The exam is closed book and closed notes.

A cylindrical pole of diameter $D = 60$ cm and height $H = 90$ m is used to hold a flag made of a very thin flat plate with $L = 8$ m long and $b = 4.2$ m wide. If wind blows parallel to the plate at $V = 29$ m/s, estimate the total drag force on the pole and the flag, considering boundary layer drag on both sides of the plate. For sea-level standard air use $\rho = 1.2$ kg/m$^3$ and $\mu = 1.8E^{-5}$ kg/m-s.

**Equations:** $C_D = \frac{F_D}{\frac{1}{2} \rho A V^2}$; Laminar boundary layer: $C_D = \frac{1.328}{Re_L^{\frac{1}{7}}}$; Turbulent boundary layer: $C_D = \frac{0.031}{Re_L^{\frac{1}{7}}}$

**Table:** Drag of two-dimensional bodies:

<table>
<thead>
<tr>
<th>Shape</th>
<th>$C_D$, laminar</th>
<th>$C_D$, turbulent</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rounded nose</td>
<td>0.1</td>
<td>0.2</td>
</tr>
<tr>
<td>Rectangular</td>
<td>0.1</td>
<td>0.2</td>
</tr>
<tr>
<td>Elliptical</td>
<td>0.13</td>
<td>0.15</td>
</tr>
</tbody>
</table>


![Diagram of pole and flag](image)
Solution:

KNOWN: wind velocity, body shapes and sizes

FIND: total drag

ASSUMPTIONS:

ANALYSIS:

For the flag:

\[ Re_L = \frac{\rho V L}{\mu} = \frac{(1.2)(29)(8)}{(1.8E-5)} \approx 1.547E7 \quad \text{(Turbulent)} \]

\[ C_{D_{flag}} = \frac{0.031}{Re_L^{1/7}} = \frac{0.031}{(1.547E7)^{1/7}} \approx 0.00291 \]

\[ F_{D_{flag}} = C_{D_{flag}} \frac{1}{2} \rho (bL)V^2 \times 2 \quad \text{(two sides)} \]

\[ = (0.00291)(0.5)(1.2)(4.2 \times 8)(29)^2 \times 2 = 98.7 \, N \]

For the pole:

\[ Re_D = \frac{\rho V D}{\mu} = \frac{(1.2)(29)(0.6)}{(1.8E-5)} \approx 1.16E6 \quad \text{(Turbulent)} \]

From the Table:

\[ C_{D_{pole}} \approx 0.3 \]

\[ F_{D_{pole}} = C_{D_{pole}} \frac{1}{2} \rho (D H)V^2 = (0.3)(0.5)(1.2)(0.6 \times 90)(29)^2 = 8174.5 \, N \]

Total drag force:

\[ F_{D_{total}} = F_{D_{flag}} + F_{D_{pole}} = 98.7 + 8174.5 = 8273.2 \, N \]