Introduction, Concepts
Chapter 1.1-1.3, 3.6.1
HOW TO STUDY FOR THIS COURSE

BEFORE CLASS

Read (at least look at) assigned sections.

IN CLASS

Do no try to take detailed notes. Notes are posted on the web site.

Listen to fill in and understand what you have read.

Write down key words for concepts, definitions, theories, problem solving techniques, etc. so you know what to emphasize when reading the book.

AFTER CLASS

Study key concepts - write out definitions and descriptions.

Work assigned problems - simultaneously study the theory and example solutions.

Check your solutions (and understanding) with posted solutions (on the web site)
ASPECTS OF THE COURSE CONTENT

1. Phenomena: Description
   Definitions
   Physical Laws

2. Theory: Physical Laws
   Equations
   Nomenclature

3. Problems: Theory/Equations
   Math Solution
   Computations
   Units

Talking Knowledge = 1
Total Understanding = 1 + 2 + 3
WHY STUDY

FLUID MECHANICS

SCIENCE: Study the fundamentals and the phenomena of fluids and fluid motions.

Examples: Chaos, Turbulence, Microgravity, etc.

Engineering: Apply the principles of fluid mechanics to practical problems.

Examples: Lift and drag on a wing, power from a turbine, thrust from a rocket, etc.
ENGINEERING APPLICATIONS

Power & Thrust

Reciprocating Engines
Jet Engine
Rocket Engine

Fluid Machinery

Pumps
Turbines
Compressors

Heating, Ventilation, & Air Conditioning

Fans
Blowers
Heat Exchangers

Aerodynamics

Airplanes
Automobiles

Flow/Fluid Measuring Devices
DEFINITIONS

Fluid: A substance which continuously deforms under the action of a shear force. Distortions are permanent.

Fluid State: Gas, Liquid, Mixture

Fluid Mechanics: The Study of the Motion and Forces in a Fluid.

Motion: Displacement
Velocity
Acceleration

Forces: Gravity
Pressure
Shear
CONTINUUM

Continuum: A continuous distribution of matter with no holes or voids.

Molecular Dynamics: Ultimately the motion and properties of a fluid are determined by the average motion of the molecules which compose the fluid.

Continuum Approximation: If arbitrarily small volumes of the fluid contain sufficiently large number of molecules, then the fluid may be considered to be a continuum.
FUNDAMENTAL LAWS
FOR A SYSTEM

SYSTEM: A defined quantity of matter

Conservation of Matter:

\[ \frac{D}{Dt} \text{(mass)} = 0 \]

Newton's Second Law:

\[ \frac{D}{Dt} \text{(momentum)} = \text{Sum of Forces} \]

\[ = \text{Pressure + Gravity + Friction} \]

First Law of Thermodynamics:

\[ \frac{D}{Dt} \text{(energy)} = \text{Heat Transfer + Work Done} \]

Energy = Internal + Kinetic
APPROACHES

Analytical: Fundamental Understanding
          Preliminary Design

Experimental: Fundamental Understanding
              Proof of Concept
              Model Testing
              Prototype Testing

Computational: Fundamental Understanding
             Design and Testing
AREAS OF FLUID MECHANICS

MAE 422  GAS DYNAMICS
MAE 423  INTRODUCTION TO PROPULSION
MAE 424  AERODYNAMICS
MAE 433  WIND POWER ENGINEERING
MAE 469  ENVIRONMENTAL TRANSPORT PROCESSES
MAE 471  AERODYNAMICS LABORATORY
MAE 515  FLUID MECHANICS 1
MAE 518  MAGNETOHYDRODYNAMICS
MAE 519  TURBULENT FLOW
MAE 534  COMBUSTION
MAE 540  COMPUTATIONAL FLUID MECHANICS
MAE 545  HEAT TRANSFER 1
MAE 607  INVISCID HYPersonic FLOW
MAE 608  VISCOUS HYPersonic FLOW
MAE 611  CONVective HEAT TRANSFER
MAE 617  INVISCID INCOMPRESSIBLE FLOW
MAE 618  VISCOUS FLOW
MAE 631  COMPRESSIBLE FLOW
FORCES

SURFACE FORCES: Forces in the fluid which act on a solid or imaginary surface. These forces are specified in terms of an intensity or stress (force per unit area).

Local: Pressure
Shear (friction) stress
Total or Resultant: Lift, Drag, etc.

BODY FORCES: Forces that act on the mass of the fluid. We will only deal with gravity. Body forces are given in terms of force per unit volume.

\[ \gamma = \text{Specific Weight} = \text{Weight/Volume} \]
\[ = \text{lbs/cubic feet or newtons/cubic m} \]

Force = \( \gamma \times \text{volume} \)

\[ \rho = \text{Density} = \text{mass/volume} \]
\[ = \text{slugs/cubic ft or kgs/cubic m} \]
\[ \gamma = \rho \cdot g \]
UNITS

English:  
Length = foot  
Time = second  
Force = pound  
Mass = slug

Force = Mass x Acceleration  
(1)pound = (1)slug x (1)foot/sec**2  
lb = slug x ft/s**2

Metric:  
Length = meter  
Time = second  
Force = Newton  
Mass = kilogram

Force = Mass x Acceleration  
(1)newton = (1)kilogram x (1)meter/sec**2  
N = kg x m/s**2

SPECIFIC GRAVITY: Ratio of the density (or weight) of a substance to the density (or weight) of water.

<table>
<thead>
<tr>
<th>Substance</th>
<th>Density</th>
<th>Specific Weight</th>
<th>Specific Gravity</th>
</tr>
</thead>
<tbody>
<tr>
<td>Air</td>
<td>1.202 kg/m**3</td>
<td>11.8 N/m**3</td>
<td>0.0012</td>
</tr>
<tr>
<td></td>
<td>0.002329 slugs/ft**3</td>
<td>0.075 lb/ft**3</td>
<td></td>
</tr>
<tr>
<td>Gasoline</td>
<td>680 kg/m**3</td>
<td>6678 N/m**3</td>
<td>0.681</td>
</tr>
<tr>
<td></td>
<td>1.32 slug/m**3</td>
<td>42.5 lb/ft**3</td>
<td></td>
</tr>
<tr>
<td>Water</td>
<td>998.2 kg/m**3</td>
<td>9802 N/m**3</td>
<td>1.00</td>
</tr>
<tr>
<td></td>
<td>1.936 slug/ft**3</td>
<td>62.4 lb/ft**2</td>
<td></td>
</tr>
<tr>
<td>Mercury</td>
<td>13,550 kg/m**3</td>
<td>133,060 N/m**3</td>
<td>13.6</td>
</tr>
<tr>
<td></td>
<td>26.29 slug/ft**3</td>
<td>846.5 lb/ft**3</td>
<td></td>
</tr>
</tbody>
</table>
STRESS

STRESS: Force per unit area of surface – N/m**2.
Can be normal and tangential components.

\[ \tau_m = \lim_{\Delta A \to 0} \frac{\Delta F_m}{\Delta A} = \text{Normal} \]

\[ \tau_s = \lim_{\Delta A \to 0} \frac{\Delta F_s}{\Delta A} = \text{Shear} \]

The normal component is unique. The tangent component requires an angle or can be given as two components.

For a given orientation there are three independent components of stress.
STRESS TENSOR

STATE OF STRESS: In general requires three components (normal and two shears) on each of three mutually perpendicular surfaces for a total of nine components.

\[
\begin{bmatrix}
\tau_{xx} & \tau_{xy} & \tau_{xz} \\
\tau_{yx} & \tau_{yy} & \tau_{yz} \\
\tau_{zx} & \tau_{zy} & \tau_{zz}
\end{bmatrix}
\]

Stress is a Second Order Tensor, has nine components.

Vector: First Order Tensor, has three components.
Velocity: Vx, Vy, Vz

Scalar: Zero Order Tensor, has magnitude only.
PRESSURE

Pressure: The normal stress acting on a physical surface. It arises from the molecules of the fluid striking the surface.

For an imaginary surface in the fluid, the pressure is the normal stress on the surface for a stationary fluid or for an inviscid fluid in motion.

For a viscous fluid: \( p = -\frac{\left(\tau_{xx} + \tau_{yy} + \tau_{zz}\right)}{3} \) since the normal stresses can be different. The minus signifies that the pressure acts on the surface.

All fluids are viscous – an inviscid fluid is a mathematical idealization. However, under certain circumstances, some flows can be considered inviscid. An inviscid flow has no shear stresses and all the normal stresses are equal to the pressure.

Resultant force (from pressure) acting on a surface:

\[
\hat{F} = \int \int p \hat{M} \, dA
\]

\( \hat{M} \) = UNIT NORMAL (OUTWARD)

\( d\hat{F} \) = FORCE ON \( dA \)

\( d\hat{F} = -p \hat{M} \, dA \) ACTS INWARD ON THE SURFACE
**Pressure is Isotropic**

*Figure 1.7* Pressures acting on a wedge-shaped fluid element.

In the $x$-direction gives

$$F_x = p_2 dydz - p_1 dA \sin \theta = 0$$

That is

$$p_2 dydz = p_1 dy \frac{dz}{\sin \theta} \sin \theta$$

and therefore

$$p_2 = p_1 \quad (1.1)$$

In the $z$-direction we have

$$F_z = p_3 dy dx - \frac{1}{2} \rho g dx dy dz - p_1 dA \cos \theta = 0$$

That is,

$$p_3 dy dx = \frac{1}{2} \rho g dx dy dz + p_1 dy \frac{dx}{\cos \theta} \cos \theta$$

and

$$p_3 = p_1 + \frac{1}{2} \rho g dz$$

As the volume decreases in size, the contribution from the weight of the fluid decreases rapidly as $dz \to 0$, and it becomes negligible when the volume becomes infinitesimally small. Hence,

$$p_3 = p_1$$

Since we showed that $p_2 = p_1$ (Equation 1.1),

$$p_3 = p_2 = p_1 = p \quad (1.2)$$

Therefore the pressure at a point is independent of the orientation of the surface passing through the point. In other words, the pressure is isotropic.

The pressure at a point in a fluid is independent of the orientation of the surface passing through the point. Pressure is a scalar, and it always acts at right angles to a given surface.