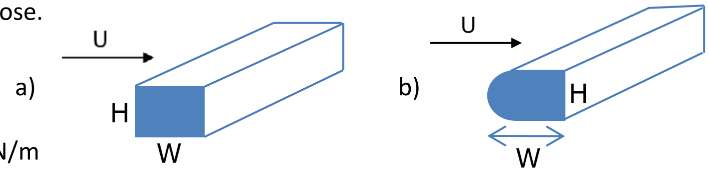
DRAG ON 2D BODIES

LIFT & DRAG SELF ASSESSMENT SHEET 1

1. A very long cylinder, H=5 cm high and W=30 cm wide, is immersed in water (density 1000 kg/m^3, viscosity =0.001 kg/ms) flowing at 12 m/s parallel to the long side of the rectangular cross-section. Estimate the drag force on the cylinder per unit width if the rectangle has: a) a flat rectangular face, or b) a rounded nose.

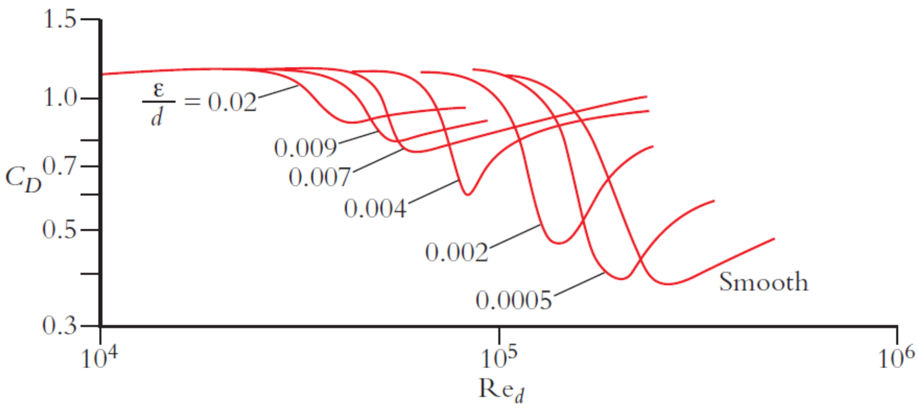
Illustration (not in scale):



Ans: a) 3240 N/m b) 2304 N/m

(The above answers are for U=12 m/s. If you used U=8.5 m/s which was erroneously given in the 1st version of this example sheet, then you would get: a) 1626 N/m and b) 1156 N/m).

2. A circular cylinder is in a flow of water (density 1000 kg/m^3, kinematic viscosity 10^{-6} m^2/s) moving at 0.9 m/s. It is observed that there is a reduction in drag just below Re = 10^5. What diameter does the cylinder have and what is the mean roughness height.



Ans: diameter 0.11m, 0.44mm

3. A fishnet consists of 1mm diameter strings overlapped and knotted to form 1cmx1cm squares. Estimate the drag of 1 m^2 of such a net when towed normal to its plane at 3m/s in seawater (density 1025 kg/m^3 and viscosity 0.00107 kg/ms) given that transition to turbulence occurs at around 10^5 for a long circular cylinder. What power is required to tow 400 ft^2 of this net?

Ans: 1119 N (or 1108 N if 2 end threads neglected), 124 kW

4. At a Reynolds number of 20,000 a NACA 4412 airfoil mounted in a wind tunnel has a drag coefficient of 0.055. If the chord length is 350mm, what speed is the air moving past the airfoil? Take the properties of air to be density 1.2 kg/m^3 and viscosity 1.8x10^{-5} kg/ms.

Ans: 0.86 m/s.

SOLUTIONS

1.

Calculate Re:

$$Re_L = \frac{\rho V H}{\mu} = \frac{1000 \times 12 \times 0.05}{0.001} = 6 \times 10^5$$

(a) Re>10^4 therefore data for finite aspect ratio cylinders from Figure 11 in Lift & Drag notes can be applied.

Flat front: calculate L/H = 30/5=6, therefore C_D = 0.9

$$C_D = \frac{D/bt}{\frac{1}{2}\rho u^2}$$

$$\frac{D}{t} = 0.9 \times \frac{1}{2} \times 1000 \times 12^2 \times 0.05 = 3240 N/m$$

(b) Rounded front: C_D = 0.64 for L/H=6

$$\frac{D}{t} = 0.64 \times \frac{1}{2} \times 1000 \times 12^2 \times 0.05 = 2304 N/m$$

2. Find diameter from Reynolds number at transition:

$$Re_d = \frac{\rho V d}{\mu} = \frac{V d}{\nu} = \frac{0.9 \times d}{10^{-6}}$$

$$\therefore d = \frac{10^5 \times 10^{-6}}{0.9} = 0.11 m$$

Estimate roughness parameter to be 0.004:

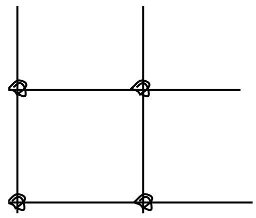
$$\frac{\varepsilon}{d} = 0.004 \quad \text{so} \quad \varepsilon = 0.004 \times 0.11 = 0.44 mm$$

3. Calculate Reynolds number (based on d for circular cylinder)

$$Re_L = \frac{\rho V d}{\mu} = \frac{1025 \times 3 \times 0.001}{0.00107} = 2.9 \times 10^3$$

Flow is therefore laminar and C_D=1.2

Find drag for one side of square, ignoring effect of knots:



$$C_D = \frac{D/dt}{\frac{1}{2}\rho u^2}$$

$$D = 1.2 \times \frac{1}{2} \times 1025 \times 3^2 \times 0.001 \times 0.01 = 0.0554 N$$

Note that for each 1cm square, only 2 of the threads do not appear in any other square.
Drag for the 2cm square shown is 0.443N

2500 of these 2cm squares in a square metre, therefore the drag from them is 1108N. To be precise, the drag from the rightmost row of thread (1m) and the uppermost row of thread (1m) is neglected here. The drag from those is 2*100*0.0554N=11.08 N (note that this is only 1% of the total drag, so could have been neglected in an engineering approximation).

Adding the two contributions (from the squares and from the two end threads), we obtain the total drag:

D=1108+11.08=1119 N.

400ft^2 = 0.0929x400=37.2m^2

Drag for whole net = 1119x37.2=41.6x10^3 N

Power = force x velocity = 41.6x10^3 x 3 = 124 kW

4. Find velocity from Reynolds number:

$$Re = 20000 = \frac{\rho V c}{\mu} = \frac{1.2 \times V \times 0.35}{1.8 \times 10^{-5}}$$

$$V = 0.86 m/s$$