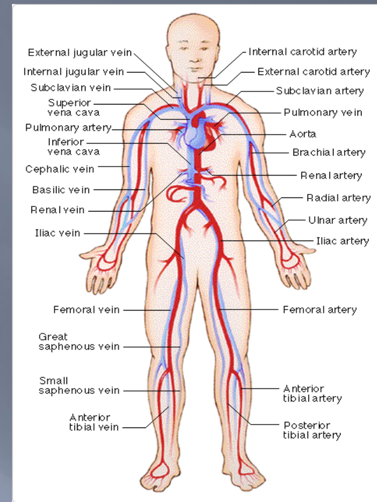
STATIC
FLUID DYNAMICS

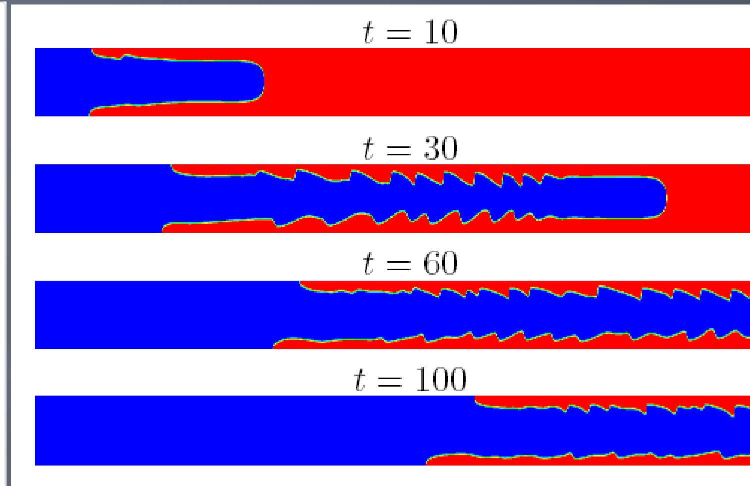
Lecture Plan

- **Introduction**

  (Definitions of fluid, Stresses, Types of fluids, Newton's law of viscosity, Laminar flow vs. Turbulent flow)

- **Where you find Fluids and Fluid-Dynamics?**
  - ✓ Blood flow in arteries and veins
  - ✓ Interfacial fluid dynamics
  - ✓ Geological fluid mechanics
  - ✓ The dynamics of ocean
  - ✓ Laminar-turbulent transition
  - ✓ Solidification of fluids





Vortex shedding off
back of Sorrocco Island

What is Fluid Mechanics?

Fluid + Mechanics

What is a Fluid?

- Substances with no strength
- Deform when forces are applied
- Include water and gases

Solid:

Deforms a fixed amount or breaks completely when a stress is applied on it.

Fluid:

Deforms continuously as long as any shear stress is applied.

What is Mechanics?

The study of motion and the forces which cause (or prevent) the motion.

Three types:

- **Kinematics (kinetics):** The description of motion: displacement, velocity and acceleration.
- **Statics:** The study of forces acting on the particles or bodies at rest.
- **Dynamics:** The study of forces acting on the particles and bodies in motion.

Type of Stresses?

Stress = Force / Area

- **Shear stress/Tangential stress:**

  The force acting parallel to the surface per unit area of the surface.

- **Normal stress:**

  A force acting perpendicular to the surface per unit area of the surface.

How Do We Study Fluid Mechanics?

Basic laws of physics:

- Conservation of mass
- Conservation of momentum – Newton's second law of motion
- Conservation of energy: First law of thermodynamics
- Second law of thermodynamics

+ Equation of state

Fluid properties e.g., density as a function of pressure and temperature.

+ Constitutive laws

Relationship between the stresses and the deformation of the material.

How Do We Study Fluid Mechanics?

Example: Density of an ideal gas

Ideal gas equation of state $PV = nRT$,

P: pressure (N/m^2), V: volume (m^3),

T: temperature (K), n: number of moles.

$$\rho = \frac{\text{mass}}{V} = \frac{nM}{V}$$

$$\Rightarrow \rho = \frac{pM}{RT}$$

Newton's law of viscosity: Stress α Strain (deformation)

$$\tau \; \alpha \; \frac{du}{dy} \Rightarrow \tau = \mu \frac{du}{dy}$$

μ: coefficient of viscosity (Dynamic viscosity)

Viscosity

It is define as the resistance of a fluid which is being deformed by the application of shear stress.

In everyday terms viscosity is "thickness". Thus, water is "thin" having a lower viscosity, while honey is "think" having a higher viscosity.

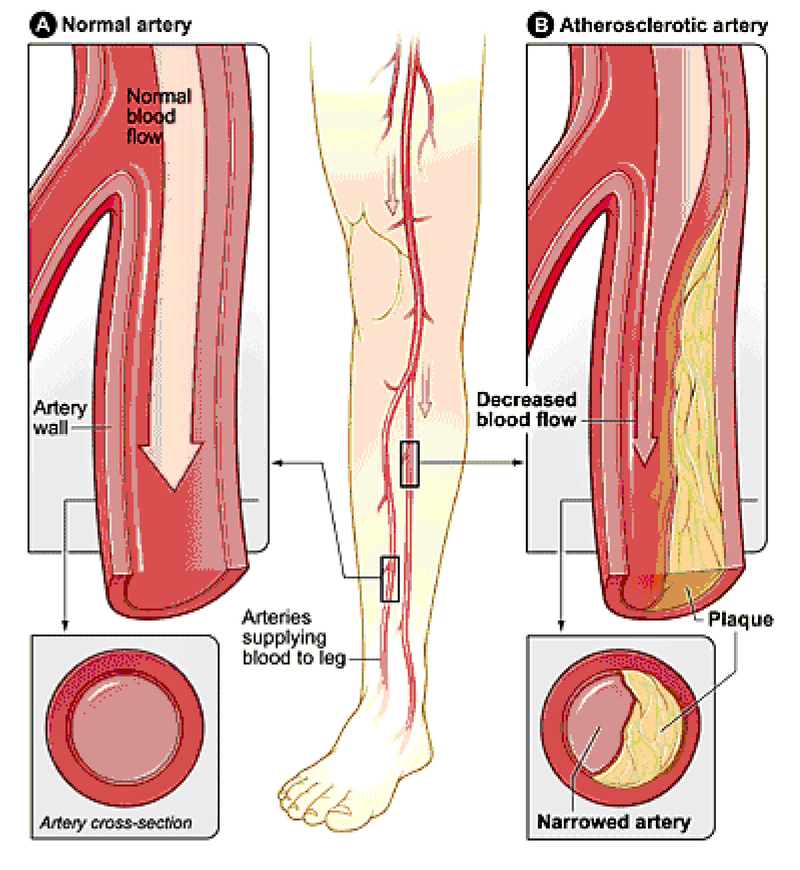
- ❑ Common fluids, e.g., water, air, mercury obey Newton's law of viscosity and are known as **Newtonian fluid**.
- ❑ Other classes of fluids, e.g., paints, polymer solution, blood do not obey the typical linear relationship of stress and strain. They are known as **non-Newtonian fluids.**

Unit of viscosity: Ns/m^2 (Pa.s)

Challenges in Fluid Mechanics

Blood Flow

- Very Complex
- Rheology of blood
- Walls are flexible
- Pressure-wave travels along the arteries.
- Frequently encounter bifurcation
- There are vary small veins

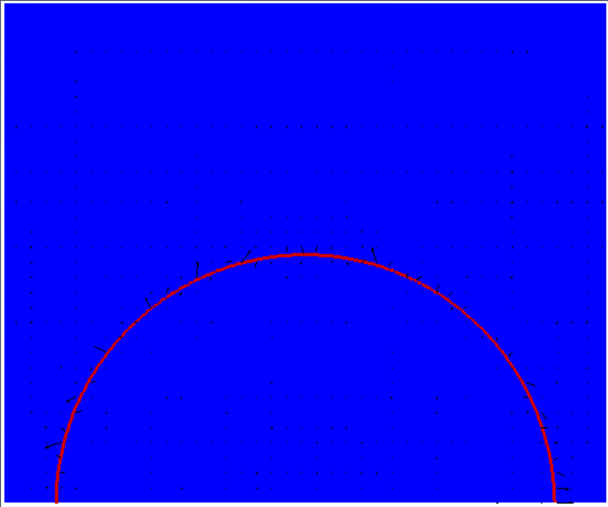


Interfacial Fluid Dynamics

- Frequently encounter
- Many complex phenomenon
  - ✓ Surface tension
  - ✓ Thermo-capillary flow
  - ✓ In industries: oil/gas
  - ✓ Hydrophobic nature

Challenges :

- Interfacial boundary condition.
- Numerical study becomes computationally very expensive.



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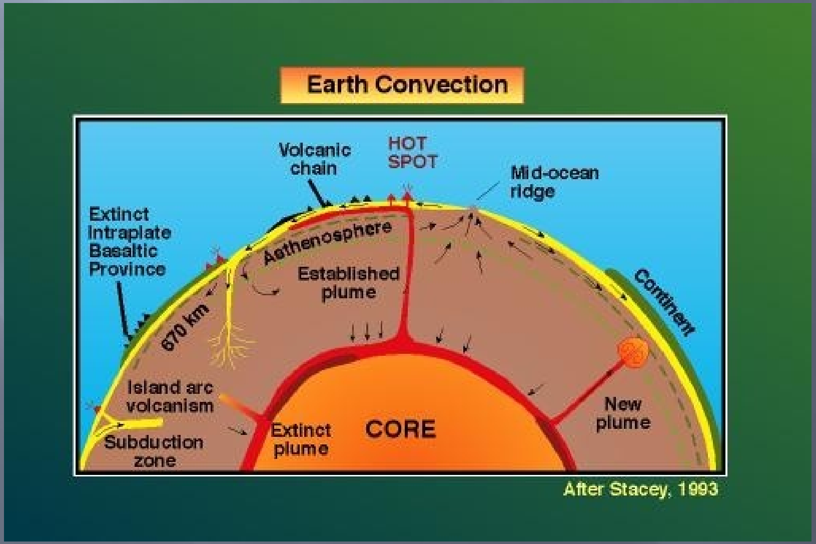
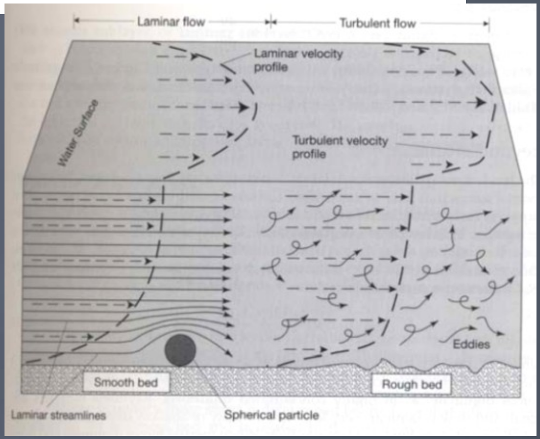
Geological Fluid Mechanics



Laminar-Turbulent Transition



- **Fluid flow: turbulent, laminar, or transitional state**

Aircraft engineers: need laminar air flow
Chemical engineers: need turbulent flow

- **Route to turbulence: different for different flows**

'Standard' route to turbulence:

$\mathrm{Re}\left(\equiv \frac{UL\rho}{\mu}\right)$ "Inertial force/Viscous force"

Laminar stable → **Laminar unstable** → **Nonlinear instability** → **Transition** → **Turbulent flow**

Laminar stable → Laminar unstable: Infinitesimal disturbance, Roughness, Entry effect etc.

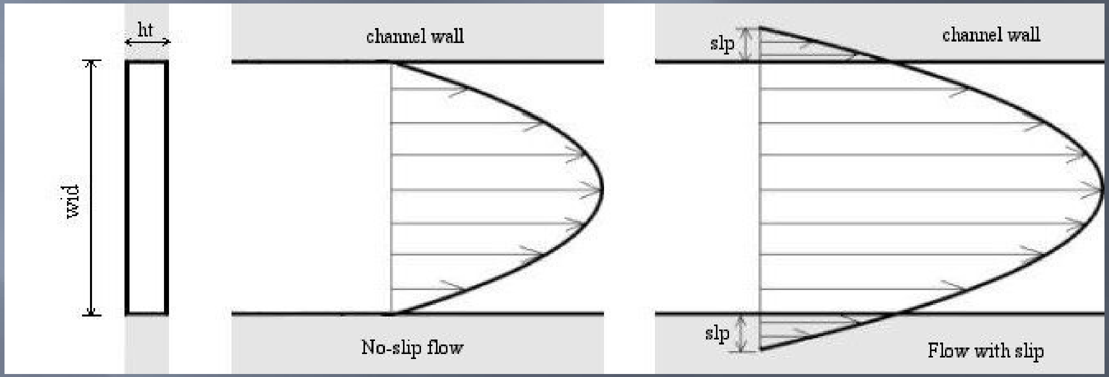
Laminar unstable → Nonlinear instability: Disturbances grow to finite amplitude

Linear stability analysis

Nonlinear analysis/
direct numerical simulation

Microfluidics

When a viscous fluid flows over a solid surface, the fluid elements adjacent to the surface attend the velocity of the surface. This phenomenon has been established through experimental observations and is known as “no-slip” condition.



Many research work have been conducted to understand the velocity slip at the wall, and has been continued to be an open topic of research.