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:

D/Dt (mass) = 0

Newton's Second Law:

D/Dt (momentum) = Sum of Forces

= Pressure +
Gravity +
Friction

First Law of Thermodynamics:

D/Dt (energy) = 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.

γ = Specific Weight = Weight/Volume
= lbs/cubic feet or newtons/cubic m

Force = γ x volume

ρ = Density = mass/volume
= slugs/cubic ft or kgs/cubic m
$\gamma = \rho g$

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 1 m = 3.28 ft
Time = second
Force = Newton 1 N = 0.225 lb
Mass = kilogram 1 kg = 0.0685 slug

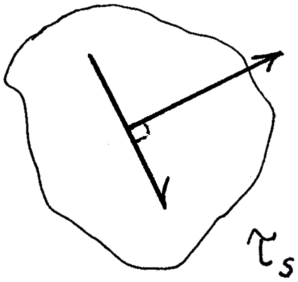
Force = Mass x Acceleration
(1)newton = (1)kilogram x (1)meter/sec**2
N = kg x m/s**2

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

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

STRESS

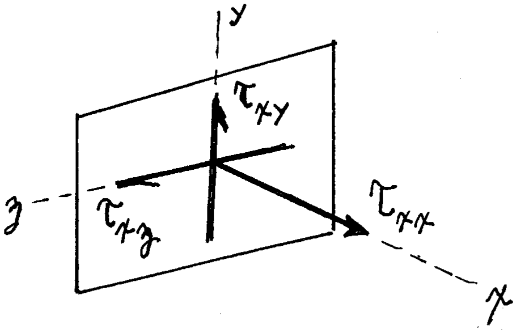
STRESS: Force per unit area of surface – N/m**2.
Can be normal and tangential components.



$$\tau_n = \lim_{\Delta A \to 0} \frac{\Delta F_n}{\Delta A} = \text{Normal}$$

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

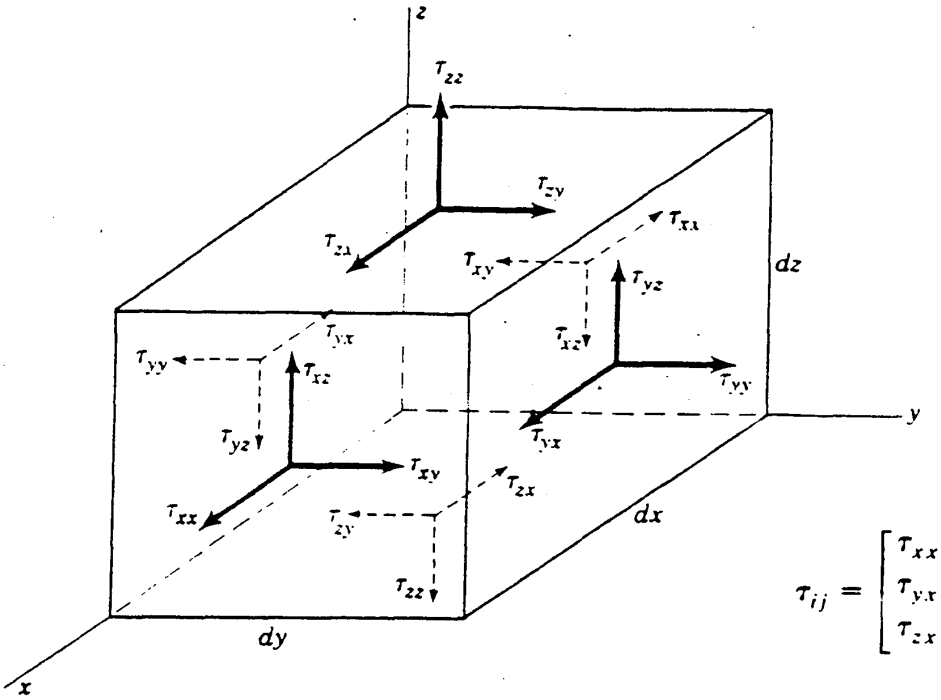
The normal component is unique. The tangent component requires an angle or can be given as two components.



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.



$$\tau_{ij} = \begin{bmatrix} \tau_{xx} & \tau_{xy} & \tau_{xz} \\ \tau_{yx} & \tau_{yy} & \tau_{yz} \\ \tau_{zx} & \tau_{zy} & \tau_{zz} \end{bmatrix}$$

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

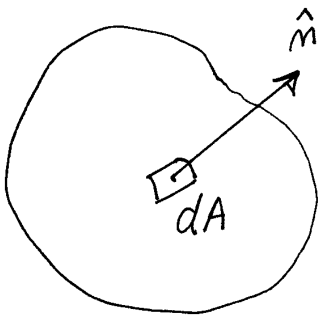
Pressure: The normal stress acting on a physical surface. It arises from the molecules of the fluid striking the surface.

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: $p = -(\tau_{xx}+\tau_{yy}+\tau_{zz})/3$ 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:



$\hat{n}$ = UNIT NORMAL (OUTWARD)

$d\vec{F}$ = FORCE ON dA

$d\vec{F} = -p\,\hat{n}\,dA$ ACTS INWARD ON THE SURFACE

$$\vec{F} = -\iint p\,\hat{n}\,dA$$

PRESSURE IS ISOTROPIC

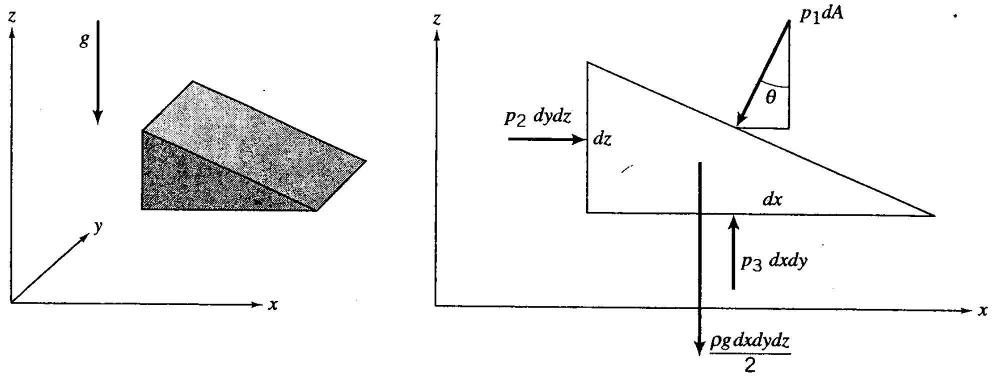


FIGURE 1.7 Pressures acting on a wedge-shaped fluid element.

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

$$p_2 = p_1 \tag{1.1}$$

In the z-direction we have

$$F_z = p_3\, dydx - \tfrac{1}{2}\rho g\, dxdydz - p_1\, dA \cos\theta = 0$$

That is,

$$p_3\, dydx = \tfrac{1}{2}\rho g\, dxdydz + p_1\, dy \frac{dx}{\cos\theta} \cos\theta$$

and

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

As the volume decreases in size, the contribution from the weight of the fluid decreases rapidly as $dz \rightarrow 0$, 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),

$$p_3 = p_2 = p_1 = p \tag{1.2}$$

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.