DRAG OF 3D BODIES

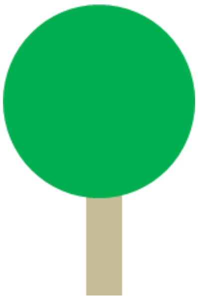
LIFT & DRAG SELF ASSESSMENT SHEET 2

1. a) A skydiver of total mass 80 kg jumps from a plane and free falls in still air until he achieves his terminal velocity of 55 m/s. His effective area is 0.45m^2. At this altitude air density is 1.01 kg/m^3. What is his drag coefficient at this point?

   b) When he deploys his parachute he falls vertically; his frontal area is reduced to 0.2m^2 and his C_D is reduced to 0.9. The drag coefficient for the parachute is 1.2 and its diameter is 7.4m^2. Assuming the wake from the skydiver is separate to that of the parachute (is this a valid assumption?) calculate his new terminal velocity.

   c) How long will it take the parachutist to fall 1000m after terminal velocity has been reached, assuming air density does not change? Factoring in the increase in density will the descent time increase or decrease?

Ans: 1.14, 5.5m/s, 182s



2. A highly idealized tree consists of a smooth sphere of diameter 9m on top of a pole of diameter 0.5m and height 2.5m. If this tree is in a crossflow of constant velocity 15 mph (1609 m in a mile), and assuming there is no atmospheric boundary layer, what is the bending moment at the base of the tree trunk? Take the density of air to be 1.2 kg/m^3 and the viscosity to be 1.8x10^{-5} kg/ms.

   If the sphere was treated as rough, would the moment be lower or higher and why?

Ans: 3630 Nm, higher

SOLUTIONS

1. At terminal velocity drag force exactly balances weight:

$$mg = D = 80 \times 9.81 = 784.8N$$

$$C_D = \frac{D/A}{\frac{1}{2}\rho U^2} = \frac{784.8}{0.45 \times 0.5 \times 1.01 \times 55^2} = 1.14$$

b) Drag force again equals weight:

$$mg = D_{man} + D_{parachute}$$

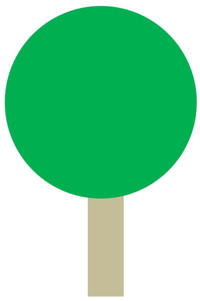
$$\frac{784.8}{\frac{1}{2}\rho U^2} = C_{D,man}A_{man} + C_{D,parachute}A_{parachute}$$

$$U^2 = \frac{784.8}{0.5 \times 1.01\left(0.9 \times 0.2 + 1.2\frac{\pi}{4}7.4^2\right)}$$

$$U = 5.5m/s$$

c) The guy falls at 5.5 m/s so $t = \frac{s}{V} = \frac{1000}{5.5} = 182s$

With a higher air density the terminal velocity reduces and so it takes longer for him to reach the ground.



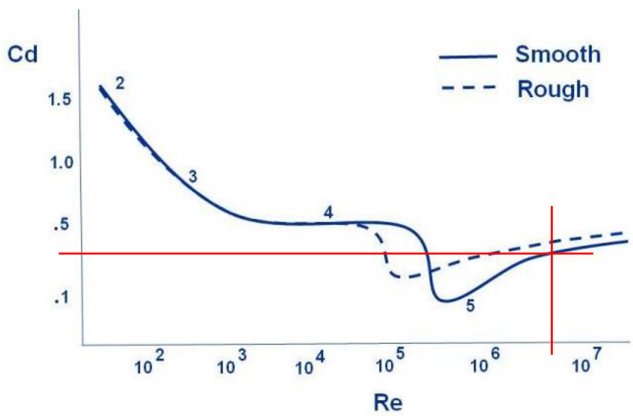
2.

Convert speed to m/s: $15 \times \frac{1609}{3600} = 6.7\ m/s$

Calculate Reynolds number for sphere:

$$Re = \frac{\rho v D}{\mu} = \frac{1.2 \times 6.7 \times 9}{1.8 \times 10^{-5}} = 4.02 \times 10^6$$

Find drag coefficient for the sphere:



Take C_D = 0.3

(Note: If we would just have concluded that the flow is turbulent, and taken Cd from the "turbulent" value for ellipsoid in the table - Figure 13, "Drag coefficients for a few 3D bodies" - we would have got Cd=0.2. The value read from the figure is most accurate. However, if nothing else is specified, the value from the table is also acceptable.)

Find drag on sphere:

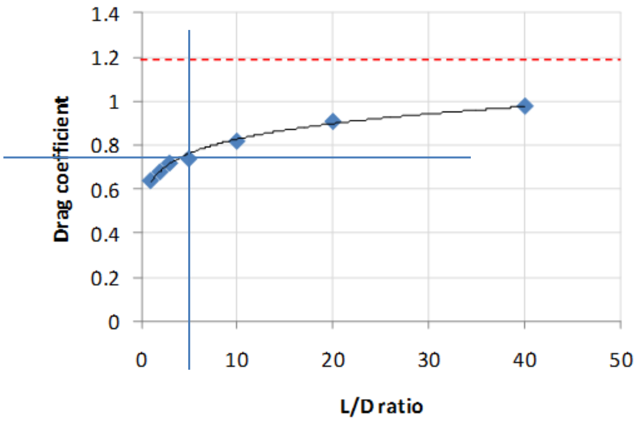
$$D = C_D \tfrac{1}{2} \rho v^2 \frac{\pi}{4} d^2 = 0.3 \times 0.5 \times 1.2 \times 6.7^2 \times \frac{\pi}{4} \times 9^2 = 514.0N$$

Find the drag on the tree trunk (short cylinder)

Calculate Reynolds number for cylinder:

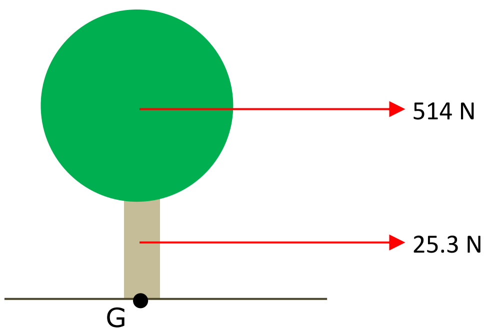
$$Re = \frac{\rho v D}{\mu} = \frac{1.2 \times 6.7 \times 0.5}{1.8 \times 10^{-5}} = 2.2 \times 10^5$$

As Re < 5×10^5, therefore laminar (check your notes, p14). Using Figure 14 from the notes, L/D is 5, therefore take C_D to be 0.75.



Find drag on cylinder:

$$D = C_D \tfrac{1}{2} \rho v^2 \frac{\pi}{4} d^2 = 0.75 \times 0.5 \times 1.2 \times 6.7^2 \times 0.5 \times 2.5 = 25.3N$$



Take moments about G:

$$514 \times (2.5 + 4.5) + 25.3 \times 1.25 = M = 3630Nm$$

If the sphere is rough then the drag coefficient will be higher at this Reynolds number and so the overall drag will be higher and the moment also.