CE 3305 Equation Sheet

Density and Specific Weight

$$\rho = \frac{m}{V} = \gamma \frac{W}{V}$$

Ideal Gas Law

$$P = \rho RT$$

Viscosity

$$\tau = \mu \frac{du}{dy} \; ; \quad \nu = \frac{\mu}{\rho}$$

Pressure

$$P_{avg} = \frac{F}{A}$$

$$P_{abs} = P_{atm} + P_g$$

$$P = P_0 + \gamma$$

Hydrostatic Resultant Force

$$F_R = \gamma \bar{h} A$$

$$y_P = \bar{y} + \frac{\overline{I_x}}{\bar{y}A}$$

$$x_P = \bar{x} + \frac{\overline{I_{xy}}}{\bar{y}A}$$

Volumetric and Mass Flow

$$Q = V \cdot A; \quad \dot{m} = \rho V \cdot A$$

Bernoulli's Equation

$$\frac{P_1}{\gamma} + \frac{V_1^2}{2g} + z_1 = \frac{P_2}{\gamma} + \frac{V_2^2}{2g} + z_2$$

Hydraulic Head

$$z + \frac{\mathrm{P}}{\gamma} + \frac{\mathrm{V}^2}{2g} = H$$

Energy Equation

$$\frac{P_{in}}{\gamma} + \frac{V_{in}^2}{2g} + z_{in} + h_{pump} = \frac{P_{out}}{\gamma} + \frac{V_{out}^2}{2g} + z_{out} + h_{turbine} + h_L$$

Power

$$\dot{W}_s = \gamma Q h_s = \dot{m} g h_s$$

Conservation of Mass

$$\frac{\partial}{\partial t}\int_{cv} \rho d\forall + \int_{cs} \rho V_{f/cs} \cdot dA = 0$$

Conservation of Momentum

$$\Sigma F = \frac{\partial}{\partial t}\int_{cs} V\rho d\forall + \int V\rho V_{f/cs} \cdot dA$$

Buckingham-Pi Theorem

$$\Pi = \mathrm{n} - \mathrm{m}$$

Conduit Flow

$$\tau_o = \frac{r}{2}\left(\frac{\Delta p}{L}\right)$$

$$u_{max} = \frac{D^2}{16\mu}\left(\frac{\Delta p}{L}\right)$$

$$V = \frac{D^2}{32\mu}\left(\frac{\Delta p}{L}\right) \rightarrow u_{max} = 2V$$

Hagen-Poiseuille Equation

$$Q = \frac{\pi D^4}{128\mu}\left(\frac{\Delta p}{L}\right)$$

$$\Delta p = \frac{128\mu L Q}{\pi D^4}$$

Reynolds Number

$$Re = \frac{inertia\ force}{viscous\ force} = \frac{\rho V D}{\mu} = \frac{VD}{\nu}$$

Shear Stress and Velocity

$$u^* = \sqrt{\frac{\tau_0}{\rho}}$$

$$\frac{\bar{u}}{u^*} = \frac{u^* y}{\nu}$$

$$\frac{\bar{u}}{u^*} = 2.5 \ln\left(\frac{u^* y}{\nu}\right) + 5.0$$

Darcy-Weisbach Equation

$$h_L = f\ \frac{L}{D}\frac{V^2}{2g}$$

$$f = \frac{64}{Re}\ (for\ laminar\ flow, otherwise\ use\ Moody\ Diagram)$$

Minor Losses

$$h_L = K_L \frac{V^2}{2g}$$

Net Positive Suction Head

$$NPSH_{avail} = \frac{p}{\gamma} + \frac{V^2}{2g} - \frac{p_v}{\gamma}$$

Froude Number

$$Fr = \frac{gravity}{inertia} = \frac{V}{\sqrt{gy}} = \frac{V}{c}$$

Specific Energy

$$E = \frac{V^2}{2g} + y = \frac{Q^2}{2gA^2} + y$$

$$E = \frac{q^2}{2gy^2} + y$$

Open Channel Flow

$$y_c = \left(\frac{q^2}{g}\right)^{\frac{1}{3}}$$

$$E_{min} = \frac{3}{2} y_c$$

$$V_c = \sqrt{g y_c}$$

$$S_c = \frac{n^2 g A_c}{k^2 b_{top} R_{hc}^{4/3}}$$

Non-rectangular Channel

$$\frac{Q^2}{g} = \frac{A_c^3}{b_{top}}$$

$$V_c = \sqrt{\frac{g A_c}{b_{top}}}$$

Reynolds Number for Open Channel Flow

$$Re = \frac{V R_h}{\nu}$$

$$R_h = \frac{A}{P_w}$$

Manning Equation

$$V = \frac{k R_h^{2/3} S_0^{1/2}}{n}$$

$$Q = \frac{k A^{5/3} S_0^{1/2}}{n P^{2/3}}$$

Hydraulic Jump

$$\frac{y_2}{y_1} = \frac{1}{2}\left[\sqrt{1 + 8Fr_1^2} - 1\right]$$

$$h_L = \frac{(y_2 - y_1)^3}{4y_1y_2}$$

Sharp-crested Weir-Rectangular

$$Q_{actual} = C_d \frac{2}{3}\sqrt{2g}bH^{3/2}$$

Sharp-crested Weir-Triangular

$$Q_{actual} = C_d \frac{8}{15}\sqrt{2g}H^{5/2}\tan\frac{\theta}{2}$$

Broad-crested Weir

$$y_c = \frac{2}{3}H$$

$$Q_{actual} = C_w b\sqrt{g}\left(\frac{2}{3}H\right)^{3/2}$$

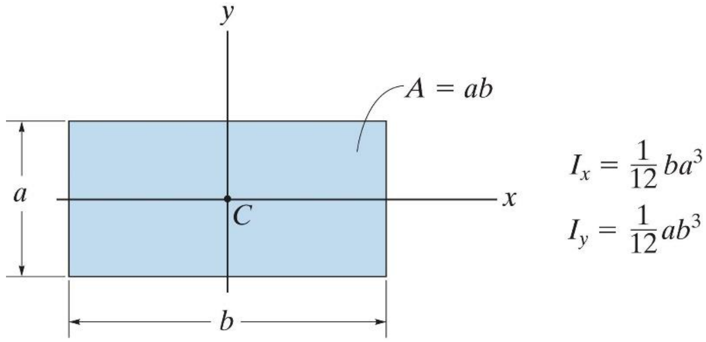
Drag Force (general)

$$F_D = C_D A_p\left(\frac{\rho V^2}{2}\right)$$

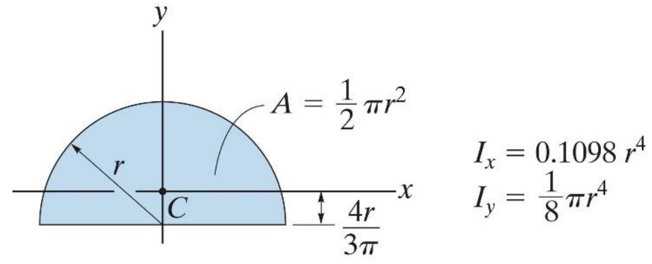
Drag Force (laminar flow around a spherical shape)

$$F_D = 3\pi\mu VD$$

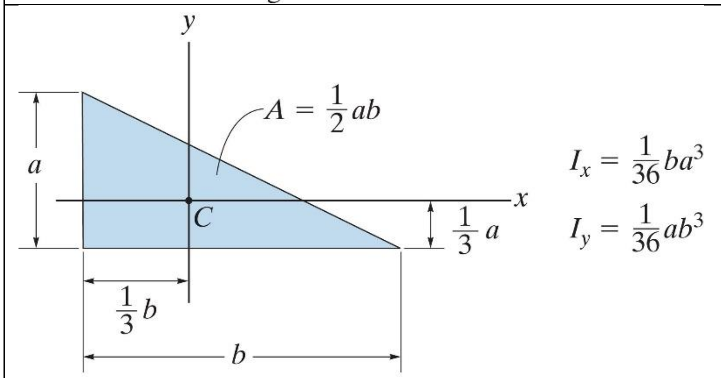
Geometric Properties of an Area



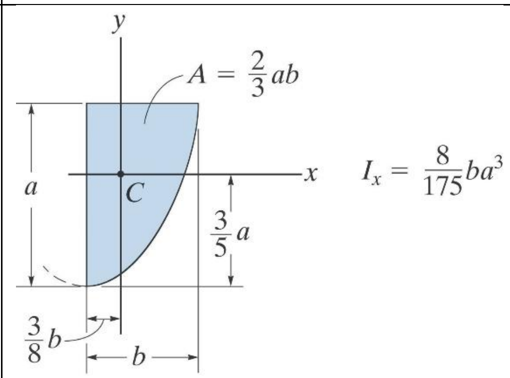
Rectangle



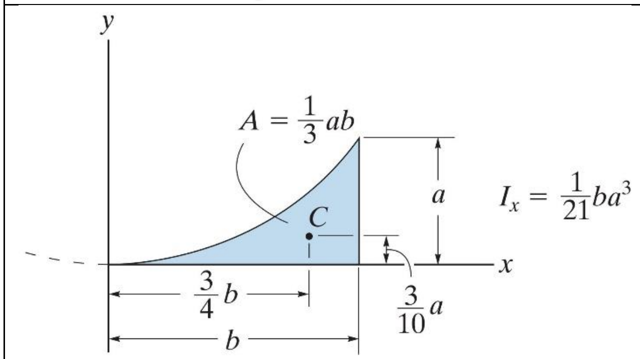
Semicircle



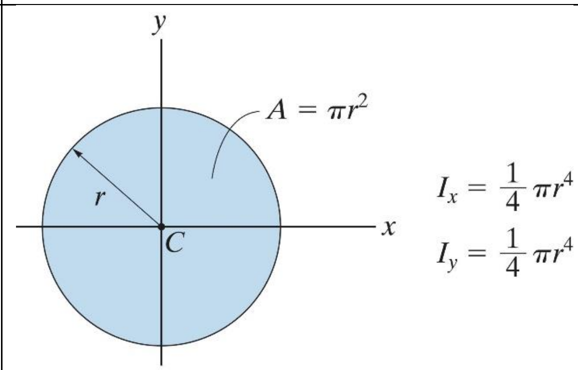
Triangle



Parabola



Exparabola



Circle

Units Table for Dimensional Analysis

TABLE 8–1

Quantity	Symbol	M-L-T	F-L-T
Area	A	L^2	L^2
Volume	$\forall$	L^3	L^3
Velocity	V	LT^{-1}	LT^{-1}
Acceleration	a	LT^{-2}	LT^{-2}
Angular velocity	ω	T^{-1}	T^{-1}
Force	F	MLT^{-2}	F
Mass	m	M	FT^2L^{-1}
Density	ρ	ML^{-3}	FT^2L^{-4}
Specific weight	γ	$ML^{-2}T^{-2}$	FL^{-3}
Pressure	p	$ML^{-1}T^{-2}$	FL^{-2}
Dynamic viscosity	μ	$ML^{-1}T^{-1}$	FTL^{-2}
Kinematic viscosity	ν	L^2T^{-1}	L^2T^{-1}
Power	$\dot{W}$	ML^2T^{-3}	FLT^{-1}
Volumetric flow rate	Q	L^3T^{-1}	L^3T^{-1}
Mass flow rate	$\dot{m}$	MT^{-1}	FTL^{-1}
Surface tension	σ	MT^{-2}	FL^{-1}
Weight	W	MLT^{-2}	F
Torque	T	ML^2T^{-2}	FL

*Recall that force and mass are not independent of each other. Instead they are related by Newton's law of motion, $F = ma$. Thus in the SI system, force has the dimensions of $ML/T^2\,(ma)$, and in the U.S. customary system, mass has the dimensions of $FT^2/L\,(F/a)$.

Roughness Factors for New Pipe

Smooth glass, plastic $\varepsilon = 0$

Concrete $\varepsilon = 0.3$ mm $-$ 3 mm (0.001 ft $-$ 0.01 ft)

Cast iron $\varepsilon = 0.26$ mm (0.000 85 ft)

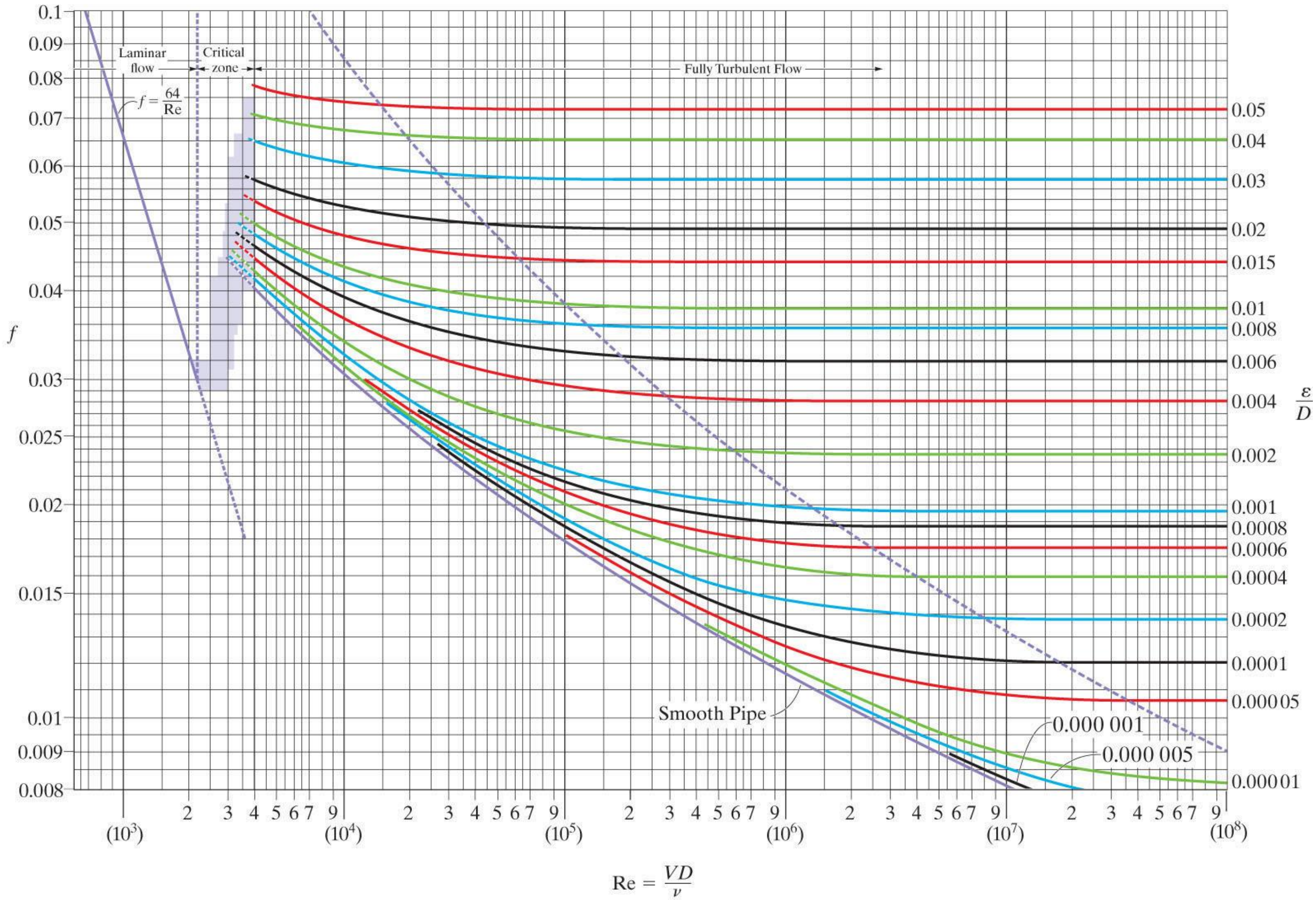
Galvanized iron $\varepsilon = 0.15$ mm (0.0005 ft)

Riveted steel $\varepsilon = 0.9$ mm $-$ 9 mm (0.003 ft $-$ 0.03 ft)

Commercial steel $\varepsilon = 0.045$ mm (0.000 15 ft)

Drawn tubing $\varepsilon = 0.0015$ mm (0.000 005 ft)

Wood stave $\varepsilon = 0.5$ mm (0.0016 ft)



Moody Diagram
(Ref. [1], Ch. 10)

Minor Loss Coefficients

TABLE 10–1

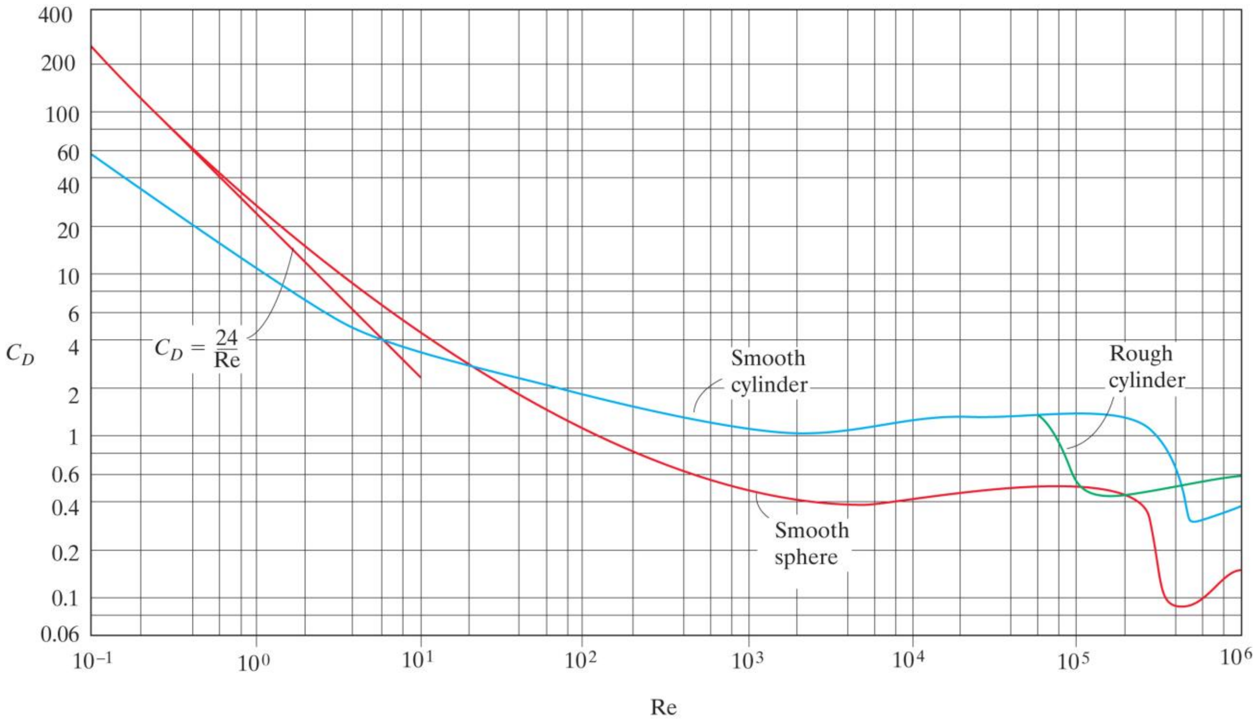
Loss coefficients for pipe fittings	K_L
Gate valve—fully opened	0.19
Globe valve—fully opened	10
Angle valve—fully opened	5
Ball valve—fully opened	0.05
Swing check valve	2
90° elbow (short radius)	0.9
90° long sweep elbow	0.6
45° bend (short radius)	0.4
180° return bend (short radius)	2
Tee for *V* along pipe run	0.4
Tee for *V* along branch	1.8

Roughness Coefficient (Manning's n)

TABLE 12–1 Surface Roughness Coefficient

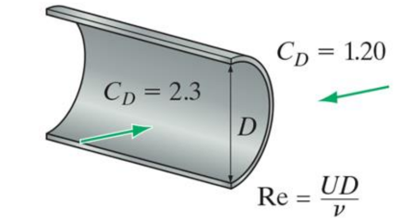
Perimeter	*n*
Earth channel	
Grass land	0.02–0.04
Sparse vegetation	0.05–0.1
Heavy weeds	0.07–0.15
Firm soil	0.025–0.032
Smooth soil	0.017–0.025
Gravel surface	0.02–0.035
Rocky surface	0.035–0.050
Artificially lined channel	
Steel	0.012–0.018
Cast iron	0.012–0.019
Corrugated metal	0.022–0.030
Finished concrete	0.010–0.013
Unfinished concrete	0.012–0.016
Precast concrete	0.011–0.015
Brick surface	0.013–0.018
Wood	0.010–0.013

Drag Coefficients for Sphere and Long Cylinder

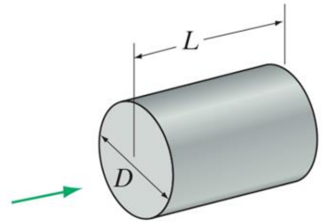


Drag Coefficients for Simple Geometric Shapes, Re>10^4

TABLE 11–3 Drag Coefficients for Simple Geometric Shapes, $\mathrm{Re} > 10^4$



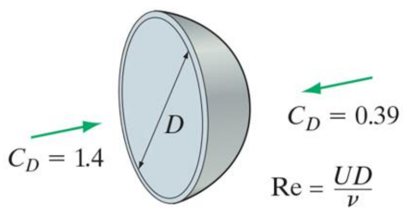
Hollow semicylinder



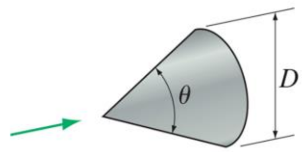
L/D	C_D
0.5	1.1
1	0.95
2	0.86

$\mathrm{Re} = \frac{UD}{\nu}$

Cylinder



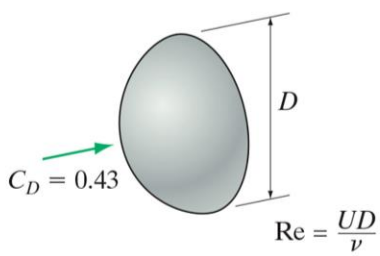
Hollow hemisphere



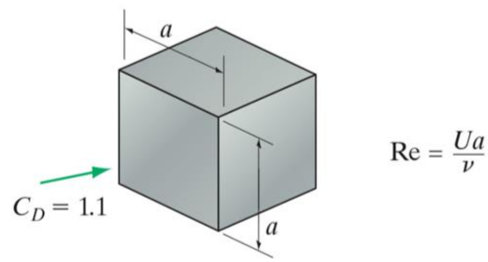
θ	C_D
30°	0.55
60°	0.80

Cone

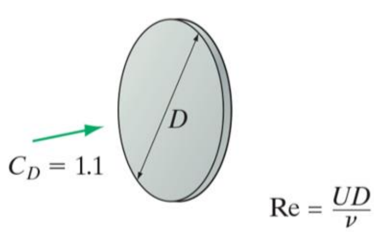
$\mathrm{Re} = \frac{UD}{\nu}$



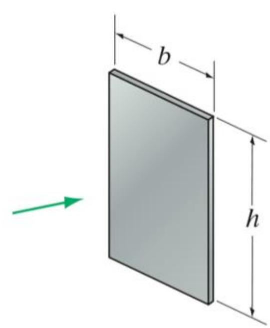
Solid hemisphere



Cube



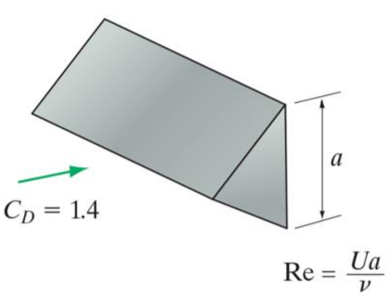
Disk



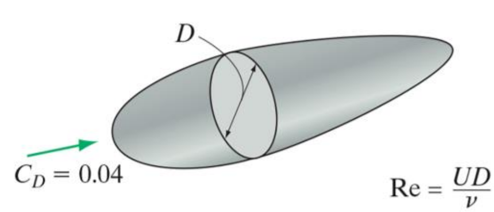
b/h	C_D
<0.1	1.9
0.5	2.5
1	1.18
5	1.2
10	1.3

$\mathrm{Re} = \frac{Uh}{\nu}$

Rectangular plate



Triangular cross section



Streamlined body

Conversion Factors

1 mi = 5280 ft

1 ft = 0.3048 m

1 kip = 1000 lb

1 lb = 4.448 N

1 slug = 14.59 kg

1 atm = 14.7 lb/in^2 (psi) = 101.3 kPa

7.48 U.S. gal = 1 ft^3

1 gal/min (gpm) = 0.002 228 ft^3/s

1000 liters (l) = 1 m^3

1 hp = 550 ft·lb/s = 745.7 W