Fluid Mechanics - MTF053

Lecture 1

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Fluid Mechanics

"Fluid mechanics is the branch of physics concerned with the mechanics of fluids (liquids, gases, and plasmas) and the forces on them. It has applications in a wide range of disciplines, including mechanical, civil, chemical and biomedical engineering, geophysics, oceanography, meteorology, astrophysics, and biology."

Wikipedia

Fluid Flows in Your Daily Life

"When you think about it, almost everything on this planet either is a fluid or moves within or near a fluid"

Frank M. White

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Governing Equations

Conservation of mass (continuity)

$$\frac{\partial \rho}{\partial t} + \frac{\partial}{\partial x}(\rho u) + \frac{\partial}{\partial y}(\rho v) + \frac{\partial}{\partial z}(\rho w) = 0$$

Governing Equations

Conservation of mass (continuity)

$$\frac{\partial \rho}{\partial t} + \frac{\partial}{\partial x}(\rho u) + \frac{\partial}{\partial y}(\rho v) + \frac{\partial}{\partial z}(\rho w) = 0$$

Conservation of linear momentum (Newton's 2:nd law)

$$\rho\left(\frac{\partial u}{\partial t} + u\frac{\partial u}{\partial x} + v\frac{\partial u}{\partial y} + w\frac{\partial u}{\partial z}\right) = \rho g_x - \frac{\partial p}{\partial x} + \mu\left(\frac{\partial^2 u}{\partial x^2} + \frac{\partial^2 u}{\partial y^2} + \frac{\partial^2 u}{\partial z^2}\right)$$

$$\rho\left(\frac{\partial v}{\partial t} + u\frac{\partial v}{\partial x} + v\frac{\partial v}{\partial y} + w\frac{\partial v}{\partial z}\right) = \rho g_y - \frac{\partial p}{\partial y} + \mu\left(\frac{\partial^2 v}{\partial x^2} + \frac{\partial^2 v}{\partial y^2} + \frac{\partial^2 v}{\partial z^2}\right)$$

$$\rho\left(\frac{\partial w}{\partial t} + u\frac{\partial w}{\partial x} + v\frac{\partial w}{\partial y} + w\frac{\partial w}{\partial z}\right) = \rho g_z - \frac{\partial p}{\partial z} + \mu\left(\frac{\partial^2 w}{\partial x^2} + \frac{\partial^2 w}{\partial y^2} + \frac{\partial^2 w}{\partial z^2}\right)$$

Governing Equations

Conservation of mass (continuity)

$$\frac{\partial \rho}{\partial t} + \frac{\partial}{\partial x}(\rho u) + \frac{\partial}{\partial y}(\rho v) + \frac{\partial}{\partial z}(\rho w) = 0$$

Conservation of linear momentum (Newton's 2:nd law)

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$$\rho\left(\frac{\partial w}{\partial t} + u\frac{\partial w}{\partial x} + v\frac{\partial w}{\partial y} + w\frac{\partial w}{\partial z}\right) = \rho g_z - \frac{\partial p}{\partial z} + \mu\left(\frac{\partial^2 w}{\partial x^2} + \frac{\partial^2 w}{\partial y^2} + \frac{\partial^2 w}{\partial z^2}\right)$$

Conservation of energy (1:st law of thermodynamics)

$$\rho C_v\left(\frac{\partial T}{\partial t} + u\frac{\partial T}{\partial x} + v\frac{\partial T}{\partial y} + w\frac{\partial T}{\partial z}\right) = p\left(\frac{\partial u}{\partial x} + \frac{\partial v}{\partial y} + \frac{\partial w}{\partial z}\right) + k\left(\frac{\partial^2 T}{\partial x^2} + \frac{\partial^2 T}{\partial y^2} + \frac{\partial^2 T}{\partial z^2}\right) + \Phi$$

Fluid Flow Applications

Analytical solutions limited to very specific simplified cases

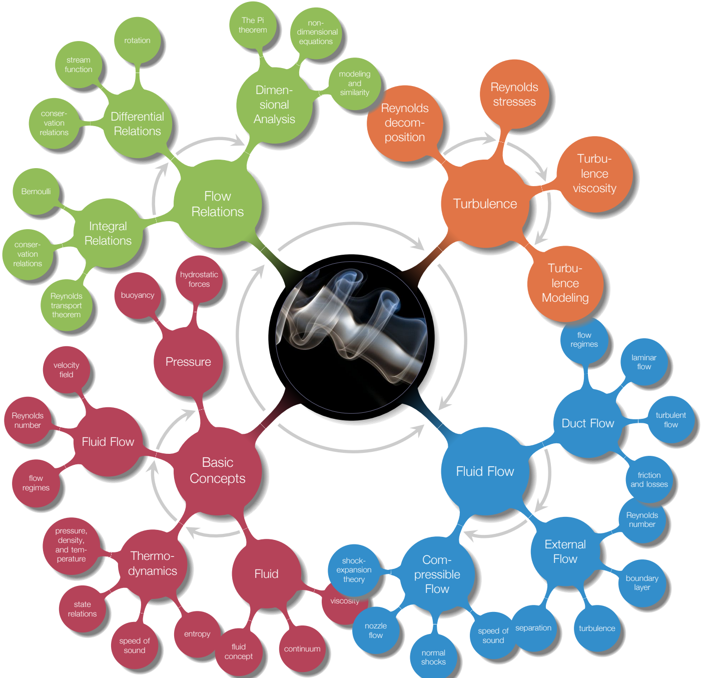
Complex geometries and flows leads to the need for experiments and Computational Fluid Dynamics (CFD)

Chief obstacles to a general theory:

Geometry | Viscosity | Non-linearity | Turbulence

Understanding the basic principles is a key factor for a correct analysis

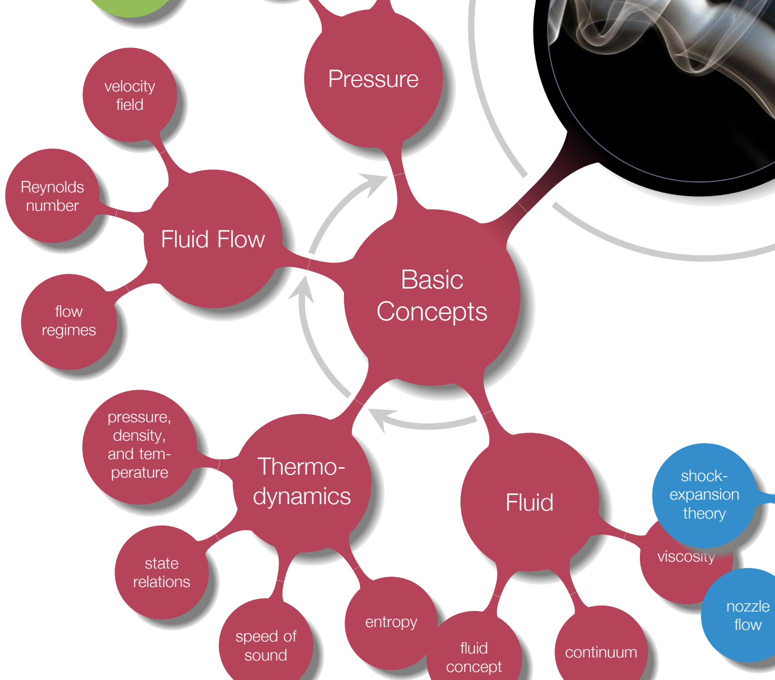
Overview



Flow Relations
Differential Relations
rotation
stream function
conser-vation relations
Dimen-sional Analysis
The Pi theorem
non-dimensional equations
modeling and similarity
Integral Relations
Bernoulli
conser-vation relations
Reynolds transport theorem
Turbulence
Reynolds decom-position
Reynolds stresses
Turbu-lence viscosity
Turbu-lence Modeling
Basic Concepts
Pressure
buoyancy
hydrostatic forces
Fluid Flow
velocity field
Reynolds number
flow regimes
Thermo-dynamics
pressure, density, and tem-perature
state relations
speed of sound
entropy
Fluid
fluid concept
continuum
viscosity
Fluid Flow
Duct Flow
flow regimes
laminar flow
turbulent flow
friction and losses
External Flow
Reynolds number
boundary layer
turbulence
separation
Com-pressible Flow
shock-expansion theory
nozzle flow
normal shocks
speed of sound

Chapter 1 - Introduction

Overview



Pressure
velocity field
Reynolds number
Fluid Flow
flow regimes
Basic Concepts
pressure, density, and tem-perature
Thermo-dynamics
state relations
speed of sound
entropy
Fluid
fluid concept
continuum
viscosity
shock-expansion theory
nozzle flow

Learning Outcomes

1 **Explain** the difference between a fluid and a solid in terms of forces and deformation

2 **Understand** and be able to explain the viscosity concept

3 **Define** the Reynolds number

5 **Explain** the difference between Lagrangian and Eulerian frame of reference and know when to use which approach

7 **Explain** the concepts: streamline, pathline and streakline

8 **Understand** and be able to **explain** the concept shear stress

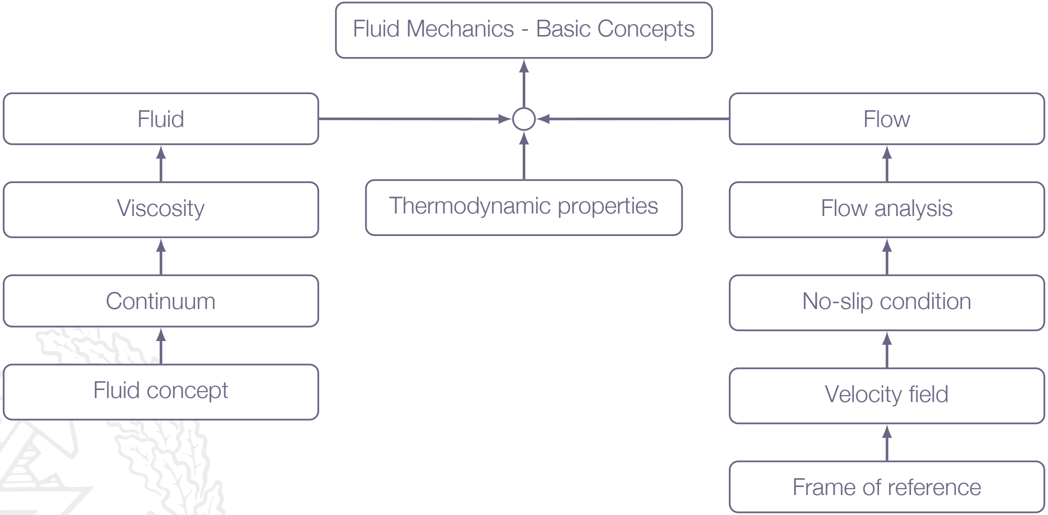
9 **Explain** how to do a force balance for fluid element (forces and pressure gradients)

10 **Understand and explain** buoyancy and cavitation

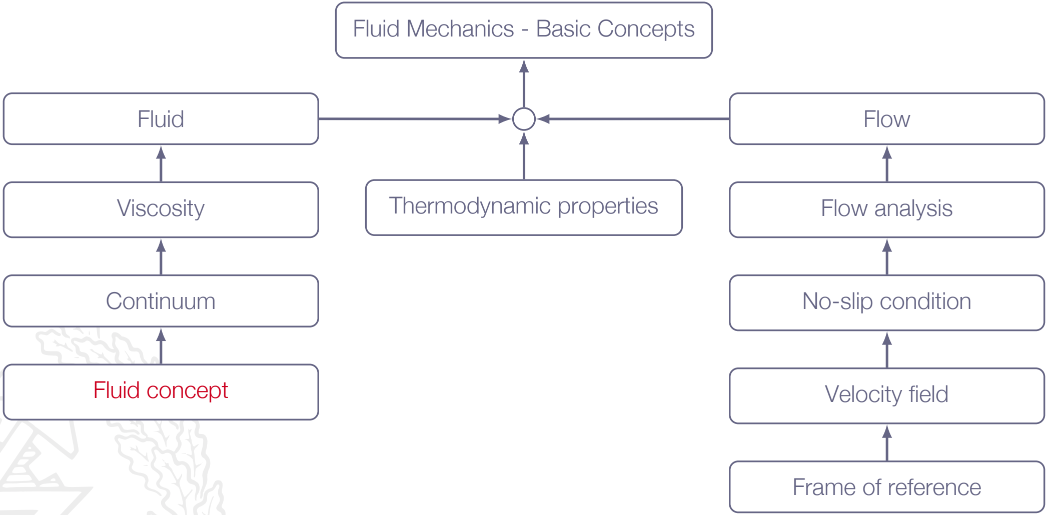
16 **Understand** and **explain** the concept Newtonian fluid

in this lecture we will find out what a fluid flow is

Roadmap - Introduction to Fluid Mechanics



Roadmap - Introduction to Fluid Mechanics



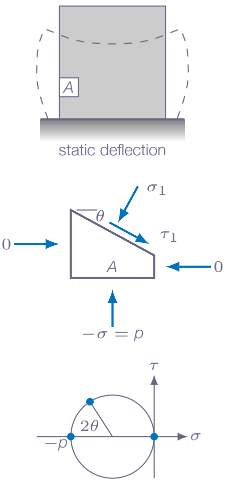
The Concept of a Fluid

"In physics, a fluid is a substance that continually deforms (flows) under an applied shear stress, or external force. Fluids are a phase of matter and include liquids, gases and plasmas. They are substances with zero shear modulus, or, in simpler terms, substances which cannot resist any shear force applied to them."

Wikipedia

The Concept of a Fluid

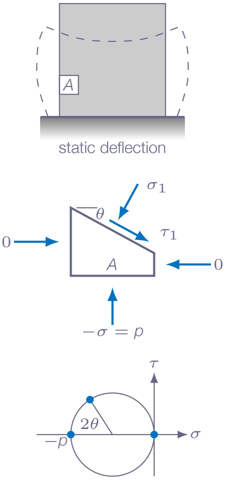
Solid



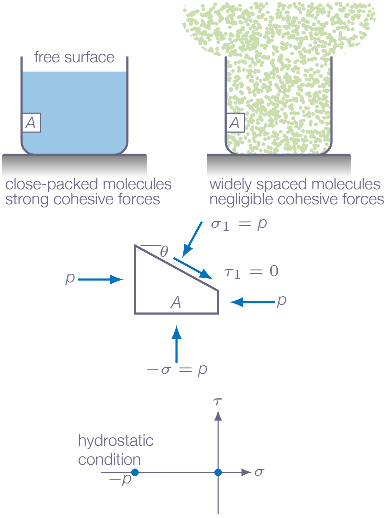
The Concept of a Fluid

”A solid can resist a shear stress by a static deflection; a fluid cannot”

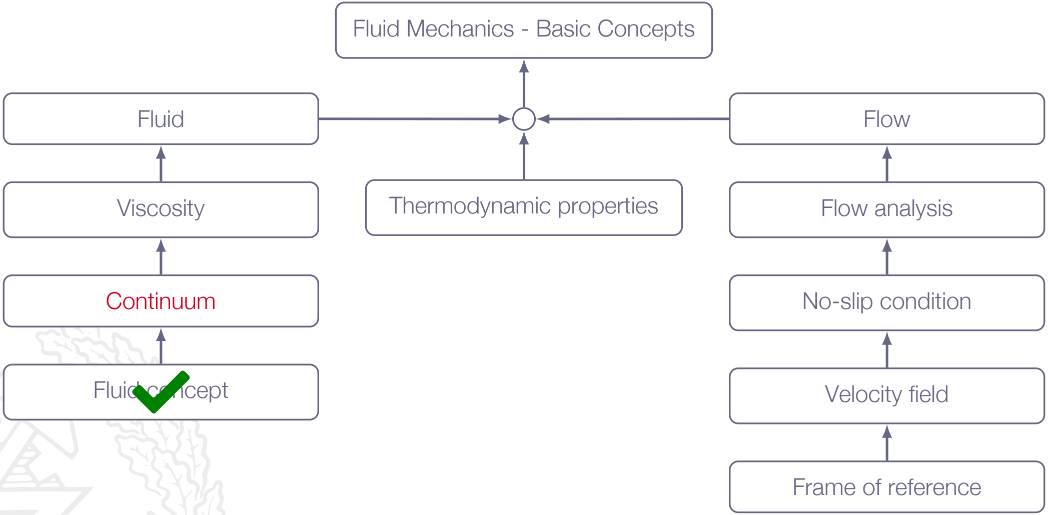
Solid



Fluid



Roadmap - Introduction to Fluid Mechanics



The Fluid as a Continuum

Fluid **density** is essentially a **point function**

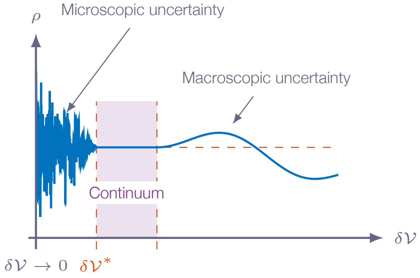
Fluid **properties** can be thought of as **varying continually in space**

Volume large enough such that the **number of molecules** within the volume is **constant**

Volume small enough **not** to **introduce macroscopic fluctuations**

$$\rho = \lim_{\delta\mathcal{V} \to \delta\mathcal{V}^*} \frac{\delta m}{\delta\mathcal{V}}$$

standard air: $\delta\mathcal{V}^* \approx 10^{-9} mm^3 \Rightarrow \sim 3 \times 10^7$ molecules



The Fluid as a Continuum

Flow properties varies smoothly $\Rightarrow$ Differential calculus can be used