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solids4foam-v2.1: A toolbox for performing solid mechanics and fluid-solid interaction simulations in OpenFOAM

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Summary

`solids4foam` is a toolbox designed for conducting solid mechanics and fluid-solid interaction simulations within the widely-used OpenFOAM software (ESI-OpenCFD, 2024; foam-extend, 2024; Foundation, 2024). The toolbox has a comprehensive set of features, including advanced algorithms for fluid-solid and thermo-fluid-solid coupling, a variety of solid material models, non-trivial solid boundary conditions, and numerous discretisation and solution methods for solid mechanics.

Statement of Need

The `solids4foam` toolbox addresses four primary needs within the OpenFOAM community:

1. The need to perform fluid-solid interactions using OpenFOAM.
2. The need to solve complex solid mechanics problems directly within OpenFOAM.
3. The necessity for a modular approach to coupling various solid and fluid processes in OpenFOAM.
4. The demand for an extendable framework to facilitate research into innovative finite volume methods for solid mechanics.

The design of `solids4foam` adheres to four guiding principles:

1. **Usability:** If you can use OpenFOAM, you can use `solids4foam`.
2. **Compatibility:** Supports the three main OpenFOAM forks: OpenFOAM.com, OpenFOAM.org, and foam-extend.
3. **Ease of Installation:** The toolbox is easy to install and requires minimal additional dependencies beyond OpenFOAM.
4. **Code Quality:** Emphasis on code design and style, closely following the OpenFOAM coding style guide.

Features

`solids4foam` employs a modular design, offering generic class interfaces for solid mechanics, fluid dynamics, fluid-solid coupling methods, and solid material models. It also supports all native OpenFOAM modularity, including boundary conditions and function objects.

The `solids4foam-v2.1` release includes the following features:

Partitioned Fluid-Solid Interaction Coupling Methods

- Fixed under-relaxation (Tuković, Karač, et al., 2018)
- Aitkens accelerated under-relaxation (Tuković, Karač, et al., 2018)
- Interface-quasi-Newton coupling (Degroote J, 2009)
- Robin-Neumann coupling (Tuković, Bukač, et al., 2018)
- Thermo-fluid-solid interaction coupling

Finite Volume Solid Model Discretizations and Solution Algorithms

- Segregated (Cardiff et al., 2018), coupled (Cardiff, Tuković, Jasak, et al., 2016), and explicit solution algorithms
- Linear geometry (small strain) and nonlinear geometry (finite strain) formulations, including total and updated Lagrangian
- Cell-centered and vertex-centered formulations
- Continuum and plate formulations

Solid Material Models

- Linear elasticity (isotropic, orthotropic (Cardiff et al., 2014)), plasticity (J_2 (Cardiff, Tuković, De Jaeger, et al., 2016), Mohr-Coulomb (Tang et al., 2015)), viscoelasticity (Cardiff et al., 2018), thermo-elasticity (Cardiff et al., 2018), poroelasticity (Tang et al., 2015)
- Hyperelasticity (neo-Hookean, Ogden, Mooney-Rivlin (Oliveira et al., 2022, 2023), Fung (Oliveira et al., 2022, 2023), Yeoh (Oliveira et al., 2022, 2023)), hyperelastoplasticity (Cardiff, Tuković, De Jaeger, et al., 2016)
- Interface to Abaqus material model subroutines (UMATs)

Solid Boundary Conditions

- Frictional contact (node-to-segment (Cardiff et al., 2012; Cardiff, Tuković, De Jaeger, et al., 2016), segment-to-segment (Batistić et al., 2022; **?**))
- Cohesive zone models
- Traction, displacement, rotation

Fluid Models

- Incompressible (PIMPLE, PIMPLE-overset)
- Multiphase (volume-of-fluid)
- Weakly compressible (Oliveira et al., 2022)

Function Objects

- Energies, displacements, forces, stresses, principal stresses, torques

Utilities and Scripts

- Scripts for ensuring compatibility with the main OpenFOAM forks
- Mesh conversion utilities: OpenFOAM to/from Abaqus

Tutorials

- A suite of example cases and benchmark problems to demonstrate functionality and verify performance

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