Spring, 2022

ME 597 – Solid Mechanics II

Lecture 22
Fluid-solid interactions

PURDUE UNIVERSITY | Mechanical Engineering

Instructor: Prof. Marcial Gonzalez

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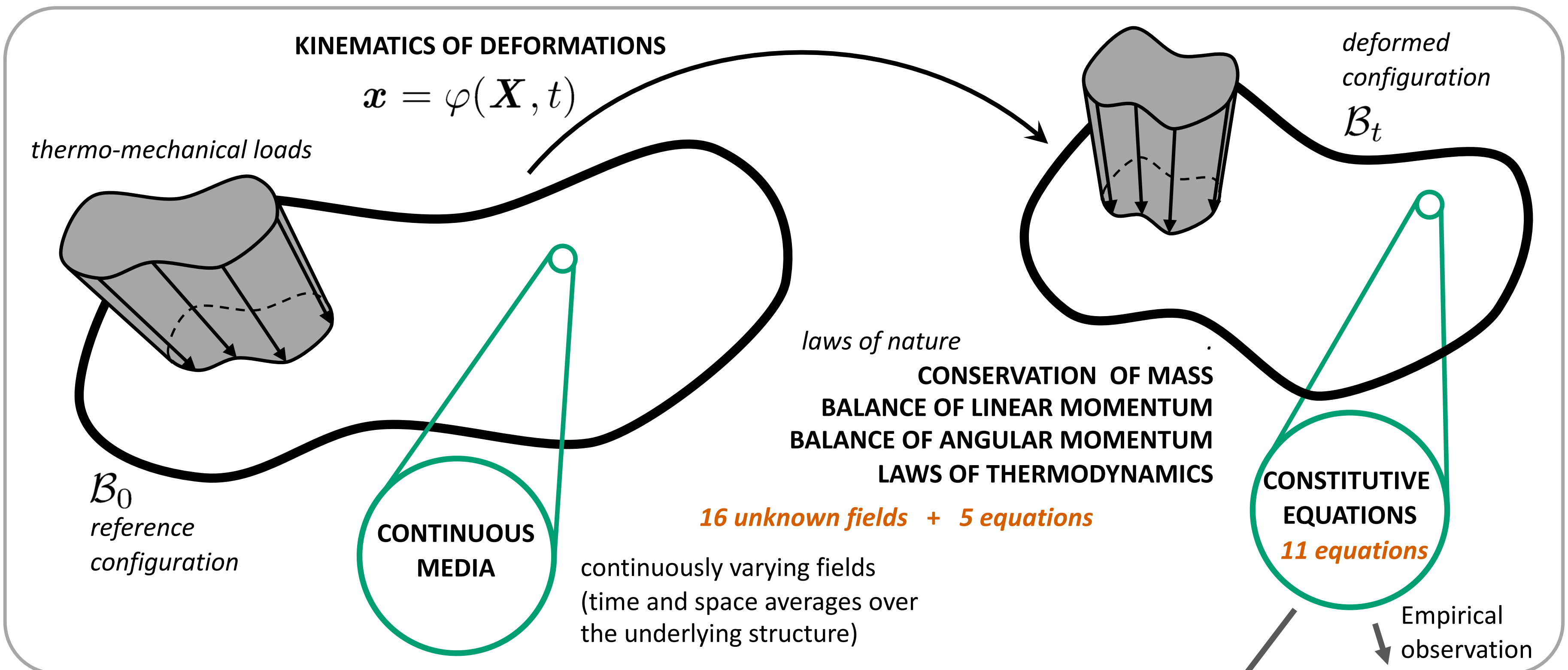
ME 597 – Solid Mechanics II … so far …



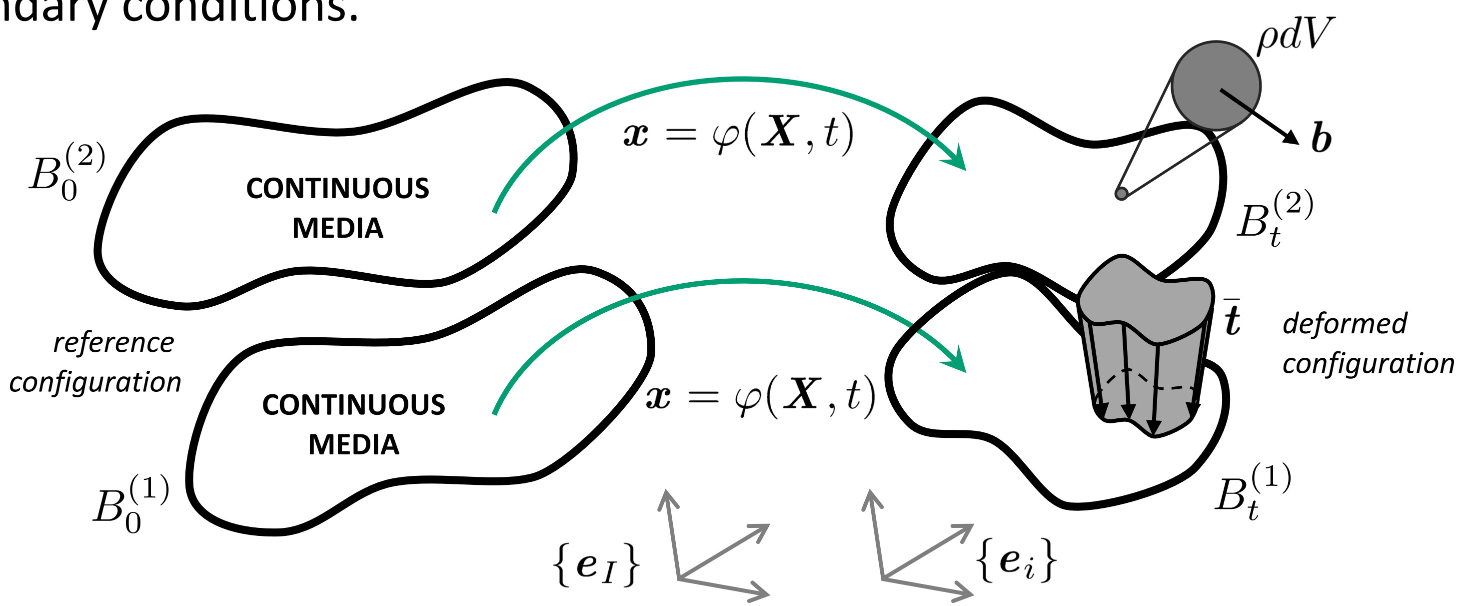
Tensor algebra
Tensor analysis

Hyperelastic isotropic solids ✓
Viscoelastic isotropic solids ✓
Plastic isotropic solids ✓

Material parameter estimation ✓

Lecture 22 – Solid-solid interactions …

Formulation of **solid-solid interactions (contact mechanics)** as the analytical upscaling of continuum solids under kinematic assumptions and specific boundary conditions.



- Unilateral contact law in continuum mechanics (normal direction)

Hertz-Signorini conditions

$g(\partial B_t^{(1)}, \partial B_t^{(2)}) \geq 0$ no penetration (gap function)

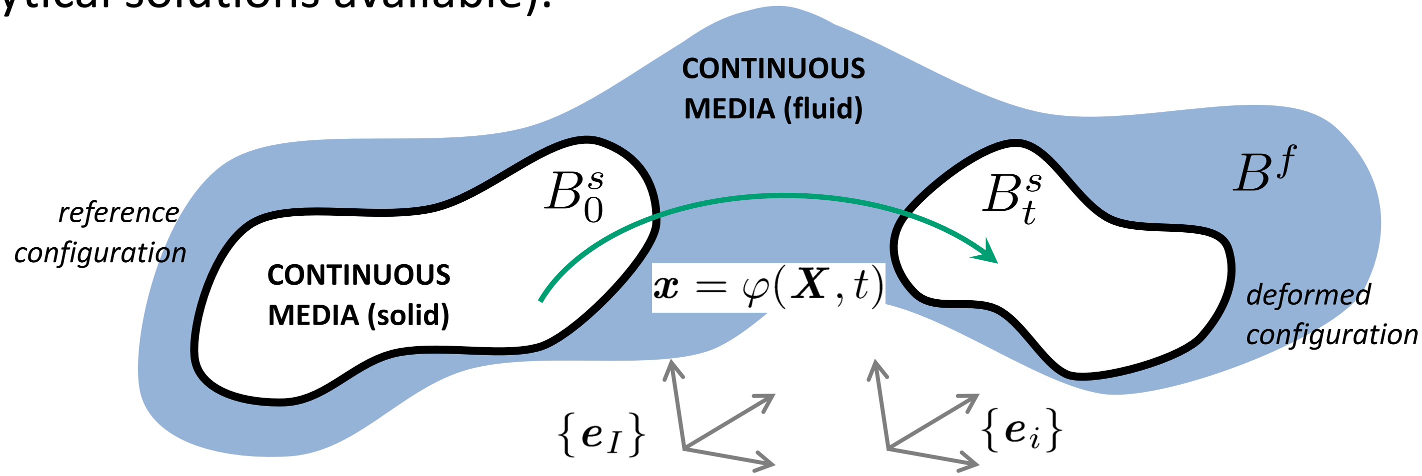
$p(\partial B_t^{(1)}) \leq 0$ no tension (contact pressure)

$g(\partial B_t^{(1)}, \partial B_t^{(2)}) p(\partial B_t^{(1)}) = 0$ complementary conditions

- Friction law (tangential direction)

Lecture 22 – … and fluid-solid interactions

Formulation of **fluid-solid interactions or fluid-structure interactions (FSI)** have well-defined kinematic and equilibrium compatibility conditions at the fluid-solid interface, but their implementation is very difficult (very few analytical solutions available).



- The coupling conditions are the equilibrium and kinematic compatibilities at the fluid–structure interface $\partial B^f \cap \partial B_t^s$

$$\boldsymbol{\sigma}^f \cdot \boldsymbol{n}^f = \boldsymbol{\sigma}^s \cdot \boldsymbol{n}^s \qquad \text{equilibrium compatibility}$$

$$\boldsymbol{v}^f = \boldsymbol{v}^s \qquad \text{kinematic compatibility}$$

Lecture 22 – Fluid-solid interactions

Formulation of **fluid-solid interactions or fluid-structure interactions (FSI)** have well-defined kinematic and equilibrium compatibility conditions at the fluid-solid interface, but their implementation is very difficult.

- Very few analytical solutions available, using significant simplifying assumptions (this is in sharp contrast to contact mechanics).
- Otherwise, complex numerical formulations are used (e.g., ALE methods, that is arbitrary Lagrangian-Eulerian methods).

Fields of study within engineering:

- Tribology, bearings (*lubrication, friction and wear*).
- Porous media and poroelasticity.
- Particulate flow.
- Acoustic-structure interaction (structures: shells and plates).
- … and many more areas of application.

Lecture 22 – Fluid-solid interactions

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A stabilized assumed deformation gradient finite element formulation for strongly coupled poromechanical simulations at finite strain

WaiChing Sun[1,*,†], Jakob T. Ostien[1] and Andrew G. Salinger[2]

[1]*Mechanics of Materials, Sandia National Laboratories, 7011 East Avenue, Livermore, CA, U.S.A.*
[2]*Numerical Analysis and Application, Sandia National Laboratories, PO Box 5800, Albuquerque, NM, U.S.A.*

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Lecture 22 – Fluid-solid interactions

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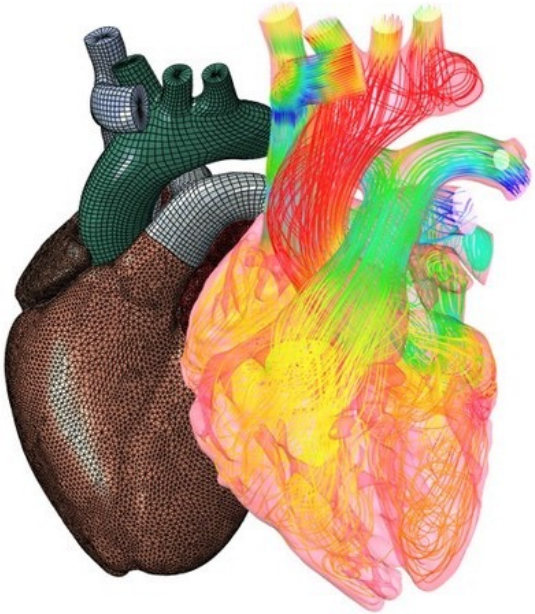
In general, challenges are in coupling fluid flow with structural deformation in solids. Two approaches and countless different implementations:

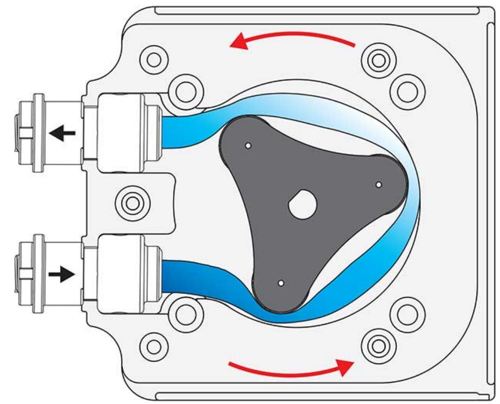
- One-way coupling
- Two-way coupling (e.g., peristaltic pump, air flow around solar panel or airplane wing, stirred mixing vessel, cardiovascular modeling)

Lecture 22 – Fluid-solid interactions

cardiovascular modeling



peristaltic pump



air flow around an airplane wing

talking about large (elastic) deformation

Fluid-solid interactions and FSI

Any questions?