Example 3

A flat plate is oriented parallel to a $15\,m/s$ air flow at $20^{o}C$ and atmospheric pressure. The plate is $1.0m$ long in the flow direction and $0.5m$ wide. On one side of the plate, the boundary layer is tripped at leading edge (turbulent flow on that side). Find the total drag force on the plate.



Solution of Example 3:

Properties of air at 1atm and 15°C:

$$\nu = 1.5\times10^{-5}\,m^2/s \text{ and } \rho = 1.2\,kg/m^3$$

The force due to shear stress is

$$F_D = C_D \frac{1}{2}\rho U^2 BL$$

The Reynolds number based on the plate length is

$$\mathrm{Re}_L = \frac{UL}{\nu} = \frac{15\times1}{1.5\times10^{-5}} = 10^6$$

The average shear stress coefficient on the tripped side of the plate is

$$C_D = \frac{0.074}{\left(10^6\right)^{1/5}} = 0.0047$$

On the untripped side of the plate:

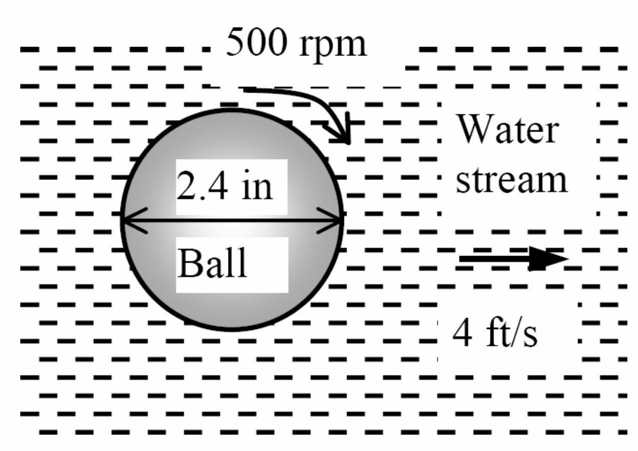
$$C_D = \frac{0.523}{\ln^2\left(0.06\times10^6\right)} - \frac{1520}{10^6} = 0.0028$$

The totaol force is

$$F_x = \left(0.0047+0.0028\right)\times\left(\frac{1}{2}\times1.2\times15^2\right)\times\left(1.0\times0.5\right) = 0.506N$$

Example 4

A 2.4-in-diameter smooth ball rotating at 500 rpm is dropped in a water stream at 60°F flowing at 4 ft/s. Determine the lift and the drag force acting on the ball when it is first dropped in the water.



Solution of Example 4:

Properties of water at 60°F:

$\mu = 7.536\times10^{-4}\ lbm/ft\cdot s$ and $\rho = 62.36\ lbm/ft^3$

The drag and lift forces can be determined from

$F_D = C_D A\dfrac{\rho V^2}{2}$ and $F_L = C_L A\dfrac{\rho V^2}{2}$

Where $A = \pi D^2/4$ is the frontal area and $D = 2.4/12 = 0.2\ ft$

The Reynolds number and angular velocity of the ball are

$$\mathrm{Re} = \frac{\rho VD}{\mu} = \frac{(62.36)(4)(0.2)}{7.536\times10^{-4}} = 6.62\times10^4$$

$$\omega = (500\ rev/min)\left(\frac{2\pi rad}{1rev}\right)\left(\frac{1min}{60s}\right) = 52.4\ rad/s$$ and

$$\frac{\omega D}{2V} = \frac{(52.4)(0.2)}{2(4)} = 1.31 rad$$

From Fig. 11-53, $C_D = 0.56$ and $C_L = 0.35$

The drag and lift forces are

$$F_D = (0.56)\frac{\pi(0.2\ \mathrm{ft})^2}{4}\frac{(62.36\ \mathrm{lbm/ft^3})(4\ \mathrm{ft/s})^2}{2}\left(\frac{1\ \mathrm{lbf}}{32.2\ \mathrm{lbm\cdot ft/s^2}}\right) = \mathbf{0.27\ lbf}$$

$$F_L = (0.35)\frac{\pi(0.2\ \mathrm{ft})^2}{4}\frac{(62.36\ \mathrm{lbm/ft^3})(4\ \mathrm{ft/s})^2}{2}\left(\frac{1\ \mathrm{lbf}}{32.2\ \mathrm{lbm\cdot ft/s^2}}\right) = \mathbf{0.17\ lbf}$$