Table 10-19. Drag of Bluff Bodies.

Notation: C_D = drag coefficient = Drag/($\rho U^2 A/2$); A = reference area; Drag = force exerted parallel to the approach flow; D = reference width; Re = Reynolds number = UD/ν; U = free stream velocity; ρ = fluid density; ν = fluid kinematic viscosity. Consistent sets of units are given in Table 3-1. Data are for high Reynolds numbers, $Re > 10^4$, incompressible, low-turbulence flow unless otherwise noted. → denotes direction of approaching free stream. Also see Table 10-20. Accuracy is approximately ±5%.

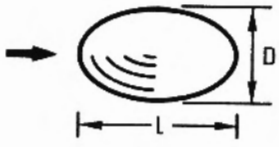
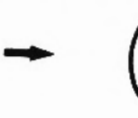
Geometry	Reference Area, A	Drag Coefficient, C_D, and Remarks
1. Sphere 	$\frac{\pi D^2}{4}$	Re: 10^2 | 10^3 | 10^4 | 10^5 | 10^6 | 5×10^6 C_D: 1.0 | 0.41 | 0.39 | 0.52 | 0.12 | 0.18 Also see Fig. 10-22. For Re < 1, $C_D \approx 24/\{Re[1 + (3/16)Re]\}$, Ref. 10-134.
2. Hemisphere 	$\frac{\pi D^2}{4}$	→ 0.42 ← 1.17 Ref. 10-102, p. 3-17.
3. Thin Hemispherical Cup 	$\frac{\pi D^2}{4}$	→ 0.38 ← 1.42 Ref. 10-102, p. 3-17.
4. Ellipsoid of Revolution 	$\frac{\pi D^2}{4}$	$0.44(D/L) + 0.016(L/D) + 0.016(D/L)^{1/2}$ $1 < L/D < 10$. $Re < 2 \times 10^5$, Ref. 10-102.
5. Sphere in a Circular Duct 	$\frac{\pi D^2}{4}$	$C_D = \left[1 + 1.45\left(\frac{D}{D_o}\right)^{4.5}\right] C_D\Big\|_{D_o/D=\infty}$ $0 < D/D_o < 0.92$, $C_D(D_o/D = \infty)$ from frame 1. $Re = 2 \times 10^5$, Ref. 10-136. Also see Ref. 10-181.
6. Thin Circular Disk 	$\frac{\pi D^2}{4}$	Re: 1 | 2 | 5 | 10 | 10^2 | 10^3 | 10^4 | 10^5 C_D: 25 | 15 | 6 | 3.6 | 1.5 | 1.1 | 1.1 | 1.15 Ref. 10-173.

Table 10-19. Drag of Bluff Bodies. *(Continued)*

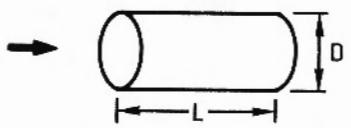
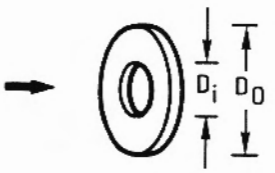
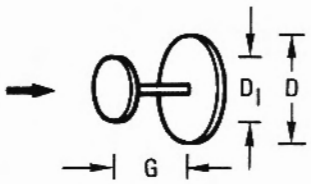
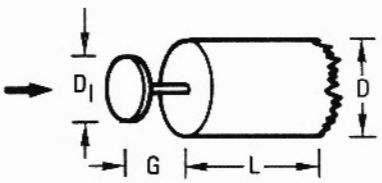
Geometry	Reference Area, A	Drag Coefficient, C_D, and Remarks
7. Circular Rod Parallel to Flow 	$\frac{\pi D^2}{4}$	L/D | C_D ~0 | 1.15 0.5 | 1.10 1.0 | 0.93 1.5 | 0.85 2.0 | 0.83 3.0 | 0.85 4.0 | 0.85 5.0 | 0.85 Ref. 10-174.
8. Thin Annular Disk 	$\frac{\pi}{4}(D_o^2 - D_i^2)$	D_i/D_o | C_D 0 | 1.20 0.2 | 1.22 0.4 | 1.25 0.6 | 1.30 0.7 | 1.35 0.75 | 1.60 0.80 | 1.80 ~1.0 | 2.0 Ref. 10-102, p. 3-16.
9. Two Thin Disks in Tandem 	$\frac{\pi D^2}{4}$	C_D vs D_1/D and G/D G/D | 0.25 | 0.50 | 0.65 | 0.80 | 1.0 | 1.2 0.0 | 1.15 | 1.15 | 1.15 | -- | 1.15 | 1.70 0.125 | 1.13 | 1.05 | 0.80 | 0.55 | 1.16 | 1.72 0.25 | 1.10 | 0.80 | 0.88 | 0.30 | 1.16 | 1.73 0.50 | 0.96 | 0.80 | 0.42 | 0.22 | 1.15 | 1.75 0.75 | 0.87 | 0.75 | 0.45 | 0.30 | 1.10 | 1.70 1.0 | 0.80 | 0.68 | 0.55 | 0.42 | 1.05 | 1.67 1.50 | 0.97 | 0.73 | 0.73 | 0.65 | 0.85 | 1.58 2.00 | -- | -- | -- | 0.85 | 0.93 | 1.38 Re = 10^5, Ref. 10-173.
10. Thin Disk in Tandem with Cylindrical Rod  50 D > L > 10 D	$\frac{\pi D^2}{4}$	C_D vs D_1/D and G/D G/D | 0.125 | 0.25 | 0.50 | 0.625 | 0.75 | 1.0 0.05 | 0.74 | 0.73 | 0.72 | 0.67 | 0.55 | 0.75 0.10 | 0.72 | 0.70 | 0.53 | 0.48 | 0.23 | 0.73 0.25 | 0.71 | 0.60 | 0.38 | 0.16 | 0.03 | 0.73 0.50 | 0.55 | 0.43 | 0.25 | 0.04 | 0.04 | 0.71 0.75 | 0.45 | 0.35 | 0.23 | 0.14 | 0.11 | 0.70 1.0 | 0.53 | 0.33 | 0.25 | 0.23 | 0.18 | 0.68 1.25 | 0.55 | 0.40 | 0.27 | 0.30 | 0.30 | 0.65 1.50 | 0.57 | 0.50 | 0.32 | 0.37 | 0.43 | 0.63 Re = 5×10^5, Ref. 10-175.

Table 10-19. Drag of Bluff Bodies. *(Continued)*

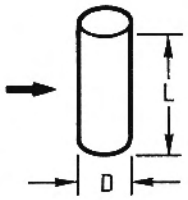
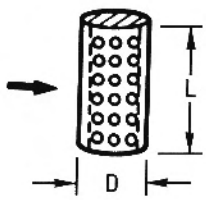
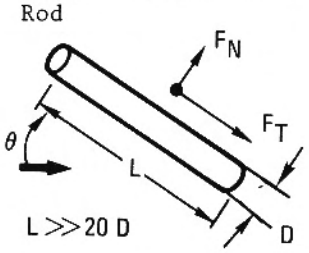
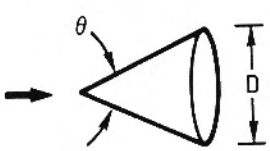
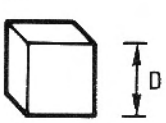
Geometry	Reference Area, A	Drag Coefficient, C_D, and Remarks
11. Cylindrical Rod Perpendicular to Flow 	LD	L/D | C_D 1.0 | 0.64 1.98 | 0.68 2.96 | 0.74 5.0 | 0.74 10. | 0.82 20. | 0.91 40. | 0.98 ∞ | 1.20 Also see Table 10-18. Re = 8.8×10^4, Ref. 10-5, pp. 419, 439.
12. Thin, Hollow, Perforated Circular Cylinder with End Caps  HOLES ARE 0.01 D IN DIAMETER AND COVER 40% OF SURFACE	LD	L/D | C_D 2.07 | 0.80 4.02 | 0.89 5.45 | 0.91 6.5 | 0.95 7.92 | 0.95 ∞ | ∿1.0 Re = 8.8×10^4, Ref. 10-176.
13. Long, Inclined Circular Rod  L >> 20 D	LD - - - - - πDL	Normal Force $C_N \approx 1.2 \sin^2\theta$ - Tangent Force $C_T \approx 0.083 \cos\theta - 0.035 \cos^2\theta$. Refs. 10-159, 10-177.
14. Cone 	$\frac{\pi D^2}{4}$	θ (deg) | C_D 10 | 0.30 20 | 0.40 30 | 0.55 40 | 0.65 60 | 0.80 75 | 1.05 90 | 1.15 180 | 1.40 Ref. 10-102, p. 3-18.
15. Cube 	D^2	→ 1.05 ↗ 0.80 Ref. 10-102, p. 3-17.

Table 10-19. Drag of Bluff Bodies. *(Continued)*

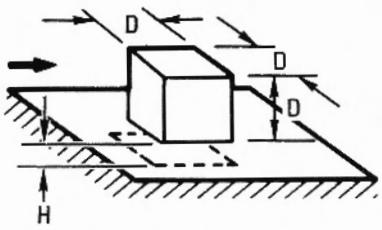
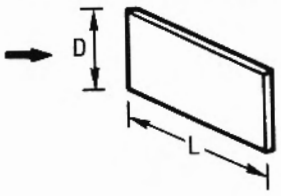
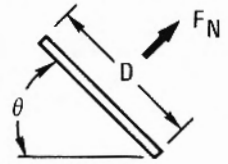
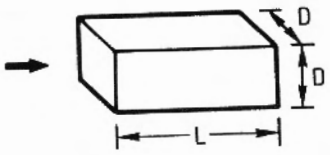
Geometry	Reference Area, A	Drag Coefficient, C_D, and Remarks
16. Cube Above a Surface  BOUNDARY LAYER THICKNESS ON SURFACE = 0.09 D	D^2	H/D | C_D | C_L 0. | 1.18 | -1.1 0.25 | 1.10 | -1.5 0.5 | 1.15 | -0.70 1.0 | 1.13 | -0.30 1.5 | 1.10 | -0.20 2.0 | 1.08 | 0.0 Lift is vertically upward. Thus, there is a downforce on the cube. Re > 3×10^5, Ref. 10-178.
17. Thin Rectangular Plate Perpendicular to Flow 	LD	L/D | C_D 1.0 | 1.05 2.0 | 1.10 4.0 | 1.12 8.0 | 1.20 10.0 | 1.22 12.0 | 1.22 17.8 | 1.33 ∞ | 1.90 Re ≈ 10^5, Ref. 10-5, p. 439
18. Inclined, Thin Rectangular Plate  L = BREADTH	LD	$C_N/C_N(\theta = 90°)$ vs L/D θ (deg) | 1/6 | 1/3 | 1.0 | 1.5 | 2 | 3 0 | ∿0 | ∿0 | ∿0 | ∿0 | ∿0 | ∿0 10 | 0.15 | 0.22 | 0.38 | 0.37 | 0.45 | 0.50 20 | 0.40 | 0.53 | 0.83 | 0.80 | 0.90 | 0.76 30 | 0.67 | 0.87 | 1.22 | 0.80 | 0.73 | 0.76 40 | 0.92 | 1.20 | 1.40 | 0.85 | 0.78 | 0.85 50 | 1.04 | 1.13 | 1.05 | 0.90 | 0.83 | 0.90 60 | 1.05 | 1.05 | 1.03 | 0.94 | 0.90 | 0.94 70 | 1.04 | 1.04 | 1.02 | 0.97 | 0.95 | 0.97 80 | 1.03 | 1.02 | 1.01 | 0.98 | 0.97 | 0.98 90 | 1.0 | 1.0 | 1.0 | 1.0 | 1.0 | 1.0 $C_N(\theta = 90°)$ from frame 17 L/D | 1/6 | 1/3 | 1.0 | 1.5 | 2 | 3 $C_N(\theta = 90°)$ | 1.16 | 1.11 | 1.05 | 1.07 | 1.10 | 1.11 $C_L = C_N \cos \theta$ $C_D = C_N \sin \theta$
19. Square Rod Parallel to Flow 	D^2	L/D | C_D ∿0 | 1.25 0.5 | 1.25 1.0 | 1.15 1.5 | 0.97 2.0 | 0.87 2.5 | 0.90 3.0 | 0.93 4.0 | 0.95 5.0 | 0.95 Re = 1.7×10^5, Ref. 10-174; Also see this reference for inclined square rod.

Table 10-19. Drag of Bluff Bodies. *(Continued)*

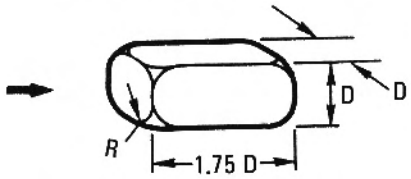
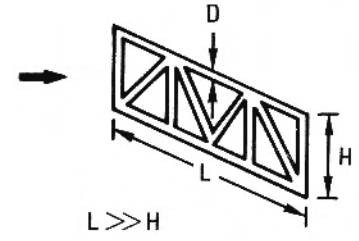
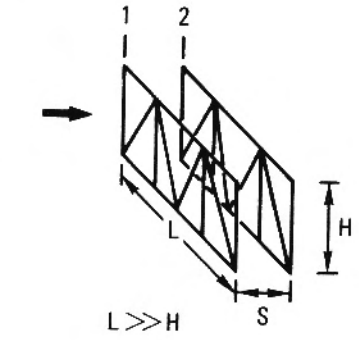
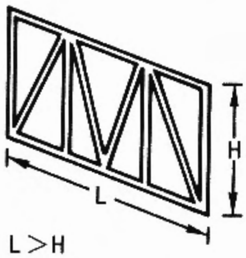
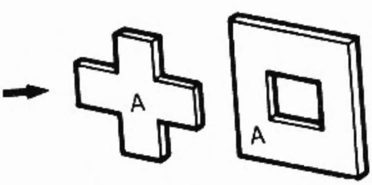
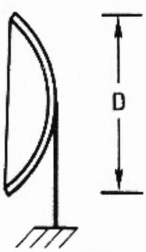
Geometry	Reference Area, A	Drag Coefficient, C_D, and Remarks
20. Square Rod with Rounded Corners  ALL CORNERS ARE ROUNDED	D^2	C_D vs Re R/D: 0.0, 0.025, 0.50, 0.10, 0.20, 0.25 C_D at Re = 5.5×10^5: 0.75, 0.60, 0.55, 0.32, 0.17, 0.17 C_D at Re = 8.2×10^6: 0.75, 0.35, 0.25, 0.15, 0.15, 0.15 R = edge radius, Ref. 10-180.
21. Open Frame  Frame details for example only.	Projected solid area, A_s	Solidarity Ratio, A_s/A Truss Type: Square Edges; Round Edge, Re < 2×10^5; Round Edge, Re > 5×10^5 0: 2.0; 1.5; 1.1 0.1: 1.8; 1.3; 0.9 0.2: 1.7; 1.3; 0.9 0.3: 1.6; 1.2; 0.8 0.4: 1.6; 1.2; 0.8 0.6: 1.6; 1.2; 0.8 0.8: 1.6; --; -- 0.9: 1.6; --; -- 1.0: 2.0; --; -- A = total area = HL. Re = UD/ν, Ref. 10-181, p. 167.
22. Multiple Frames  	Projected solid area, A_s	Drag coefficient of 1st truss given by frame 21. Drag coefficient of second or more trusses given by $\alpha C_D\big\|_{\text{frame 21}}$, where $\alpha = f(A_s/A, S/L)$. α vs A_s/A S/H: 0.5, 1.0, 2.0, 3.0, 4.0, 6.0 0.1: 0.95, 1.0, 1.0, 1.0, 1.0, 1.0 0.2: 0.75, 0.82, 0.87, 0.90, 0.92, 0.94 0.3: 0.55, 0.63, 0.72, 0.75, 0.77, 0.83 0.4: 0.38, 0.50, 0.55, 0.61, 0.65, 0.70 0.5: 0.18, 0.32, 0.43, 0.48, 0.50, 0.60 0.6 to 1.0: 0.0, 0.15, 0.30, 0.35, 0.40, 0.50 A = total area = HL. Ref. 10-181, p. 168.

Table 10-19. Drag of Bluff Bodies. *(Continued)*

<table>
<tr><th>Geometry</th><th>Reference Area, A</th><th>Drag Coefficient, C_D, and Remarks</th></tr>
<tr><td>23. Effect of Aspect Ratio on Open Frame
 
L > H</td><td>Projected solid area, A_s</td><td>$\beta C_D \Big|_{\substack{\text{frame 20} \\ \text{frame 21}}}$,
where $\beta = F(H/L, A_s/A)$
<table><tr><th></th><th colspan="5">β</th></tr><tr><th></th><th colspan="5">A_s/A</th></tr><tr><th>H/L</th><th>0.25</th><th>0.50</th><th>0.90</th><th>0.95</th><th>1.0</th></tr><tr><td>0</td><td>1.0</td><td>1.0</td><td>1.0</td><td>1.0</td><td>1.0</td></tr><tr><td>0.02</td><td>0.99</td><td>0.98</td><td>0.97</td><td>0.95</td><td>0.89</td></tr><tr><td>0.05</td><td>0.98</td><td>0.97</td><td>0.95</td><td>0.89</td><td>0.75</td></tr><tr><td>0.2</td><td>0.95</td><td>0.92</td><td>0.88</td><td>0.78</td><td>0.59</td></tr></table>A = total area = HL.
Ref. 10-181, p. 167.</td></tr>
<tr><td>24. Average Man
  </td><td>See data at right.</td><td>→ $C_D A = 9\ ft^2\ (0.84\ m^2)$
↑ $C_D A = 1.2\ ft^2\ (0.11\ m^2)$
• $C_D A = 5\ ft^2\ (0.46\ m^2)$
Sitting → $C_D A = 6\ ft^2\ (0.56\ m^2)$
Crouching → $C_D A = 2$ to $3\ ft^2\ (0.19\ m^2$ to $0.28\ m^2)$
Ref. 10-102, p. 3-14.</td></tr>
<tr><td>25. Various Plate Sections
  </td><td>Solid area</td><td>$C_D = 1.2$
Solidity is 40% to 70% of square plate of same overall dimensions.
Ref. 10-102, p. 20-1.</td></tr>
<tr><td>26. Porous Parabolic Dish
  </td><td>$\frac{\pi D^2}{4}$</td><td><table><tr><th>Porosity</th><th>0</th><th>0.1</th><th>0.2</th><th>0.3</th><th>0.4</th><th>0.5</th></tr><tr><td>→ C_D</td><td>1.42</td><td>1.33</td><td>1.20</td><td>1.05</td><td>0.95</td><td>0.82</td></tr><tr><td>← C_D</td><td>0.95</td><td>0.92</td><td>0.90</td><td>0.86</td><td>0.83</td><td>0.80</td></tr></table>Porosity = open area/total area.
$Re = 2 \times 10^6$.
Ref. 102, p. 20-2.</td></tr>
</table>