TYPES OF FLUID FLOW

The fluid flow can be categorized as:

- Steady flow & Unsteady Flow
- Uniform flow & Non-uniform Flow
- Laminar flow & Turbulent flow
- Incompressible flow & Compressible flow
- Rotational flow & Irrotational flow
- One, Two and Three dimensional flow

Steady flow Vs Unsteady Flow

Steady flow:

Fluid properties (velocity, pressure, density, etc.) at a given point in space does not vary with time

$$\left(\frac{\partial V}{\partial t}\right)_{x_0, y_0, z_0} = 0, \left(\frac{\partial p}{\partial t}\right)_{x_0, y_0, z_0} = 0, \left(\frac{\partial \rho}{\partial t}\right)_{x_0, y_0, z_0} = 0$$

Unsteady flow:

Fluid properties (velocity, temperature, density, etc.) at a given point in space vary with time.

$$\left(\frac{\partial V}{\partial t}\right)_{x_0, y_0, z_0} \neq 0, \left(\frac{\partial p}{\partial t}\right)_{x_0, y_0, z_0} \neq 0 \text{ etc.}$$

Uniform flow Vs Non-uniform Flow

Uniform flow:

Velocity at any given time instant does not vary with space (for eg., along the flow direction)

$$\left(\frac{\partial V}{\partial s}\right)_{t\,=\,\text{constant}} = 0$$

Non-Uniform flow:

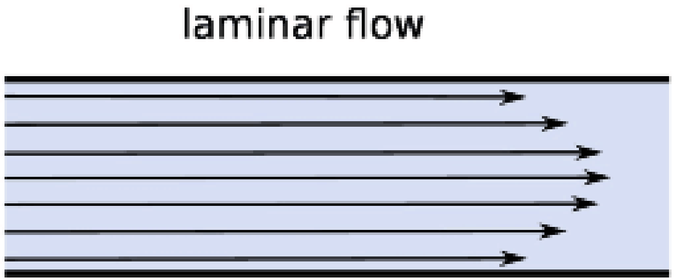
Velocity at any given time instant vary with space

$$\left(\frac{\partial V}{\partial s}\right)_{t\,=\,\text{constant}} \neq 0.$$

Laminar flow Vs Turbulent flow

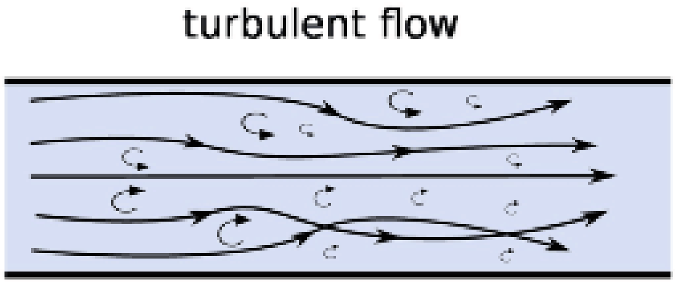
Laminar flow:

- The fluid particles move along well-defined paths or streamlines.
- All the streamlines are straight and parallel.
- No mixing between adjacent layers of flow
- The fluid particles move in laminas or layers gliding smoothly over the adjacent layer



Turbulent flow:

- Fluid particles move in a random way
- Eddy (vortex) formation takes place which are responsible for high energy loss
- Intense mixing takes place between fluid layers



https://www.youtube.com/watch?v=QzuzbwJWlYs

Incompressible flow Vs Compressible flow

Incompressible flow:

Density variations are very small in a flow and can be neglected

$$\rho = \text{constant}$$

Condition for incompressible flow

$$\vec{\nabla}.\vec{V} = 0 \quad \Rightarrow \quad \frac{\partial u}{\partial x} + \frac{\partial v}{\partial y} + \frac{\partial w}{\partial z} = 0$$

Compressible flow:

Density variations are significant and cannot be neglected

$$\rho \neq \text{constant}$$

$$\vec{\nabla}.\vec{V} \neq 0 \quad \Rightarrow \quad \frac{\partial u}{\partial x} + \frac{\partial v}{\partial y} + \frac{\partial w}{\partial z} \neq 0$$

Rotational flow Vs Irrotational flow

Irrotational flow:

- A flow in which the fluid particles do not rotate about their own axis
- Vorticity is zero in the flow

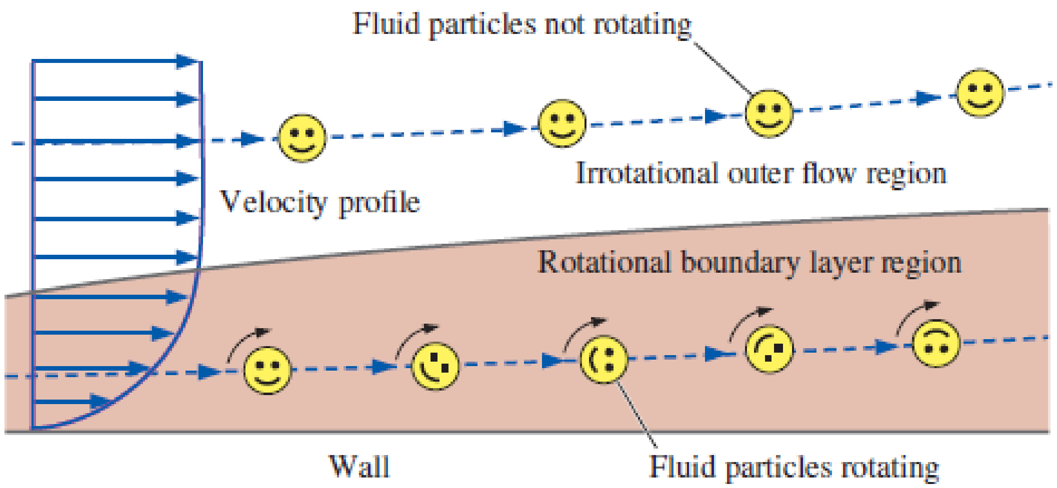
$$\text{vorticity} \quad \vec{\omega} = \vec{\nabla} \times \vec{V} = 0$$

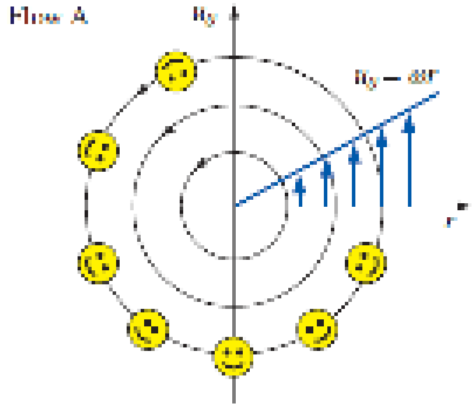
$$\omega = \left(\frac{\partial v}{\partial x} - \frac{\partial u}{\partial y} \right)$$

Rotational flow:

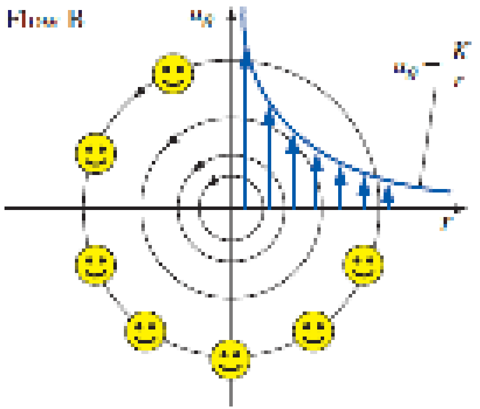
- A flow in which the fluid particles rotate about their own axis.
- Flow has vorticity

$$\text{vorticity} \quad \vec{\omega} = \vec{\nabla} \times \vec{V} \neq 0$$





Forced vortex – Rotational flow



Free vortex – Irrotational flow

One, Two and Three dimensional flow

Generally, a fluid flow is a rather complex three-dimensional, time-dependent phenomenon

$$\vec{V} = \vec{V}(x, y, z, t) = u(x, y, z, t)\hat{i} + v(x, y, z, t)\hat{j} + w(x, y, z, t)\hat{k}$$

Three dimensional flow

Velocity is a function of three independent directions x, y and z

$$\vec{V} = \vec{V}(x, y, z, t) = u(x, y, z, t)\hat{i} + v(x, y, z, t)\hat{j} + w(x, y, z, t)\hat{k}$$

Steady, Three dimensional flow: $\vec{V}(x, y, z) = u(x, y, z)\hat{i} + v(x, y, z)\hat{j} + w(x, y, z)\hat{k}$

Two dimensional flow

Velocity is a function of two directions x and y. It is independent of the third direction z.

$$\vec{V} = \vec{V}(x, y, t) = u(x, y, t)\hat{i} + v(x, y, t)\hat{j} \qquad w = 0$$

Steady, Two dimensional flow: $\vec{V}(x, y) = u(x, y)\hat{i} + v(x, y)\hat{j}$

One dimensional flow

Velocity is a function of only one direction x. It is independent of the other two directions y and z.

$$\vec{V} = \vec{V}(x, t) = u(x, t)\hat{i} \qquad v = 0 \qquad w = 0$$

Steady, One dimensional flow: $\vec{V}(x) = u(x)\hat{i}$

Flow acceleration in various types of flow

Total acceleration
$$\underbrace{\frac{D\vec{V}}{Dt}}_{\text{Total acceleration}} = \underbrace{\frac{\partial \vec{V}}{\partial t}}_{\text{Local acceleration}} + \underbrace{u\frac{\partial \vec{V}}{\partial x} + v\frac{\partial \vec{V}}{\partial y} + w\frac{\partial \vec{V}}{\partial z}}_{\text{Convective acceleration}}$$

	Local Acceleration	Convective acceleration	Total acceleration
Steady flow	= 0	≠ 0	≠ 0
Uniform flow	≠ 0	= 0	≠ 0
Steady and uniform flow	= 0	= 0	= 0
Unsteady and non-uniform flow	≠ 0	≠ 0	≠ 0