→ Two different methods are used to set up equations arising out of physical principles

→ Differential element approach

→ Control volume approach

→ Differential element approach

→ A small fluid element is studied in terms of stresses acting on it

→ its responses to these stresses in terms of deformation rate

→ Control volume approach

→ Principles of conservation of mass and Newton's second law of motion are applied to a finite, fixed region in the flow field thru the Reynolds Transport Theorem

→ A third approach is used in Continuum mechanics

— Minimization of potential energy principle

— Equivalent to variational formulation of the governing eqns.

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→ Differential element approach leads to a system of differential eqns that describe the flow field

→ Control volume approach leads to integral equations for the flow quantities

→ is more mathematically rigorous and doesn't assume the solution to be continuous beforehand

→ very few techniques that can solve integral eqns are available

→ integral eqns form the starting point for a numerical solution using computational algorithms

→ The flow must satisfy the three basic laws of mechanics plus a thermodynamic state relation and associated boundary conditions

→ Conservation of mass (continuity)
→ Linear momentum (Newton's Second law)
→ First law of thermodynamics (Conservation of energy)
→ A state relation like $\rho = \rho(P, T)$
→ Appropriate boundary conditions at solid surfaces, interfaces, inlets and exits

→ In integral and differential analyses, these five relations are modeled mathematically and solved by computational methods

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→ In an experimental study — the fluid itself performs the task without use of any mathematics

→ In other words, these laws are believed to be fundamental to physics, and no fluid flow is known to violate them

Properties of the Velocity fluid

→ In a given flow situation, the determination, by experiment or theory, of the properties of the fluid as a function of position and time is considered to be the solution to the problem

→ In almost all cases, the emphasis is on the space-time distribution of the fluid properties

→ One rarely keeps track of the actual fate of the specific fluid particles

→ This treatment of properties as continuum-field functions distinguishes fluid mechanics from solid mechanics

→ In solid mechanics we are more likely to be interested in trajectories of individual particles or systems

Velocity field →

→ foremost among the properties of a flow is the velocity field $V(x, y, z, t)$

→ determination of the velocity is often tantamount to solving flow problems since other properties follow directly from the velocity field

→ pressure field can be calculated from velocity field

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→ Even temperature fields can be obtained from velocity fields (Heat Transfer)

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

$u \rightarrow V_x$
$v \rightarrow V_y$
$w \rightarrow V_z$

Acceleration field →

→ Acceleration vector, $a = d\vec{V}/dt$, occurs in Newton's law for a fluid

$$\vec{a} = \frac{d\vec{V}}{dt} = \frac{\partial \vec{V}}{\partial t} + u\frac{\partial \vec{V}}{\partial x} + v\frac{\partial \vec{V}}{\partial y} + w\frac{\partial \vec{V}}{\partial z}$$

Thermodynamic Properties of a Fluid →

Velocity field $\vec{V}$ is the most important fluid property → it interacts closely with the thermodynamic properties

③ { → pressure, p → density, ρ → Temperature, T } most common

Four other intensive properties (thermodynamics)

④ { → internal energy, u → enthalpy, $h = u + p/\rho$ → entropy, s → Specific heats, c_p and c_v } Important when work, heat & energy balances are treated

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In addition friction and heat conduction effects are governed by the two so-called transport properties:

(2) } → Coefficient of viscosity μ
→ Thermal conductivity

All nine of these quantities are true thermodynamic properties that are determined by the thermodynamic condition or state of the fluid

→ for a single-phase substance
(example water, oxygen)

two basic properties such as pressure and temperature are sufficient to fix the value of all the others:

$$\rho = \rho(p, T), \quad h = h(p, T), \quad \mu = \mu(p, T)$$

and so on for every quantity

→ Thermodynamic properties describe the state of a system

→ System — a collection of matter of fixed identity that interacts with its surroundings

→ Most cases the system will be a small fluid element, and all properties will be assumed to be continuum properties of the flow field:

$$\rho = \rho(x, y, z, t) \text{ \& so on}$$

State Relations for Gases

→ Thermodynamic properties are found both theoretically and experimentally to be related to each other by state relations that differ for each substance

→ Discussion confined to single-phase pure substance — water in its liquid phase
→ air (mixture of gases
[As the mixture ratio remains nearly constant between 160 and 2200K — considered as pure substance in this range]

All gases at high temperatures and low pressures (relative to their critical point) are in good agreement with the perfect-gas law

$$p = \rho R T$$

$$R = c_p - c_v = \text{gas constant}$$

c_p, c_v } are specific heats

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State Relations for Liquids

→ There is no 'perfect-liquid law' comparable to that for gases

→ Liquids are nearly incompressible and have a single, reasonable constant specific heat

An idealized state relation for a liquid is

$$\rho \simeq \text{constant}$$

$$C_p \simeq C_v \simeq \text{constant}$$

$$dh \simeq C_p dT$$

Most of the flow problems can be solved with these simple assumptions

→ Water is normally taken to have a density of 998 kg/m³ & a specific heat $C_p = 4210$ J/kg K

→ The density of a liquid usually decreases slightly with temperature and increases moderately with pressure

→

Neglecting the temperature effect, empirical pressure-density relation for a liquid is

$$\frac{p}{p_a} \simeq (B+1)\left(\frac{\rho}{\rho_a}\right)^n - B$$

where B and n are dimensionless parameters that vary slightly with temperature

ρ_a and p_a are standard atmospheric values

Water can be fitted approximately to the values $B \simeq 3{,}000$ and $n \simeq 7$

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Problem – Solving Technique

→ first step — grasp the fundamentals and gain a sound knowledge

→ next step — master the fundamentals by testing this knowledge

→ solving significant real world problems

↓

Such problems are usually complicated ones — requires a systematic approach

Using a step-by-step approach, one can reduce solution of a complicated problem into the solution of series of simple problems

Following steps to be adopted :

Step 1 : Problem statement

Step 2 : Schematic

Step 3 : Assumptions & approximations

Step 4 : Physical laws

Step 5 : Properties

Step 6 : Calculations

Step 7 : Reasoning, Verification & Discussion

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