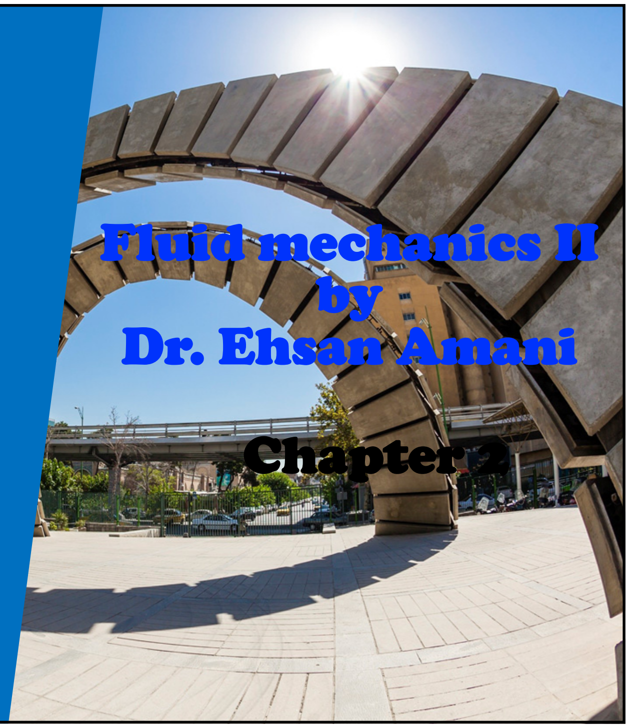


Fluid mechanics II
by
Dr. Ehsan Amani

Chapter 2

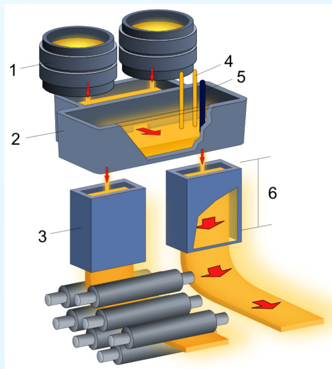
Fluid mechanics applications

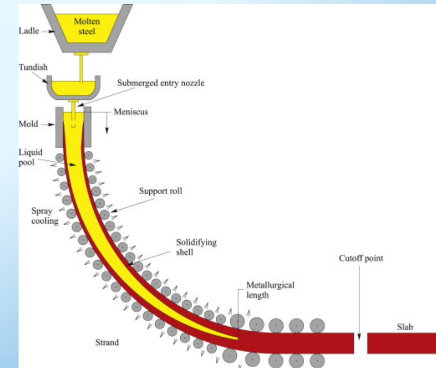
- Energy

Chapter 2 By E. Amani

Fluid mechanics applications

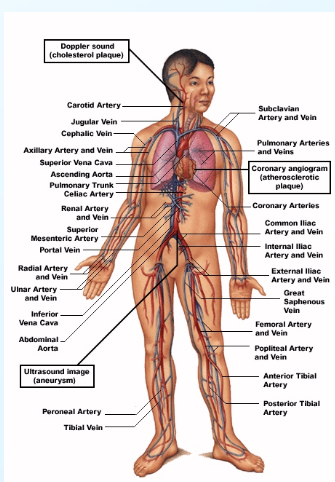
- **Energy**





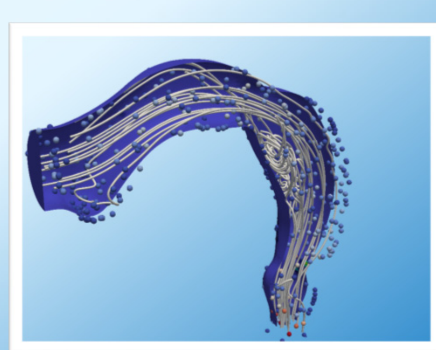
Fluid mechanics applications

- **Bioengineering**



Fluid mechanics applications

- **Bioengineering**



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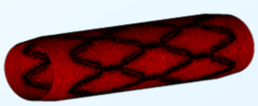
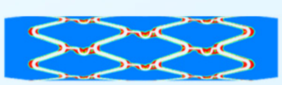
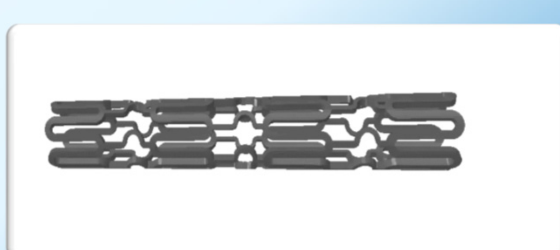
Fluid mechanics applications

- **Bioengineering**







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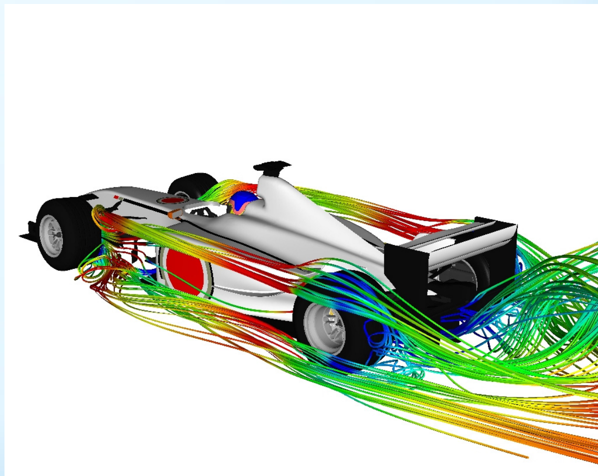
Fluid mechanics applications

- Aerodynamics



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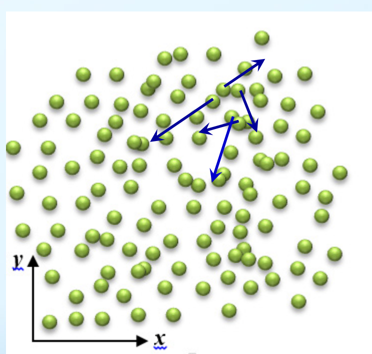
Different points of view

- Discrete particles mechanics
  - Lagrangian: Molecule particles



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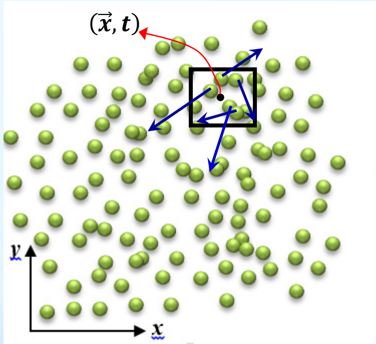
Different points of view

- **Discrete particles mechanics vs. continuum**



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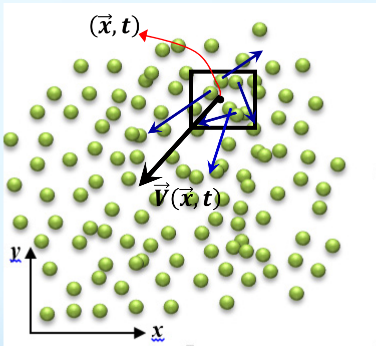
Different points of view

- **Discrete particles mechanics vs. continuum**



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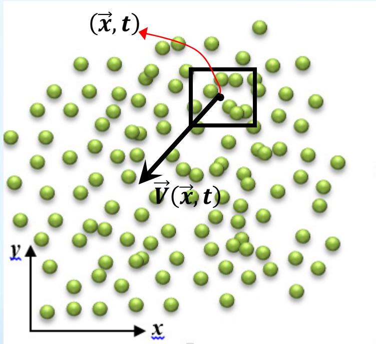
Different points of view

- Discrete particles mechanics vs. continuum



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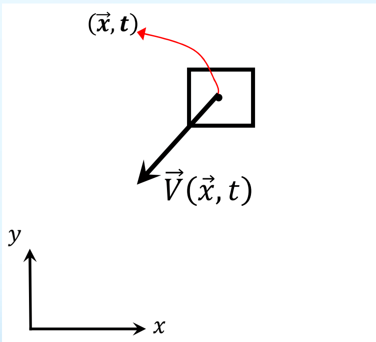
Different points of view

- Continuum mechanics



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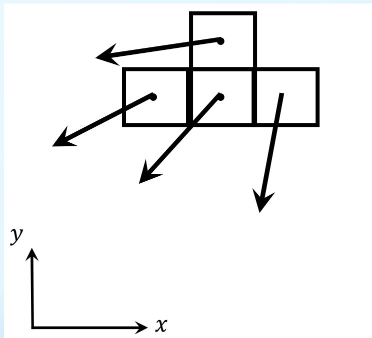
Different points of view

- Continuum mechanics



Velocity field

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

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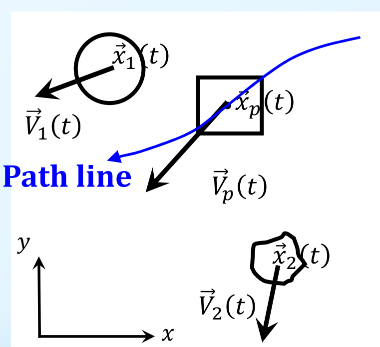
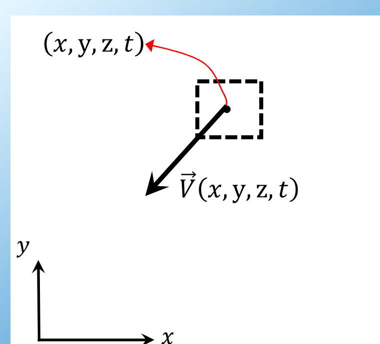
Different points of view

- Continuum mechanics
  - Eulerian: Fields of fluid properties $\vec{V}(x,y,z,t)$, $p(x,y,z,t)$, …
  - Lagrangian: Fluid particles (mass elements)





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Different points of view

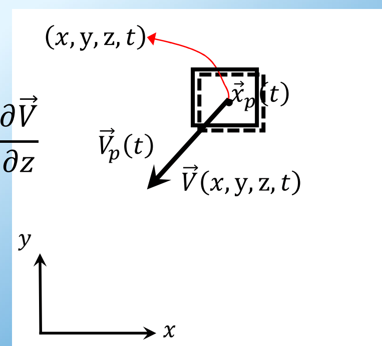
- **Continuum mechanics**
  - **Connection between Eulerian and Lagrangian view points**

$$\vec{V}_p(t) = \vec{V}\left(x = x_p, y = y_p, z = z_p, t\right)$$

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

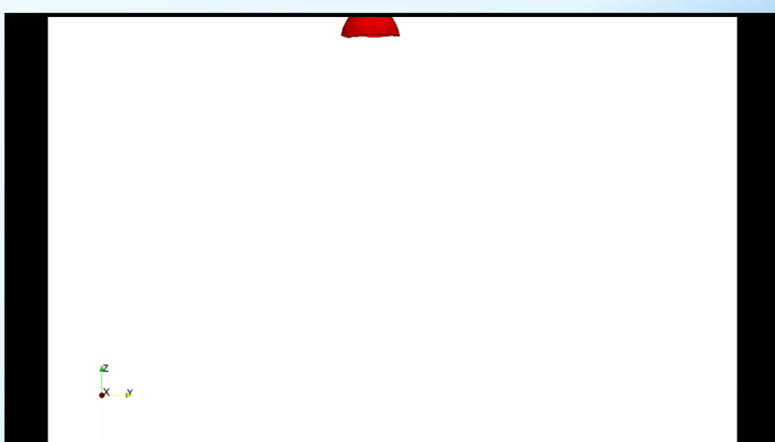
$$\equiv \frac{D\vec{V}}{Dt}$$

Material derivative



Different points of view

- **Continuum mechanics**
  - **Eulerian-Lagrangian: Multiphase flows**



Continuum mechanics

- **Primary variables**
  - **Velocity** $\vec{V}(x, y, z, t)$
  - **Pressure** $p(x, y, z, t)$
  - **Temperature** $T(x, y, z, t)$
  - …
- **Fluid properties**
  - **Viscosity** $\mu(x, y, z, t)$
  - **Surface tension coefficient** $\sigma(x, y, z, t)$
  - …

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Forces within a fluid

- **Body forces (per unit mass)**
  - **Gravity** $\vec{g}$
  - **Electromagnetic**
  - …
- **Surface force (per unit area: stress)**
  - **Viscous shear (and normal) stresses** $\tau_{xy}(x, y, z, t), \tau_{xz}(x, y, z, t), \ldots, \tau_{xx}(x, y, z, t), \ldots$
  - **Pressure** $p(x, y, z, t)$ **(normal stress)**
- **Line force (per unit length)**
  - **Surface tension** $\sigma(x, y, z, t)$

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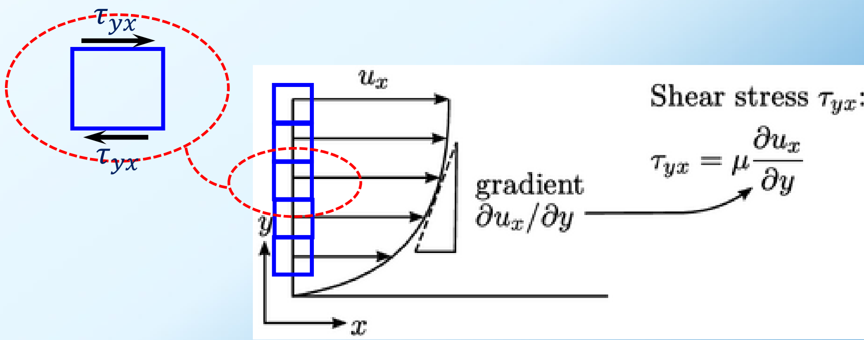
Forces within a fluid

- Stokes empirical law
  - Newtonian fluid
  - Parallel flow



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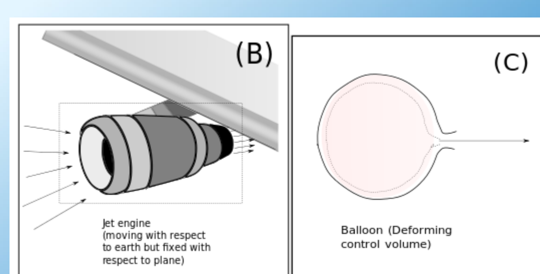
Basic principles of classical mechanics

Mass conservation
Momentum
Energy conservation
+
State equations

- Finite system (free-body diagram)
  - ✓ Control volume
  - ✓ Control mass



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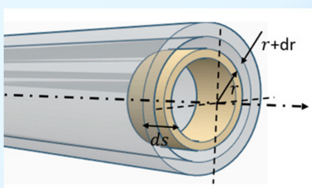
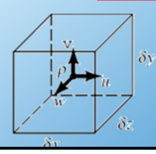
Basic principles of classical mechanics

Mass conservation
Momentum
Energy conservation
+
State equations

- **Finite system (free-body diagram)**
  - ✓ **Control volume**
  - ✓ **Control mass**
- **Differential system (element)**





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Basic principles of classical mechanics

- **Finite system (free-body diagram)**
  - ✓ **Control volume**
  - ✓ **Control mass**

→

- **Integral equations**
  - ✓ **Simplified to system of algebraic equations**

- **Differential system (element)**

→

- **Differential equations + Boundary conditions**

Chapter 2 By E. Amani

Basic principles of classical mechanics

- Integral equations
  - ✓ Simplified to system of algebraic equations

→

- Solution
  - ✓ Net force
  - ✓ Mean velocity
  - ✓ ...

- Differential equations + Boundary conditions

→

- Analytical or numerical solution
  - ✓ Velocity field
  - ✓ Pressure field
  - ✓ ...

→

- Post-processing
  - ✓ Net force
  - ✓ ...

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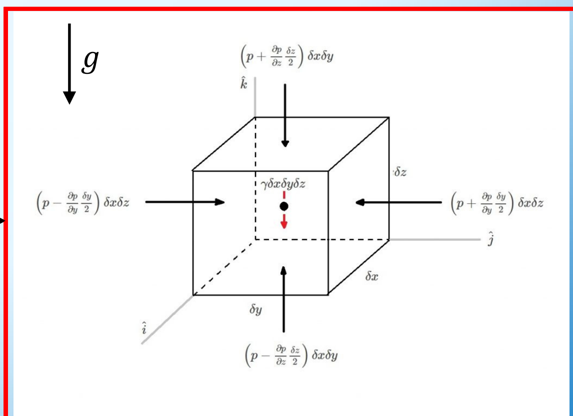
Example: Fluid statics

Momentum



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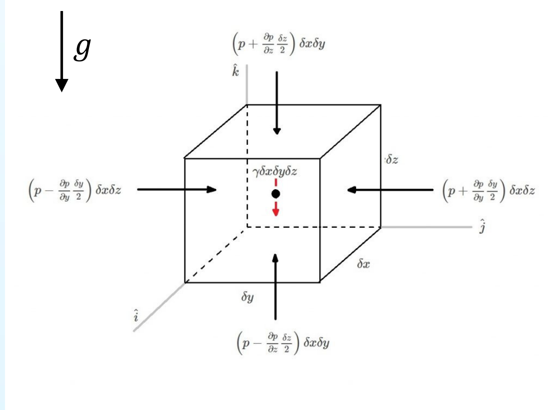
Basic principles of classical mechanics



$$\frac{\partial p}{\partial x} = 0$$
$$\frac{\partial p}{\partial y} = 0$$
$$\frac{\partial p}{\partial z} = -\gamma$$
$+$
$$p(z = z_{\text{ref}}) = p_{\text{ref}}$$

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Basic principles of classical mechanics

$$\frac{\partial p}{\partial x} = 0$$
$$\frac{\partial p}{\partial y} = 0$$
$$\frac{\partial p}{\partial z} = -\gamma$$
$+$
$$p(z = z_{\text{ref}}) = p_{\text{ref}}$$

→

- **Analytical solution**

$$p(x, y, z, t) = p(z) = p_{\text{ref}} - \gamma(z - z_{\text{ref}})$$

→

- **Post-processing**
  - ✓ **Net force on a flat surface**
  - ✓ **Net force on a curved surface**
  - ✓ **Buoyancy**
  - ✓ **...**

- **Exercise:** **Draw a similar flowchart for the Bernoulli equation**

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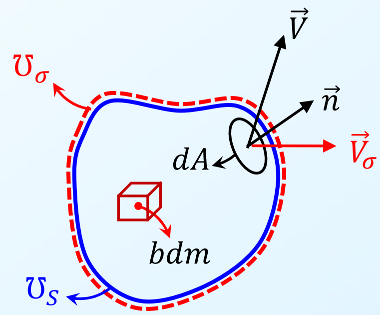
Reynolds transport theorems



$$B = \int_{\mho} \overbrace{bdm}^{\rho d\mho} \leftrightarrow b = \frac{dB}{dm}$$

$$\frac{DB_S}{Dt} = \frac{dB_\sigma}{dt} + \int_A \rho b(\vec{V} - \vec{V}_\sigma).\vec{n}dA$$

$$\underbrace{\frac{D}{Dt}\int_{\mho_S} \rho b d\mho}_{\text{Rate of change of } B \text{ in the system}} = \underbrace{\frac{d}{dt}\int_{\mho_\sigma} \rho b d\mho}_{\text{Rate of change of } B \text{ in the control volume}} + \underbrace{\overbrace{\int_A \rho b \underbrace{(\vec{V} - \vec{V}_\sigma)}_{\vec{V}_r}.\vec{n}dA}^{\sum_{\text{out}} \dot{m}b - \sum_{\text{in}} \dot{m}b}}_{\text{Net outflow of } B \text{ from the control surface}}$$

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Reynolds transport theorems

- **Example: Mass conservation**

$$B = m \leftrightarrow b = \frac{dm}{dm} = 1$$

$$0 = \frac{DB_S}{Dt} = \frac{d}{dt}\int_{\mho_\sigma} \rho 1 d\mho + \int_A \rho 1(\vec{V} - \vec{V}_\sigma).\vec{n}dA$$

$$\frac{d}{dt}\int_{\mho_\sigma} \rho d\mho + \int_A \rho(\vec{V} - \vec{V}_\sigma).\vec{n}dA = 0$$

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The end of chapter 2