Drag Coefficients

Learning Objectives:
• Explain the dynamics of friction and pressure drag
• Calculate drag forces on objects using the graphical data in Chapter 9
• Describe ways to design objects having lower drag

Motivational Question:
• If your club-head speed is 1/2 of Tiger Woods', would you benefit much from using his golf ball?
**Drag:** Net fluid force on an object II to upstream flow.

- Due to complete dynamics of flow
- Found mostly by experiment.

\[ C_D = \frac{8}{\pi} \frac{\text{KE of oncoming flow}}{\frac{1}{2} \rho V^2 A} \]

Dimensionless

\[ C_D = \Phi (\text{shape}, \text{Re}, \text{Fr}, \frac{E}{L}) \]

\( \Phi_f \): due to friction (like in b.i.l.)

\( \Phi_p \): due to pressure (separation)

**Cylinder or Sphere:**

<table>
<thead>
<tr>
<th>Re</th>
<th>Flow Morphology</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.1-1 (A)</td>
<td>Friction Drag only.</td>
</tr>
<tr>
<td>10 (B)</td>
<td>Friction + mild Pressure drag.</td>
</tr>
<tr>
<td>100 (C)</td>
<td>Friction + large Pressure drag.</td>
</tr>
</tbody>
</table>

von Kármán vortex street.
Continued

Re

Flow Morphology

100 - 10,000
(D)

Friction + large
Pressure Drag

3 \times 10^5
(E)

Friction + mild
Pressure Drag

Data:

\[
C_D \quad \text{laminar} \quad A \quad B \quad C \quad D \quad \text{transition} \quad E \quad \text{turb.}
\]

\[
\text{Re:} \quad \frac{\nu D}{D}
\]
Moderate Reynolds number flows tend to take on a boundary layer flow structure. For such flows past streamlined bodies, the drag coefficient tends to decrease slightly with Reynolds number. The \( C_D \sim \text{Re}^{-1/2} \) dependence for a laminar boundary layer on a flat plate (see Table 9.3) is such an example. Moderate Reynolds number flows past blunt bodies generally produce drag coefficients that are relatively constant. The \( C_D \) values for the spheres and circular cylinders shown in Fig. 9.21a indicate this character in the range \( 10^3 < \text{Re} < 10^5 \).

The structure of the flow field at selected Reynolds numbers indicated in Fig. 9.21a is shown in Fig. 9.21b. For a given object there is a wide variety of flow situations, depending

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**Figure 9.21** (a) Drag coefficient as a function of Reynolds number for a smooth circular cylinder and a smooth sphere. (b) Typical flow patterns for flow past a circular cylinder at various Reynolds numbers as indicated in (a).
Applications:

\[ \frac{\Delta p}{\Delta x} \text{ if separation occurs even for turbulent boundary layers.} \]

Sports balls:
- turbulence delays separation.
- laces, dimples, fuzz.

Vehicles:
- streamlining suppresses separation.

Boats:
- wave-making drag \((C_D)\) dominant.

Example:

Tiger Woods hits a golf ball at 170 mph.

\[ Re = \frac{(75 \text{ m/s})(0.025 \text{ m})}{10^{-3} \text{ m}^2/\text{s}} = 1930. \]

From Fig 9.21

\[ C_D = 0.4 \]

If dimples trigger turbulence

\[ C_D \sim 0.08 \text{ to } 0.2 \]

\[ 5 \text{ to } 2 \times \text{ reduction.} \]

\~ \( \Phi(Re \rightarrow U) \)

\^ different designs for different players.