Chapter 12

Fluid Mechanics

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– Hugh D. Young and Roger A. Freedman

Lectures by Wayne Anderson

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Goals for Chapter 12

• To study the concept of density

• To investigate pressure in a fluid

• To study buoyancy in fluids

• To compare laminar versus turbulent fluid flow and how the fluid speed depends on the size of the tube

• To learn how to use Bernoulli’s equation to relate pressure and flow speed of a fluid
Introduction

• Why must the shark keep moving to stay afloat while the small fish can remain at the same level with little effort?

• We begin with fluids at rest and then move on to the more complex field of fluid dynamics.
Density

• The *density* of a material is its mass per unit volume: \( \rho = \frac{m}{V} \).

• The *specific gravity* of a material is its density compared to that of water at 4°C.

• How much does the air in a room weigh? Follow Example 12.1 using Table 12.1 (next slide).
# Densities of some common substances

<table>
<thead>
<tr>
<th>Material</th>
<th>Density (kg/m^3)*</th>
<th>Material</th>
<th>Density (kg/m^3)*</th>
</tr>
</thead>
<tbody>
<tr>
<td>Air (1 atm, 20°C)</td>
<td>1.20</td>
<td>Iron, steel</td>
<td>$7.8 \times 10^3$</td>
</tr>
<tr>
<td>Ethanol</td>
<td>$0.81 \times 10^3$</td>
<td>Brass</td>
<td>$8.6 \times 10^3$</td>
</tr>
<tr>
<td>Benzene</td>
<td>$0.90 \times 10^3$</td>
<td>Copper</td>
<td>$8.9 \times 10^3$</td>
</tr>
<tr>
<td>Ice</td>
<td>$0.92 \times 10^3$</td>
<td>Silver</td>
<td>$10.5 \times 10^3$</td>
</tr>
<tr>
<td>Water</td>
<td>$1.00 \times 10^3$</td>
<td>Lead</td>
<td>$11.3 \times 10^3$</td>
</tr>
<tr>
<td>Seawater</td>
<td>$1.03 \times 10^3$</td>
<td>Mercury</td>
<td>$13.6 \times 10^3$</td>
</tr>
<tr>
<td>Blood</td>
<td>$1.06 \times 10^3$</td>
<td>Gold</td>
<td>$19.3 \times 10^3$</td>
</tr>
<tr>
<td>Glycerine</td>
<td>$1.26 \times 10^3$</td>
<td>Platinum</td>
<td>$21.4 \times 10^3$</td>
</tr>
<tr>
<td>Concrete</td>
<td>$2 \times 10^3$</td>
<td>White dwarf star</td>
<td>$10^{10}$</td>
</tr>
<tr>
<td>Aluminum</td>
<td>$2.7 \times 10^3$</td>
<td>Neutron star</td>
<td>$10^{18}$</td>
</tr>
</tbody>
</table>

*To obtain the densities in grams per cubic centimeter, simply divide by $10^3$. 

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Pressure in a fluid

• The pressure in a fluid is the normal force per unit area: \( p = \frac{dF}{dA} \).

• Refer to Figures 12.2 and 12.3 at the right.

• Follow Example 12.2.
**Pressure at depth in a fluid**

- The pressure at a depth $h$ in a fluid of uniform density is given by $P = P_0 + \rho gh$. As Figure 12.6 at the right illustrates, the shape of the container does not matter.

- The *gauge pressure* is the pressure above atmospheric pressure. The *absolute pressure* is the total pressure.

- Follow Example 12.3, which involves both gauge and absolute pressure.
**Pascal’s law**

- **Pascal’s law**: Pressure applied to an enclosed fluid is transmitted undiminished to every portion of the fluid and the walls of the containing vessel.

- The hydraulic life shown in Figure 12.7 is an application of Pascal’s law.
Two types of pressure gauge

- Figure 12.8 below shows two types of gauges for measuring pressure.

(a) Open-tube manometer

- There is a near-vacuum at the top of the tube.
- The pressure is the same at the bottoms of the two tubes.

(b) Mercury barometer

- The height to which the mercury rises depends on the atmospheric pressure exerted on the mercury in the dish.
- \[ p = p_{\text{atm}} \]
A tale of two fluids

- Follow Example 12.4 using Figure 12.10 below.
Archimedes Principle

- **Archimedes’ Principle**: When a body is completely or partially immersed in a fluid, the fluid exerts an upward force (the “buoyant force”) on the body equal to the weight of the fluid displaced by the body. (See Figure 12.11 below.)

(a) Arbitrary element of fluid in equilibrium

(b) Fluid element replaced with solid body of the same size and shape
Buoyancy

- Follow Example 12.5.
- Refer to Figure 12.13 at the right.

(a) Immersed statue in equilibrium

(b) Free-body diagram of statue

\[ mg = 147 \text{ N} \]
Surface tension

• The surface of a liquid behaves like a membrane under tension, so it resists being stretched. This force is the *surface tension*. (See Figure 12.15 at the right.)

• The surface tension allows the insect shown at the right to walk on water.
Fluid flow

- The flow lines in the bottom figure are *laminar* because adjacent layers slide smoothly past each other.

- In the figure at the right, the upward flow is laminar at first but then becomes *turbulent flow*.
The continuity equation

- The figure at the right shows a flow tube with changing cross-sectional area.
- The *continuity equation* for an incompressible fluid is \( A_1 v_1 = A_2 v_2 \).
- The *volume flow rate* is \( \frac{dV}{dt} = Av \).
- Follow Example 12.6.
Bernoulli’s equation

- Bernoulli’s equation is

\[ p_1 + \rho g y_1 + \frac{1}{2} \rho v_1^2 = p_2 + \rho g y_2 + \frac{1}{2} \rho v_2^2 \]

- Refer to Figure 12.22 at the right.
Water pressure in the home

• Follow Problem-Solving Strategy 12.1.

• Follow Example 12.7 using Figure 12.23 at the right.
Speed of efflux

- Follow Example 12.8 using Figure 12.24 at the right.
The Venturi meter

- Follow Example 12.9 using Figure 12.25 below.

Difference in height results from reduced pressure in throat (point 2).
Lift on an airplane wing

• Follow Conceptual Example 12.10 using Figure 12.26 below.

(a) Flow lines around an airplane wing

Flow lines are crowded together above the wing, so flow speed is higher there and pressure is lower.

Equivalent explanation: Wing imparts a net downward momentum to the air, so reaction force on airplane is upward.

(b) Computer simulation of air parcels flowing around a wing, showing that air moves much faster over the top than over the bottom.

Notice that air particles that are together at the leading edge of the wing do not meet up at the trailing edge!
Viscosity and turbulence

- **Viscosity** is internal friction in a fluid. (See Figures 12.27 and 12.28 at the right.)

- **Turbulence** is irregular chaotic flow that is no longer laminar. (See Figure 12.29 below.)

(a)  
(b)  

Cross section of a cylindrical pipe

The velocity profile for viscous fluid flowing in the pipe has a parabolic shape.
A curve ball (Bernoulli’s equation applied to sports)

- Does a curve ball *really* curve? Follow Conceptual Example 12.11 and Figure 12.30 below to find out.

(a) Motion of air relative to a nonspinning ball

(b) Motion of a spinning ball

This side of the ball moves opposite to the airflow.

This side moves in the direction of the airflow.

(c) Force generated when a spinning ball moves through air

A moving ball drags the adjacent air with it. So, when air moves past a spinning ball:

- On one side, the ball slows the air, creating a region of **high pressure**.
- On the other side, the ball speeds the air, creating a region of **low pressure**.

The resultant force points in the direction of the low-pressure side.

(d) Spin pushing a tennis ball downward

(e) Spin causing a curve ball to be deflected sideways

(f) Backspin of a golf ball