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Module1.Fluid kinematics

Types of Flow



□ Types Of Fluid Flow:-

- 1) Steady & Unsteady Flows.
- 2) Uniform & Non-uniform Flows.
- 3) Laminar & Turbulent Flows.
- 4) Compressible & Incompressible Flows.
- 5) Rotational & Irrotational Flows.
- 6) One , Two & Three Dimensional Flows.

Steady and Unsteady Flow :

- The flow in which fluid characteristics like velocity, pressure, density etc. at a point does not changes with time is called as steady flow.
- Eg flow of water with constant discharge through a pipeline is as steady flow.

$$\partial v / \partial t = 0 \quad \partial p / \partial t = 0 \quad \partial \rho / \partial t = 0$$

- The flow in which fluid characteristics like velocity, pressure, density etc. at a point changes with time is called as unsteady flow.
- E.g flow of water with varying discharge though a pipe is as unsteady flow.

$$\partial v / \partial t \neq 0 \quad \partial p / \partial t \neq 0 \quad \partial \rho / \partial t \neq 0$$



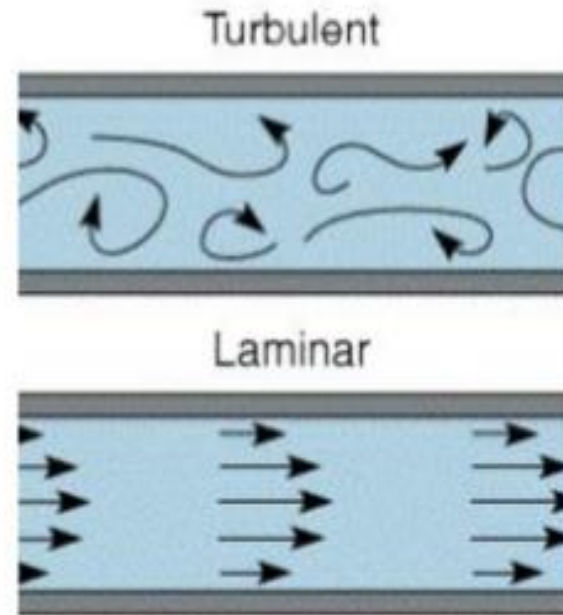
Laminar and Turbulent Flow

The flow in which the adjacent layers do not cross each other and move along the well defined path is called as laminar flow.

E.g. flow of blood in small veins

The flow in which the adjacent layers cross each other and do not move along the well defined path is called as turbulent flow.

E.g. flow through a river or canal, smoke from chimney



Types of flow:

- **Uniform:**

- velocity is constant along the streamline
- Streamlines are straight and parallel



(a)



(b)

$$\frac{\partial V}{\partial s} = 0$$

- **Non-uniform:**

- velocity changes along streamline
- Streamlines are curved and/or not parallel



$$\frac{\partial V}{\partial s} \neq 0$$

Slide from Dr. Isaac

10-1

Compressible & Incompressible Flows:-

➤ Compressible Flows:-

- ✓ In which the density of the fluid changes from point to point.
- ✓ The density is not constant for the fluid.

➤ Incompressible Flows:-

- ✓ In which the density of fluid changes from point to point.
- ✓ the density is constant for the fluid.

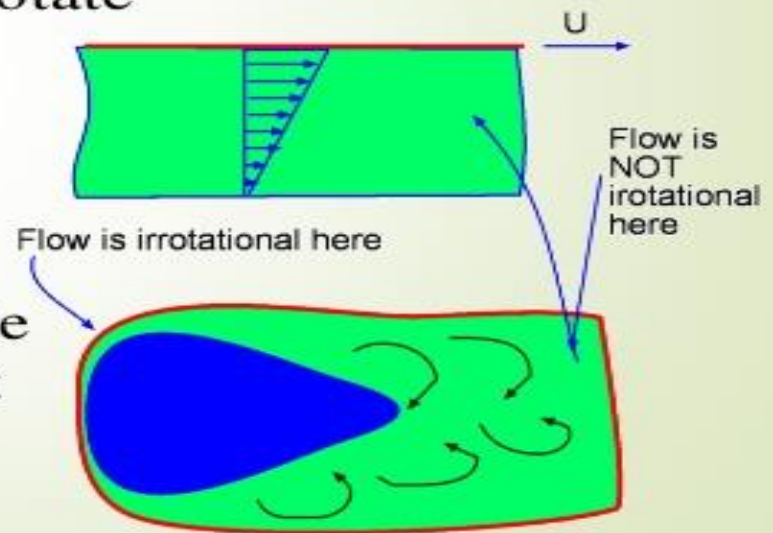
Rotational & Irrotational Flows:-

❖ Rotational Flow :-

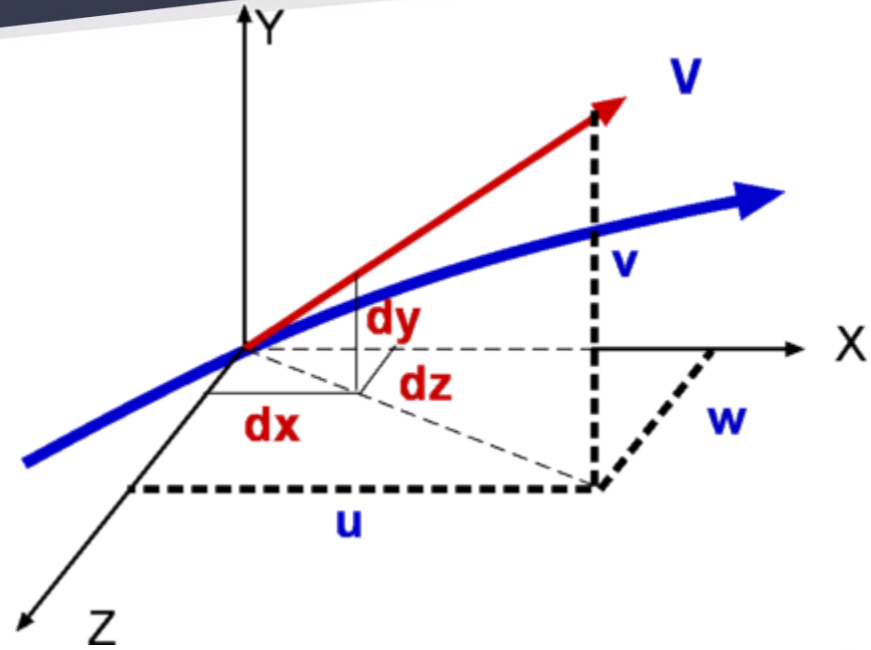
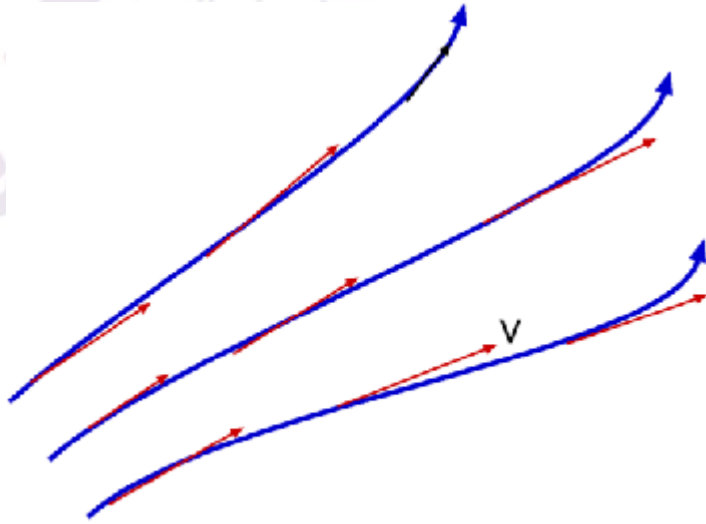
➤ In which the fluid particles while flowing along stream lines, Also rotate about their own axis.

❖ Irrotational Flow:-

➤ In which the fluid particles while flowing along stream lines, do not rotate about their own axis.



Streamline



streamline is one that drawn is tangential to the velocity vector at every point in the flow at a given instant and forms a powerful tool in understanding flows. This definition leads to the equation for streamlines.

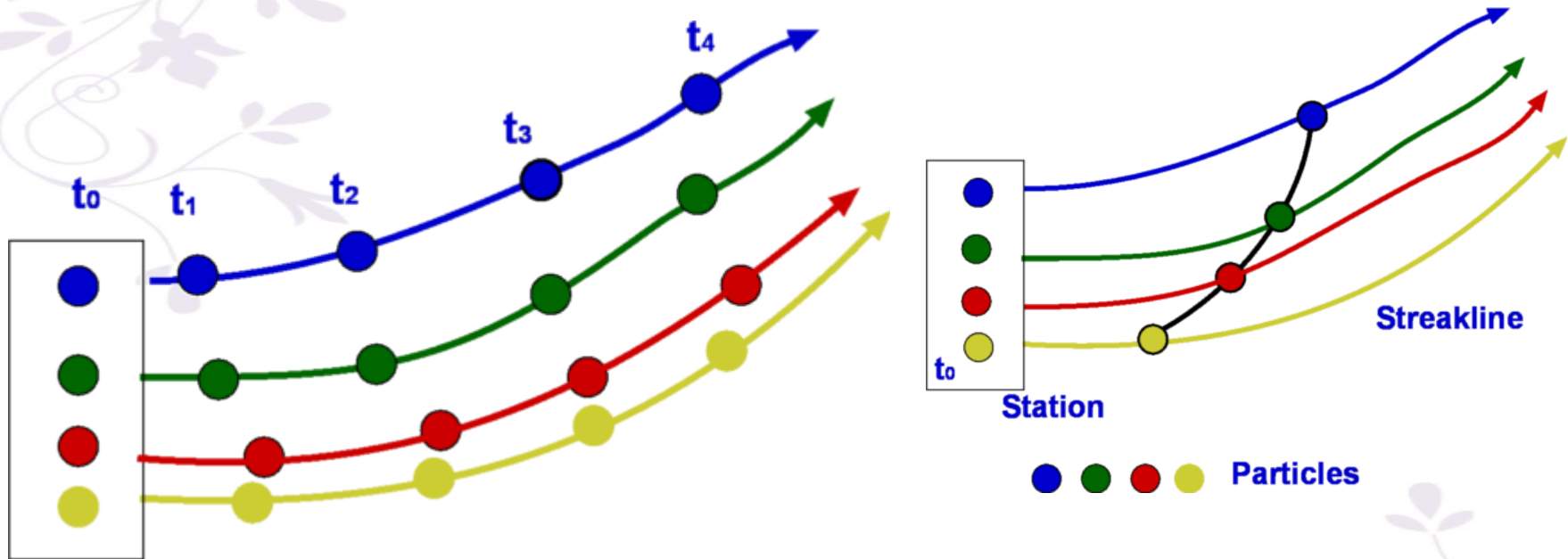
$$\frac{du}{u} = \frac{dv}{v} = \frac{dw}{w}$$

where $u, v,$ and w are the velocity components in x, y and z directions respectively as sketched.



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Path line AND Streak line



Path line is the line traced by a given particle. This is generated by injecting a dye into the fluid and following its path by photography or other means. **Streak line** concentrates on fluid particles that have gone through a fixed station or point. At some instant of time the position of all these particles are marked and a line is drawn through them. Such a line is called a streak line.

Velocity potential function

Velocity potential function is basically defined as a scalar function of space and time such that its negative derivative with respect to any direction will provide us the velocity of the fluid particle in that direction. Velocity potential function will be represented by the symbol ϕ i.e. phi.

$$u = -\frac{\partial\phi}{\partial x}, v = -\frac{\partial\phi}{\partial y}, w = -\frac{\partial\phi}{\partial z}$$

We can write here the continuity equation for incompressible steady flow in terms of velocity potential function as mentioned here.

$$\frac{\partial}{\partial x} \left(-\frac{\partial\phi}{\partial x} \right) + \frac{\partial}{\partial y} \left(-\frac{\partial\phi}{\partial y} \right) + \frac{\partial}{\partial z} \left(-\frac{\partial\phi}{\partial z} \right) = 0$$

$$\frac{\partial^2\phi}{\partial x^2} + \frac{\partial^2\phi}{\partial y^2} + \frac{\partial^2\phi}{\partial z^2} = 0$$

$$\Rightarrow \nabla^2\phi = 0 \quad (\text{Laplace equation})$$

stream function

Stream function is basically defined as a scalar function of space and time such that its partial derivative with respect to any direction will provide us the velocity component at perpendicular to that direction. Stream function will be represented by Ψ i.e. psi. It is defined only for two dimensional flow.

$$\frac{\partial \psi}{\partial x} = v, \quad \frac{\partial \psi}{\partial y} = -u$$

Let us use the value of u and v in continuity equation; we will have following equation as mentioned here.

$$\begin{aligned} \frac{\partial}{\partial x} \left(-\frac{\partial \psi}{\partial y} \right) + \frac{\partial}{\partial y} \left(\frac{\partial \psi}{\partial x} \right) &= 0 & \frac{\partial}{\partial x} \left(-\frac{\partial \psi}{\partial y} \right) + \frac{\partial}{\partial y} \left(\frac{\partial \psi}{\partial x} \right) &= 0 \\ -\frac{\partial^2 \psi}{\partial x \partial y} + \frac{\partial^2 \psi}{\partial y \partial x} &= 0 & -\frac{\partial^2 \psi}{\partial x \partial y} + \frac{\partial^2 \psi}{\partial y \partial x} &= 0 \end{aligned}$$

Therefore existence of stream function (Ψ) indicates a possible case of fluid flow. Flow might be rotational or irrotational.

If stream function (Ψ) satisfies the Laplace equation, it will be a possible case of an irrotational flow.

Equipotential line

Equipotential line is basically defined as the line along which the velocity potential (ϕ) is constant.

For equipotential line, $\phi = \text{Constant}$



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$$d\phi = \frac{\partial \phi}{\partial x} \cdot dx + \frac{\partial \phi}{\partial y} \cdot dy = 0$$

$$\Rightarrow -u \cdot dx - v \cdot dy = 0$$

$$\Rightarrow \frac{dy}{dx} = \frac{-u}{v}$$

$$\Rightarrow \frac{dy}{dx} = \text{Slope of equipotential line}$$

Streamline is basically defined as the line along which the Streamline function (Ψ) is constant.
For streamline, $\Psi = \text{Constant}$.





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Types of motion or deformation of fluid element

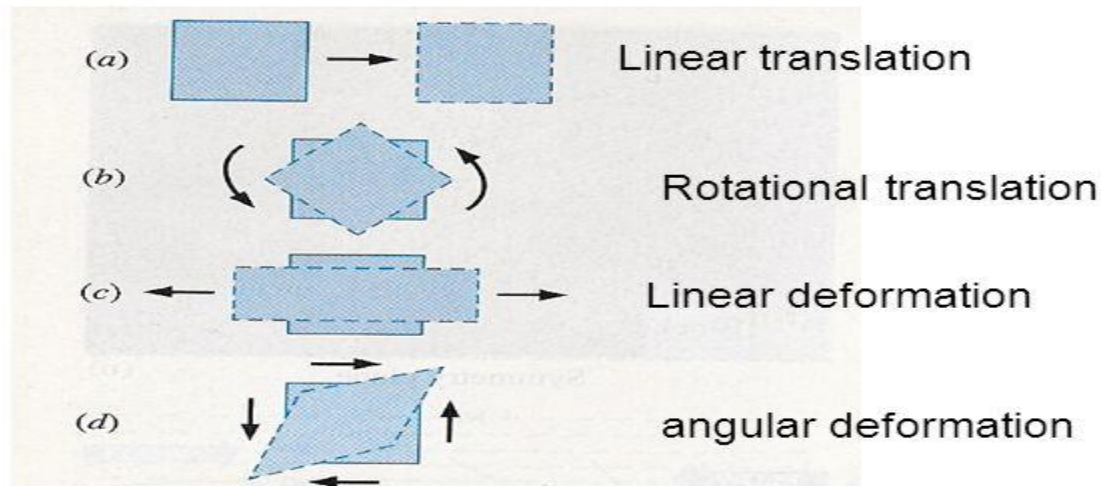


FIGURE 4-34

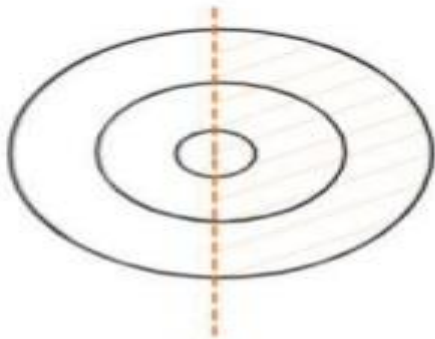
Fundamental types of fluid element motion or deformation: (a) translation, (b) rotation, (c) linear strain, and (d) shear strain.



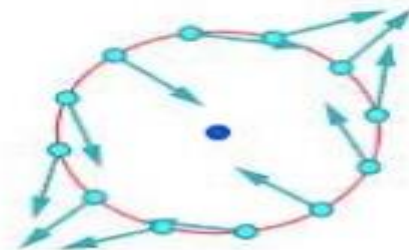
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Circulation and Vorticity

- ❖ Circulation and vorticity are two primary measures of rotation in a fluid.
- ❖ Circulation, which is a scalar integral quantity, is a macroscopic measure of rotation for a finite area of the fluid.
- ❖ Vorticity however is a vector field that gives a microscopic measure of the rotation at any point in the fluid.



CIRCULATION



VORTICITY



vorticity :- (Ω) It is defined as the circulation per unit of enclosed area.

$$\Omega = \frac{\Gamma}{A} = \frac{d\Gamma}{\Delta x \cdot \Delta y} = \frac{\left(\frac{\partial v}{\partial x} - \frac{\partial u}{\partial y}\right) \Delta x \cdot \Delta y}{\Delta x \cdot \Delta y} = \left[\frac{\partial v}{\partial x} - \frac{\partial u}{\partial y}\right]$$
$$d\Gamma = \left(\frac{\partial v}{\partial x} - \frac{\partial u}{\partial y}\right) \Delta x \cdot \Delta y$$

If a flow possess vorticity, it is rotational also.

Rotation (ω) :- It is equal to one half of the vorticity.

$$\omega = \frac{1}{2} \Omega = \frac{1}{2} \left[\frac{\partial v}{\partial x} - \frac{\partial u}{\partial y}\right] \rightarrow \text{fluid is rotational.}$$

if $\omega = 0$ then fluid is irrotational.

$$\omega \perp$$



4.5. Rotation

- The vorticity of a flow field is defined as

$$\boldsymbol{\omega} = \nabla \times \mathbf{v} = \begin{vmatrix} \mathbf{i} & \mathbf{j} & \mathbf{k} \\ \frac{\partial}{\partial x} & \frac{\partial}{\partial y} & \frac{\partial}{\partial z} \\ u & v & w \end{vmatrix}$$
$$= \left(\frac{\partial w}{\partial y} - \frac{\partial v}{\partial z} \right) \mathbf{i} + \left(\frac{\partial u}{\partial z} - \frac{\partial w}{\partial x} \right) \mathbf{j} + \left(\frac{\partial v}{\partial x} - \frac{\partial u}{\partial y} \right) \mathbf{k}$$

Vorticity

- ❖ **Vorticity is the tendency for elements of the fluid to spin.**
- ❖ **Vorticity can be related to the amount of circulation or rotation (or more strictly the angular rate of rotation) in a fluid.**
- ✓ **Vertical Component of Vorticity :**
- ❖ **In large-scale dynamic meteorology, we are in concerned only with the vertical components of absolute and relative vorticity.**
- ❖ **The vertical component of vorticity is defined as the circulation about a closed contour in the horizontal plane divided by the area enclosed, in the limit where the area approaches zero.**