Ministry Of Higher Education and Scientific Research

Salahaddin University - Erbil

College of Engineering

Aviation Engineering Department

Fluid mechanic

First year

Lecture: 5

Spring semester

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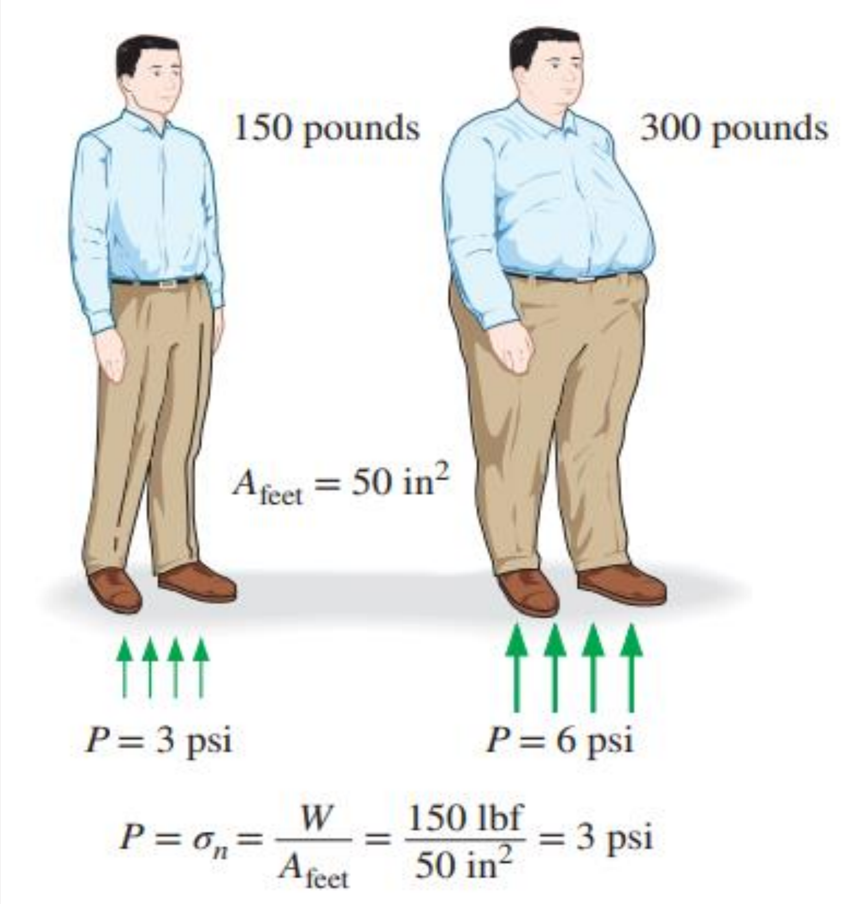
Erbil 2024

1. Pressure and Fluid static

❖ **Pressure** is defined as a normal force exerted by a fluid per unit area. We speak of pressure only when we deal with a gas or a liquid.



- Fluid static means fluid at rest.

- At rest, there is no shear stresses, the only force is the normal force du to pressure is present.

- $P = \frac{F}{A}$, Units are: N/m^2 (pa) , Ibs/ft^2 (psf), Ibs/in^2 (psi).

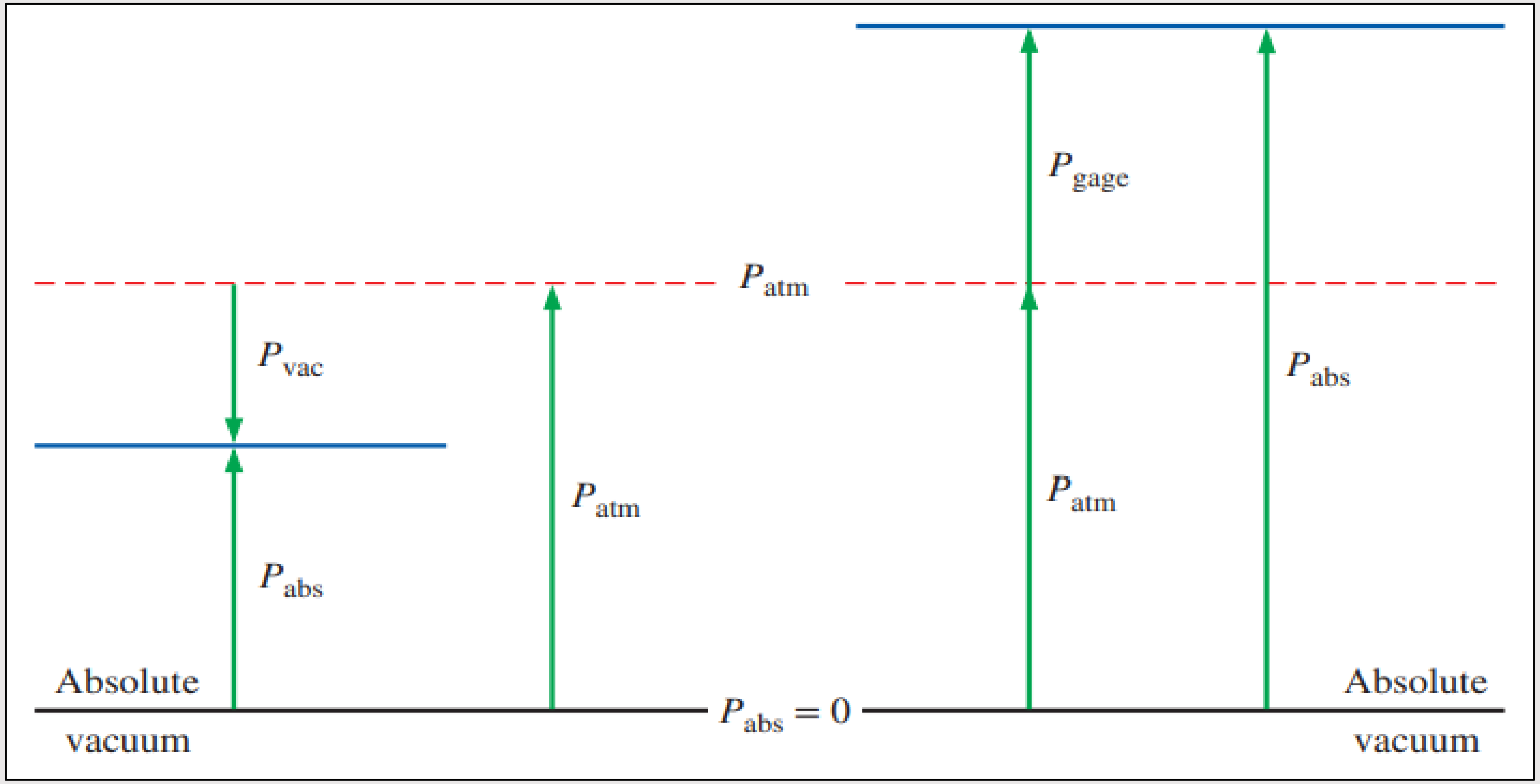
Absolute and gauge pressure

- **Atmospheric pressure:** it is the force per unit area excreted by the weight of air above the surface in the atmosphere of earth, it is also called the **barometric pressure**.

- **Gauge pressure:** it is the pressure, measured with the help of pressure measuring instruments in which the atmospheric pressure is taken as datum (reference in which measurements are made).

- **Absolute pressure:** it is the pressure equal to the sum of atmospheric pressure and the gauge pressure, or if we measure pressure relative to the absolute (vacuum) we can call it absolute pressure.

- **Vacuum pressure:** if the pressure is below the atmospheric pressure we call it vacuum.



$$P_{gage} = P_{abs} - P_{atm}$$

$$P_{vac} = P_{atm} - P_{abs}$$

In thermodynamic relations and tables, absolute pressure is almost always used. Throughout this text, the pressure P will denote absolute pressure unless specified otherwise. Often the letters “a” (for absolute pressure) and “g” (for gage pressure) are added to pressure units (such as psia and psig) to clarify what is meant.

Example

Absolute Pressure of a Vacuum Chamber

A vacuum gage connected to a chamber reads 5.8 psi at a location where the Atmospheric pressure is 14.5 psi. Determine the absolute pressure in the chamber?

Solution

The gage pressure of a vacuum chamber is given. The absolute pressure in the chamber is to be determined.

Analysis The absolute pressure is easily determined from Eq.

$$P_{abs} = P_{atm} - P_{vac} = \mathbf{8.7\ psi}$$

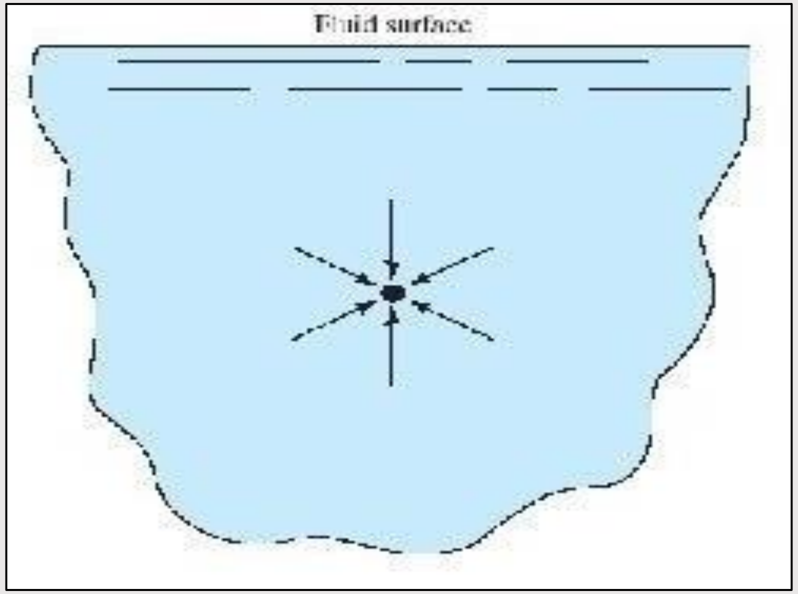
Discussion Note that the *local* value of the atmospheric pressure is used when determining the absolute pressure.

2. Fluid static

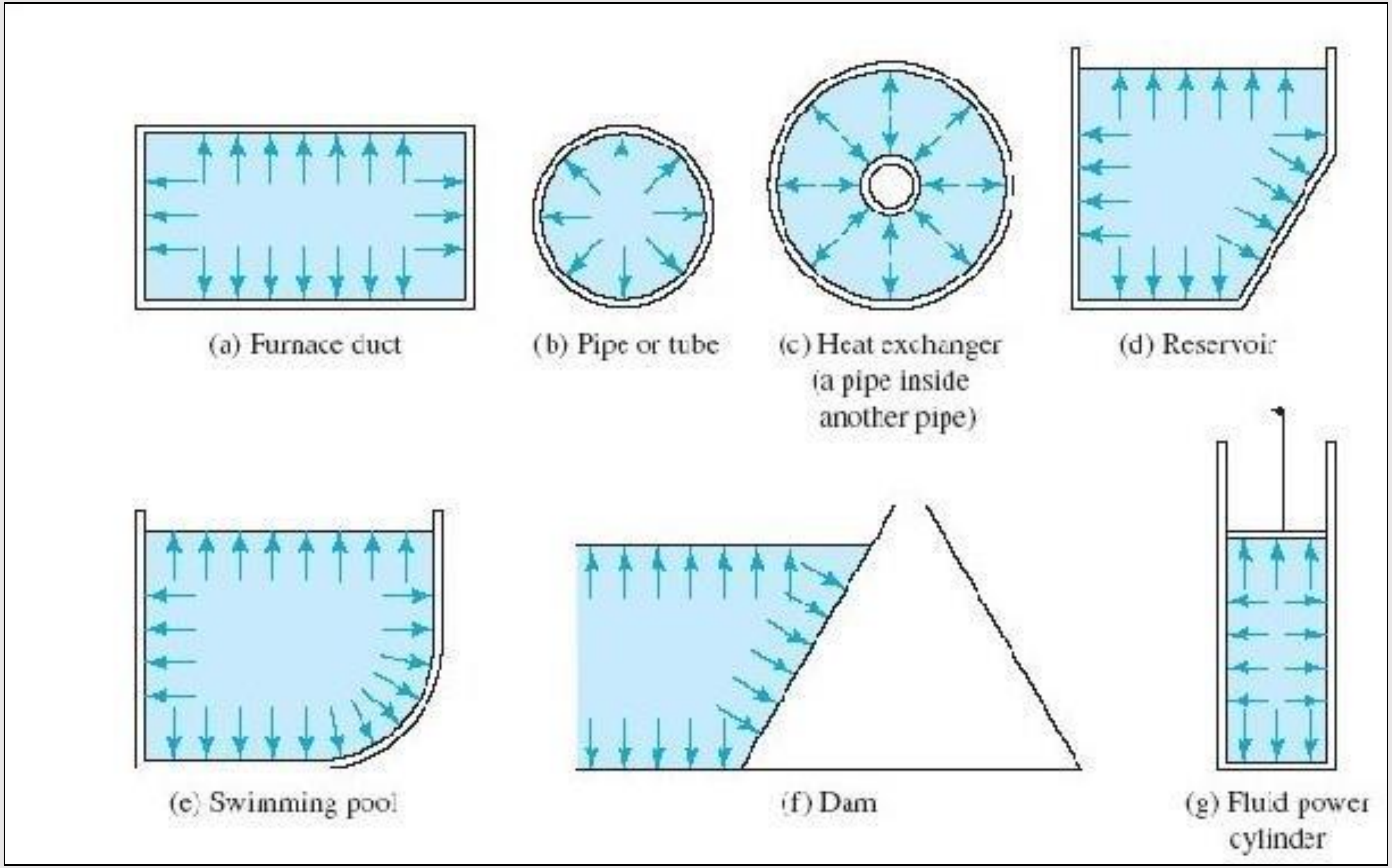
❖ Two important principle about pressure were described by **Basel Pascal** ,a seventeenth-century scientist:

1. Pressure act uniformly in all direction on a small volume of a fluid.

2. In a fluid confined by a solid boundaries, pressure act perpendicular to the boundary.



Direction of fluid pressure on boundaries



3. Hydrostatic elements

Axiom hydrostatics : → $\sum \vec{P} = 0; \ \sum \vec{M} = 0$

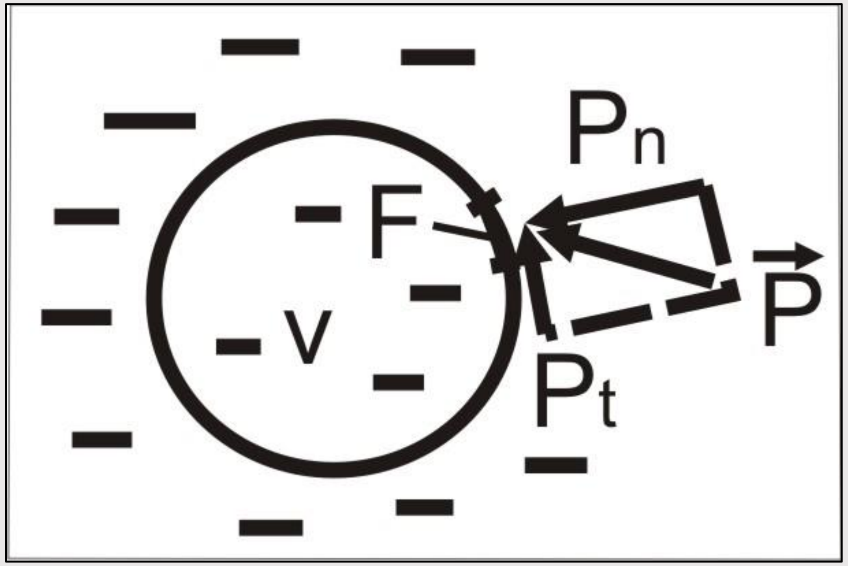
❖ Hydromechanical pressure (for liquid – hydrostatic) or simply pressure is the force compressing the liquid per unit area.

$$p = \frac{P}{F} = \frac{\text{strength}}{\text{square}} \rightarrow p = \frac{dP}{dF}$$

$$[p] = \frac{N}{м^2} = Pa \text{ (Pascal)}$$

4. Hydromechanical pressure properties

❖ In a liquid in resistance, the force of hydromechanical pressure is directional internal normal to the site to which it is applied for Equilibrium liquid needed:



$$P_t = 0$$

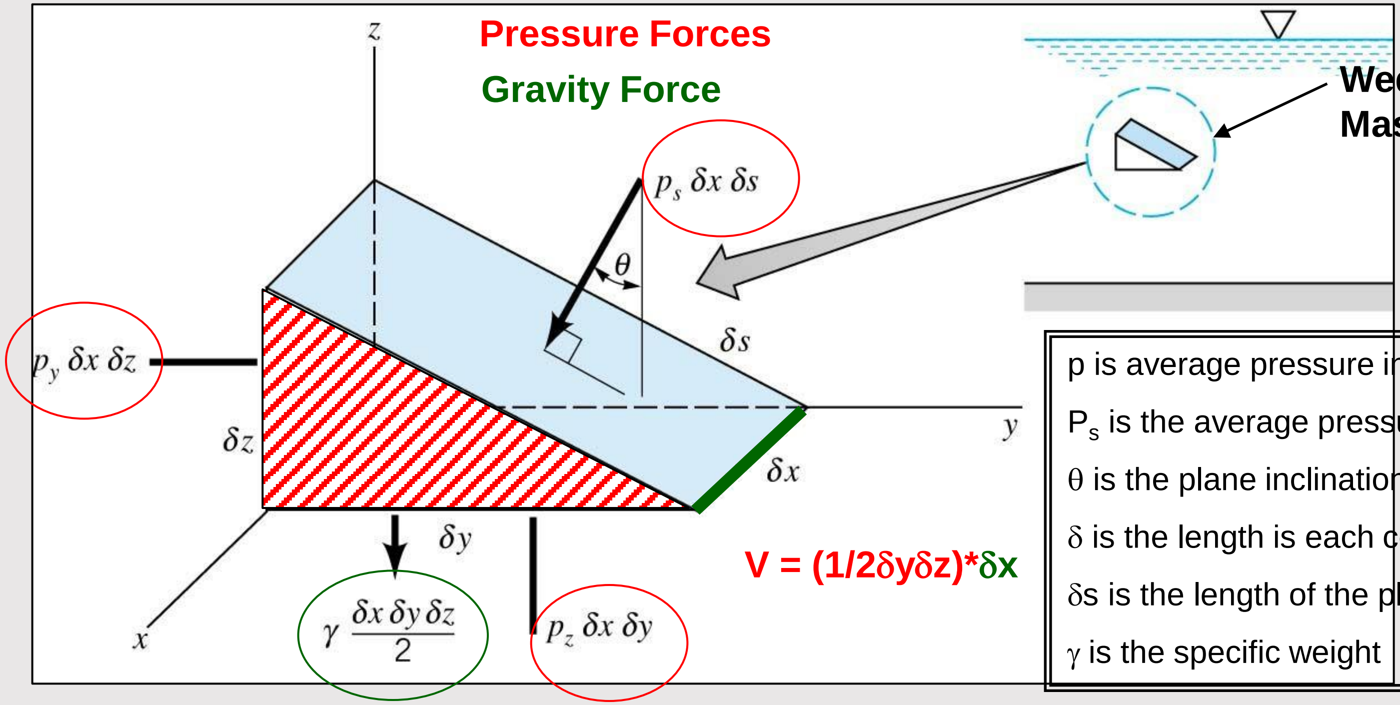
$$\vec{P} = \vec{P}_n$$

Blaise Pascal (1623-1662)

5. Pressure at a Point: **Pascal's Law**

❖ Pressure is the normal force per unit area at a given point acting on a given plane within a fluid mass of interest.

❖ How does the pressure at a point vary with orientation of the plane passing through the point?



p is average pressure in the x, y, and z direction.

P_s is the average pressure on the surface

θ is the plane inclination

δ is the length is each coordinate direction, x, y, z

δs is the length of the plane

γ is the specific weight

Pressure at a Point: Pascal's Law

❖ For simplicity in our Free Body Diagram, the x-pressure forces cancel and do not need to be shown. Thus to arrive at our solution we balance only the y and z forces:

Pressure Force in the y-direction on the y-face

Pressure Force on the plane in the y-direction

Rigid body motion in the y-direction

$$\sum F_y = p_y\,\delta x\,\delta z - p_s\,\delta x\,\delta s\,\sin\theta = \rho\,\frac{\delta x\,\delta y\,\delta z}{2}\,a_y$$

$$\sum F_z = p_z\,\delta x\,\delta y - p_s\,\delta x\,\delta s\,\cos\theta - \gamma\,\frac{\delta x\,\delta y\,\delta z}{2} = \rho\,\frac{\delta x\,\delta y\,\delta z}{2}\,a_z$$

Pressure Force in the z-direction on the z-face

Pressure Force in the plane in the z-direction

Weight of the Wedge

Rigid body motion in the z-direction

❖ Now, we can simplify each equation in each direction, noting that dy and dz can be rewritten in terms of ds:

$$\delta y = \delta s\cos\theta \qquad \delta z = \delta s\sin\theta$$

Pressure at a Point: Pascal's Law

❖ Substituting and rewriting the equations of motion, we obtain:

Math

$$p_y - p_s = \rho a_y \frac{\delta y}{2}$$

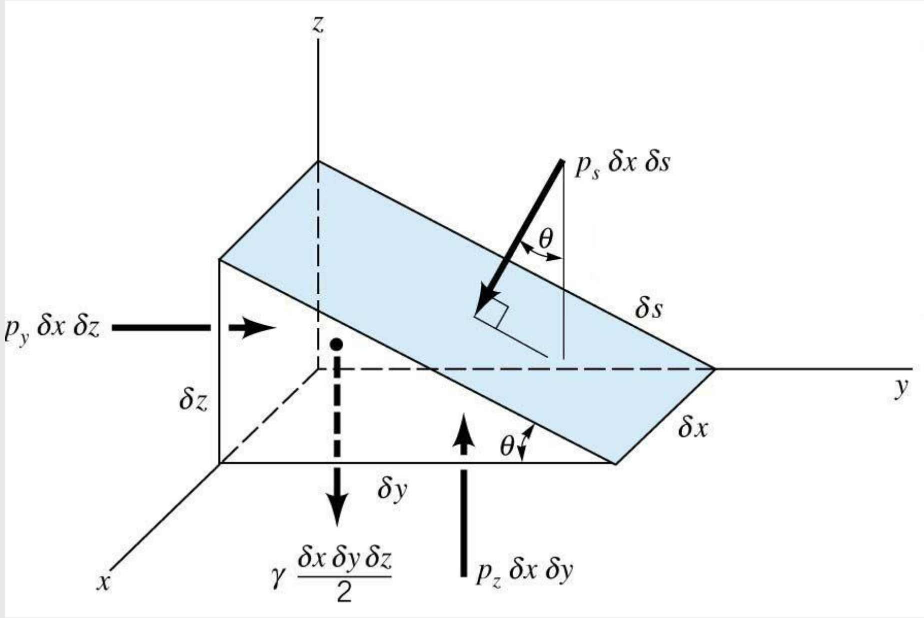
$$p_z - p_s = (\rho a_z + \gamma) \frac{\delta z}{2}$$

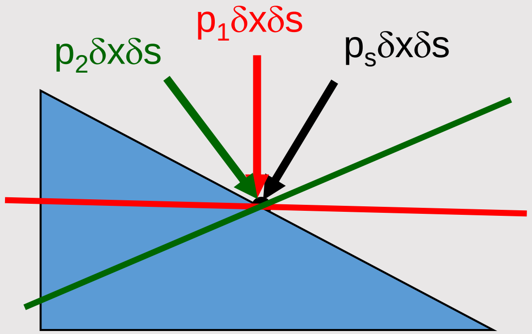
❖ Now, noting that we are really interested at point only, we let dy and dz go to zero:

$$p_y = p_s \qquad p_z = p_s$$

❖ Pascal's Law: the pressure at a point in a fluid at rest, or in motion, is independent of the direction as long as there are no shearing stresses present.

Pressure at a Point: Pascal's Law





$$p_s = p_1 = p_2$$

❖ Note: In dynamic system subject to shear, the normal stress representing the pressure in the fluid is not necessarily the same in all directions. In such a case the pressure is taken as the average of the three directions.

6. Pressure Field Equations

❖ How does the pressure vary in a fluid or from point to point when no shear stresses are present?

Consider a Small Fluid Element

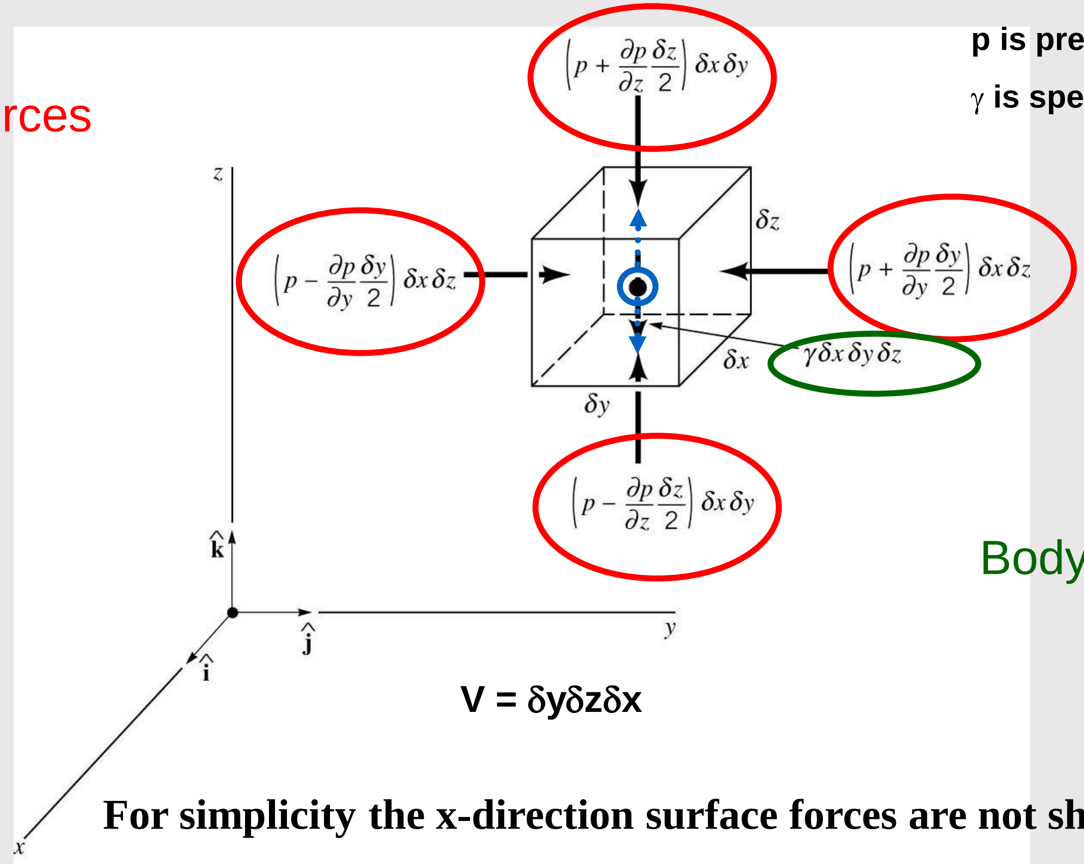
Surface Forces

↓

Taylor Series

p is pressure

γ is specific weight



Body Forces

For simplicity the x-direction surface forces are not shown

Pressure Field Equations

❖ Looking at the resultant surface forces in the y-direction:

$$\delta F_y = \left(p - \frac{\partial p}{\partial y}\frac{\delta y}{2}\right)\delta x\, \delta z - \left(p + \frac{\partial p}{\partial y}\frac{\delta y}{2}\right)\delta x\, \delta z$$

$$\delta F_y = -\frac{\partial p}{\partial y}\,\delta x\, \delta y\, \delta z$$

❖ Similarly, looking at the resultant surface forces in the x and z-direction, we obtain:

$$\delta F_x = -\frac{\partial p}{\partial x}\,\delta x\, \delta y\, \delta z \qquad \delta F_z = -\frac{\partial p}{\partial z}\,\delta x\, \delta y\, \delta z$$

Expressing these results in vector form:

$$\delta \mathbf{F}_s = \delta F_x \hat{\mathbf{i}} + \delta F_y \hat{\mathbf{j}} + \delta F_z \hat{\mathbf{k}}$$

$$\delta \mathbf{F}_s = -\left(\frac{\partial p}{\partial x}\hat{\mathbf{i}} + \frac{\partial p}{\partial y}\hat{\mathbf{j}} + \frac{\partial p}{\partial z}\hat{\mathbf{k}}\right)\delta x\, \delta y\, \delta z$$

Pressure Field Equations

- Now, we note by definition, the "del" operator or gradient is the following:

$$\nabla(\ ) = \frac{\partial(\ )}{\partial x}\hat{\mathbf{i}} + \frac{\partial(\ )}{\partial y}\hat{\mathbf{j}} + \frac{\partial(\ )}{\partial z}\hat{\mathbf{k}}$$

Then,

$$\frac{\partial p}{\partial x}\hat{\mathbf{i}} + \frac{\partial p}{\partial y}\hat{\mathbf{j}} + \frac{\partial p}{\partial z}\hat{\mathbf{k}} = \nabla p$$

- Now, rewriting the surface force equation, we obtain the following:

$$\frac{\delta \mathbf{F}_s}{\delta x\,\delta y\,\delta z} = -\nabla p$$

- Now, we return the body forces, and we will only consider weight:

$$-\delta \mathcal{W}\hat{\mathbf{k}} = -\gamma\,\delta x\,\delta y\,\delta z\,\hat{\mathbf{k}}$$

Pressure Field Equations

- Use Newton's Second Law to Sum the Forces for a Fluid Element:

$$\sum \delta \mathbf{F} = \delta m\, \mathbf{a}$$

- dm is the mass of the fluid element, and **a** is acceleration.

- Then summing the surface forces and the body forces:

δm

$$\sum \delta \mathbf{F} = \delta \mathbf{F}_s - \delta \mathcal{W} \hat{\mathbf{k}} = \delta m\, \mathbf{a}$$

$$-\nabla p\, \delta x\, \delta y\, \delta z - \gamma\, \delta x\, \delta y\, \delta z\, \hat{\mathbf{k}} = \rho\, \delta x\, \delta y\, \delta z\, \mathbf{a}$$

$$-\nabla p - \gamma \hat{\mathbf{k}} = \rho \mathbf{a}$$

"Most General Form" for No Shear

7. Hydrostatic Condition: a = 0

$$-\nabla p - \gamma \hat{\mathbf{k}} = \rho \mathbf{a} \quad (\mathbf{a} = 0) \longrightarrow \nabla p + \gamma \hat{\mathbf{k}} = 0$$

0

- Writing out the individual vector components:

$$\frac{\partial p}{\partial x} = 0 \qquad \frac{\partial p}{\partial y} = 0 \qquad \frac{\partial p}{\partial z} = -\gamma$$

- This leads to the conclusion that for liquids or gases at rest, the pressure gradient in the vertical direction at any point in fluid depends only on the specific weight of the fluid at that point. The pressure does not depend on x or y.

$$\frac{\partial p}{\partial z} = -\gamma \longrightarrow \frac{dp}{dz} = -\gamma$$

Hydrostatic Equation

Question

1) give a definition: Atmospheric pressure, Gauge pressure, Absolute pressure and Vacuum pressure?
2) How can you find out from the formula and graph of the pressure gauge and vacuum pressure?
3) Two important principles of pressure were described by Basel Pascal: What is fluid statics?
4) How does the pressure at a point vary with orientation of the plane passing through the point?
5) How does the pressure vary in a fluid or from point to point when no shear stresses are present?