Introduction to Fluid Mechanics

Background

Several scientists have contributed to the science of fluid mechanics

- Archimedes (250 B.C) : Principles of hydrostatic and flotation
- Newton: Momentum equation.
- Reynold: Laminar & Turbulence.
- Prandtl: Boundary layer.
- Euler & Bernoulli: Fluid motion.
- Mach: Supersonic flow.
- Riemann: Shock waves.

Definitions

a. Fluid Mechanics (there is more than one definition)

- The science that deals with the action of forces on fluid.
- The branch of mechanics that deal with gases and liquids, either at rest or in motion.

b. Fluid (Liquid, Gas & Plastic solids)

- Fluid is defined as a substance that continually deforms (flows) under an applied shear stress regardless of how small the applied stress.
- Anything that flows, either liquid or gas. Some solids can also exhibit fluid behavior over time.

Dimensions

A Dimension is a category that represents a physical quantity such as mass, length, time , momentum, force , acceleration, and energy.

Primary Dimensions

Dimension	Symbol	Units (SI)
Length	L	m
Mass	M	kg
Time	T	s
Temperature	q	K
Electric Current	i	A
Amount of light	C	cd
Amount of Matter	N	$Mole$

Other dimensions not mentioned in the table are called

Secondary Dimensions

Examples of Secondary dimensions

(Force, acceleration, momentum)

$$[F]=[m\times a]: Called\ Dimensions$$

$$\text{Primary dimension of force} =$$

$$[F]=[m\times a]=M\times\frac{L}{T^2}=\frac{ML}{T^2}$$

Dimensionless Groups

A Dimensionless Group is any arrangement of variables in which the primary dimensions cancel out. Examples: Mach number: (M), Reynolds number; (Re)

Dimensional Homogeneity

A Dimensional Homogeneity is when the primary dimensions on each term are the same.

Primary dimensions on a derivative

To find primary dimensions on a derivative, recall from calculus that a derivative is defined as a ratio:

$$\frac{df}{dy} = \lim_{\Delta y \longrightarrow 0} \frac{\Delta f}{\Delta y}$$

Thus, the primary dimensions of a derivative can be found by using a ratio:

$$\left[\frac{df}{dy}\right] = \left[\frac{f}{y}\right] = \frac{[f]}{[y]}$$

$$\left[\frac{d^2 f}{dy^2}\right] = \lim_{\Delta y \longrightarrow 0} \frac{\Delta(df/dy)}{\Delta y} = \left[\frac{f}{y^2}\right] = \frac{[f]}{[y^2]}$$

Primary dimensions of an integral

To find primary dimensions of an integral, recall from calculus that an integral is defined as a sum:

$$\int f\,dy = \lim_{N \longrightarrow \infty} \sum_{i=1}^{N} f\,\Delta y_i$$

Thus

$$\left[\int f\,dy\right] = [f]\,[y] \qquad (1.6)$$

For example, position is given by the integral of velocity with respect to time. Checking primary dimensions for this integral gives

$$\left[\int V\,dt\right] = [V]\,[t] = \frac{L}{T} \cdot T = L$$

Dimensional Homogeneity

Sometimes constants have primary dimensions. For example, the hydrostatic equation relates pressure p, density ρ, the gravitational constant g, and elevation z:

$$p + \rho g z = \text{constant} = C$$

For dimensional homogeneity, the constant C needs to have the same primary dimensions as either p or $\rho g z$. Thus the dimensions of C are $[C] = M/LT^2$. Another example involves expressing fluid velocity V as a function of distance y using two constants a and b:

$$V(y) = ay(b - y)$$

For dimensional homogeneity both sides of this equation need to have primary dimensions of $[L/T]$. Thus, $[b] = L$ and $[a] = L^{-1}\,T^{-1}$.

Dimensional Homogeneity

Prove the equation below for dimension homogeneity

$$V(y) = ay(b - y)$$

$$V(y) = ay(b - y) = aby - ay^2$$

$$\left[\frac{L}{T}\right] = [abL] - [aL^2]$$

$$[abL] = \left[\frac{L}{T}\right],\ [ab] = \left[\frac{1}{T}\right]........................(1)$$

$$And\ [aL^2] = \left[\frac{L}{T}\right],\ i.e.\ [a] = \left[\frac{1}{LT}\right]...........(2)$$

$$Substitute\ Eqn.(2)\ in\ Eqn.(1),\ we\ have$$

$$[b] = [L]$$

Applications and Connections of Fluid Mechanics

1. Hydraulics

Hydraulics is the study of the flow of water through pipes, rivers, and open-channels. Hydraulics includes pumps and turbines and applications such as hydropower. Hydraulics is important for ecology, policymaking, energy production, recreation, fish and game resources, and water supply.

1. Hydrology

Hydrology is the study of the movement, distribution, and quality of water throughout the earth. Hydrology involves the hydraulic cycle and water resource issues. Thus, hydrology provides results that are useful for environmental engineering and for policymaking. Hydrology is important nowadays because of global challenges in providing water for human societies.

Flow Classification

3. Aerodynamics

Aerodynamics is the study of air flow. Topics include lift and drag on objects (e.g., airplanes, automobiles, birds), shock waves associated with flow around a rocket, and the flow through a supersonic or deLaval nozzle. Aerodynamics is important for the design of vehicles, for energy conservation, and for understanding nature.

4. Bio-fluid Mechanics

Bio-fluid mechanics is an emerging field that includes the study of the lungs and circulatory system, blood flow, micro-circulation, and lymph flow. Bio-fluids also includes development of artificial heart valves, stents, vein and dialysis shunts, and artificial organs. Bio-fluid mechanics is important for advancing health care.

Flow Classification

5. Acoustics

Acoustics is the study of sound. Topics include production, control, transmission, reception of sound, and physiological effects of sound. Since sound waves are pressure waves in fluids, acoustics is related to fluid mechanics. In addition, water hammer in a piping system, which involves pressure waves in liquids, involves some of the same knowledge that is used in acoustics.

6. Micro-channel flow

Microchannel flow is an emerging area that involves the study of flow in tiny passages. The typical size of a microchannel is a diameter in the range of 10 to 200 micrometers. Applications that involve microchannels include microelectronics, fuel cell systems, and advanced heat sink designs.

Flow Classification

7. Computational Fluid Dynamics

Computational fluid dynamics (CFD) is the application of numerical methods implemented on computers to model and solve problems that involve fluid flows. Computers perform millions of calculations per second to simulate fluid flow. Examples of flows that are modeled by CFD include water flow in a river, blood flow in the abdominal aorta, and air flow around an automobile.

8. Petroleum Engineering

Petroleum engineering is the application of engineering to the exploration and production of petroleum. Movement of oil in the ground involves flow through a porous medium. Petroleum extraction involves flow of oil through passages in wells. Oil pipelines involve pumps and conduit flow.

Flow Classification

9. Atmospheric Science

Atmospheric science is the study of the atmosphere, its processes, and the interaction of the atmosphere with other systems. Fluid mechanics topics include flow of the atmosphere and applications of CFD to atmospheric modeling. Atmospheric science is important for predicting weather and is relevant to current issues including acid rain, photochemical smog, and global warming.

10. Electrical Engineering

Electrical engineering problems can involve knowledge from fluid mechanics. For example, fluid mechanics is involved in the flow of solder during a manufacturing process, the cooling of a microprocessor by a fan, sizing of motors to operate pumps, and the production of electrical power by wind turbines.

Flow Classification

11. Environmental Engineering

Environmental engineering involves the application of science to protect or improve the environment (air, water, and/or land resources) or to remediate polluted sites. Environmental engineers design water supply and wastewater treatment systems for communities. Environmental engineers are concerned with local and worldwide environmental issues such as acid rain, ozone depletion, water pollution, and air pollution.

END

of Chapter One