An open source non-Newtonian FSI solver implementation

Multiphysics applications at GSC-CE and Numerical Analysis and Mathematical Modeling at FNB

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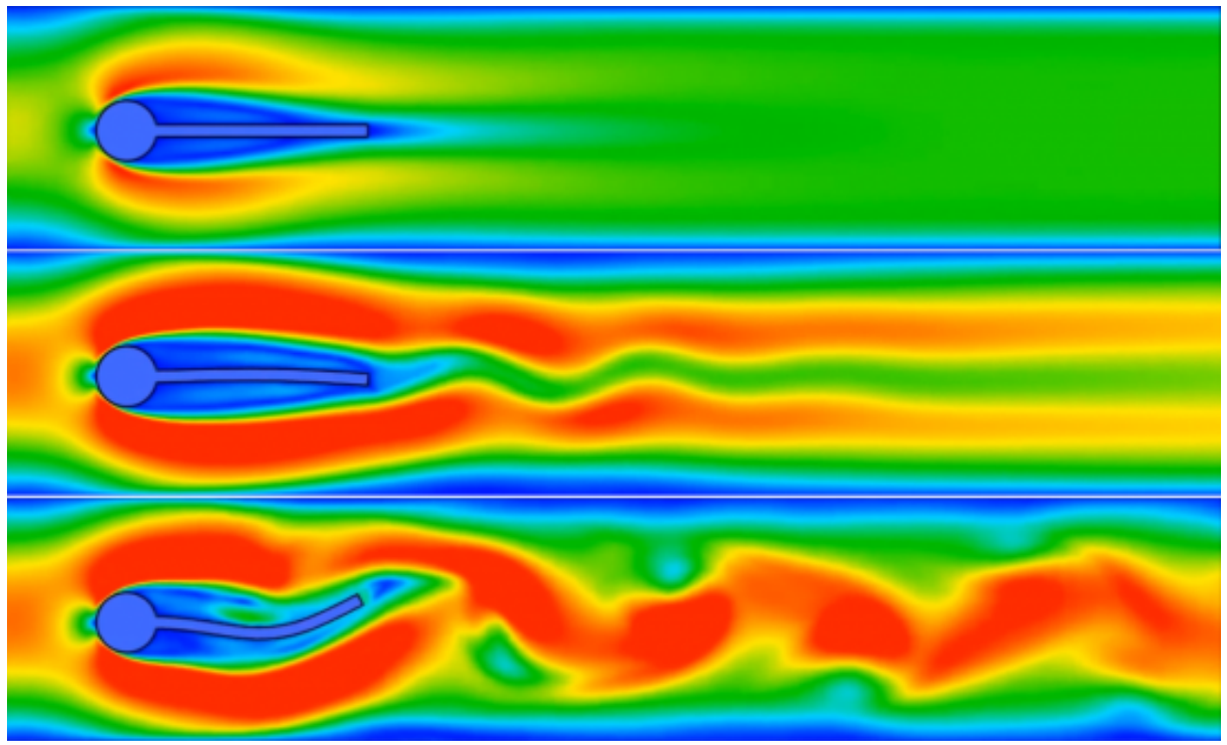

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Motivation

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- **A tool**: This work is part of a bigger research project
- **Goal**: Create a non-Newtonian Fluid Structure Interaction (nNFSI) solver
- **Means**: Based on an existing Newtonian FSI (NFSI) solver taking in consideration the principle of reusability of software
- **Challenges**: Lacking of a benchmarking papers and difficult numerical convergence
- **Related work**: Mostly with focus on NFSI solver
- **Contribution**: The whole scientific community can now use an open-source nNFSI solver that is free to use, distribute and modify

Implementation

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- The base code is the FSI-toolkit developed for foam-extended-3.1 [Tukovic - 2014]
- **Shift of paradigm**: The FSI treats the flow and the structure solvers as classes that constitute the FSI library and not as executables, as usually happens in OpenFOAM.
- Two new classes were created
  - nonNewtonianIcoFlow
  - nonNewtonianConsistentIcoFlow

Implementation

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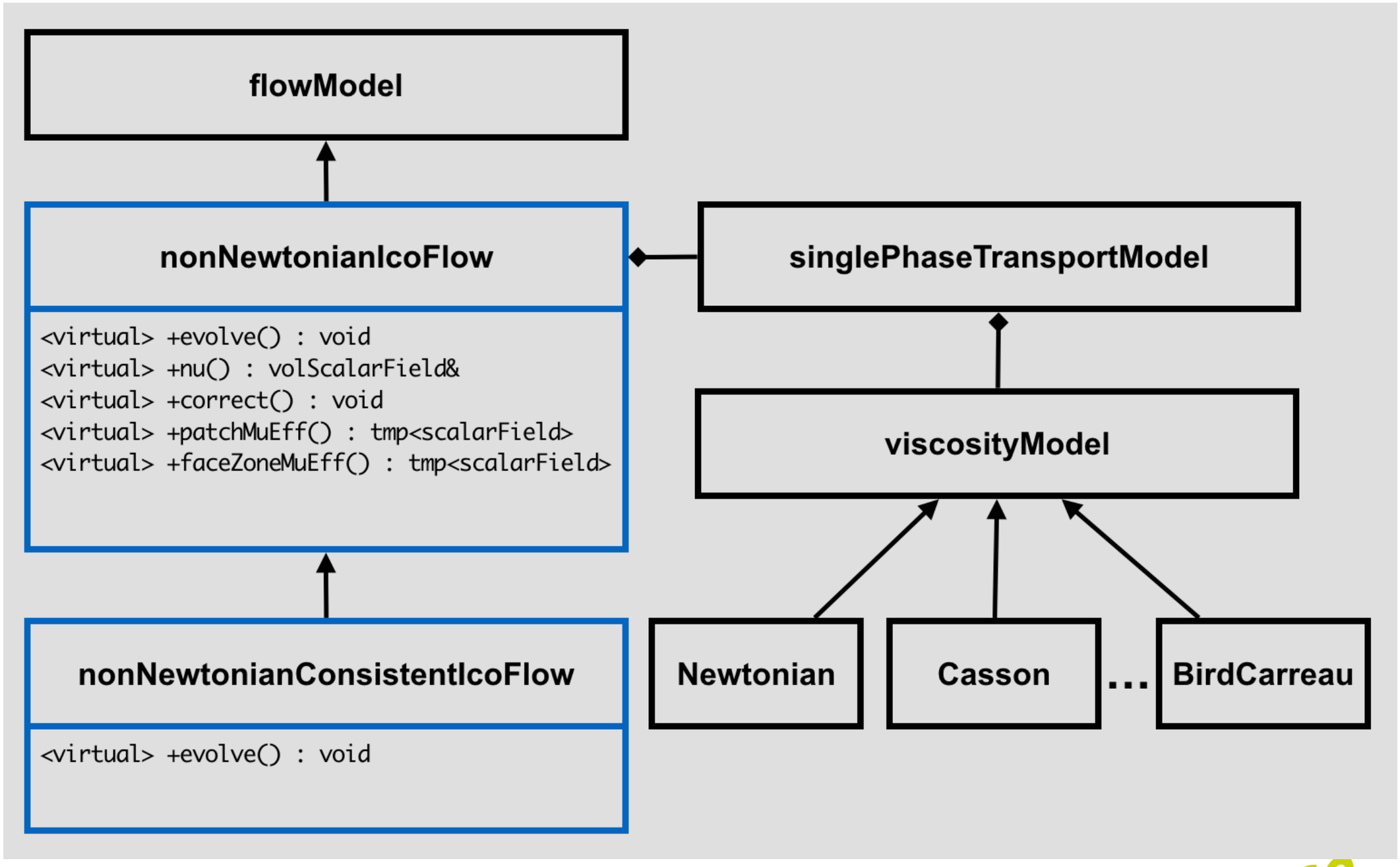

Verification

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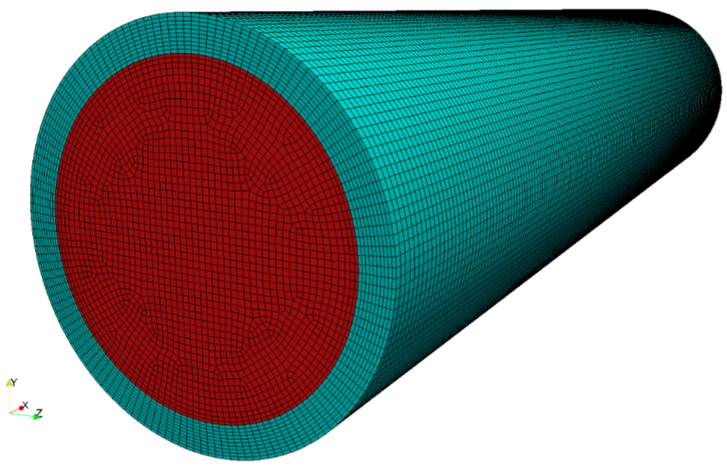
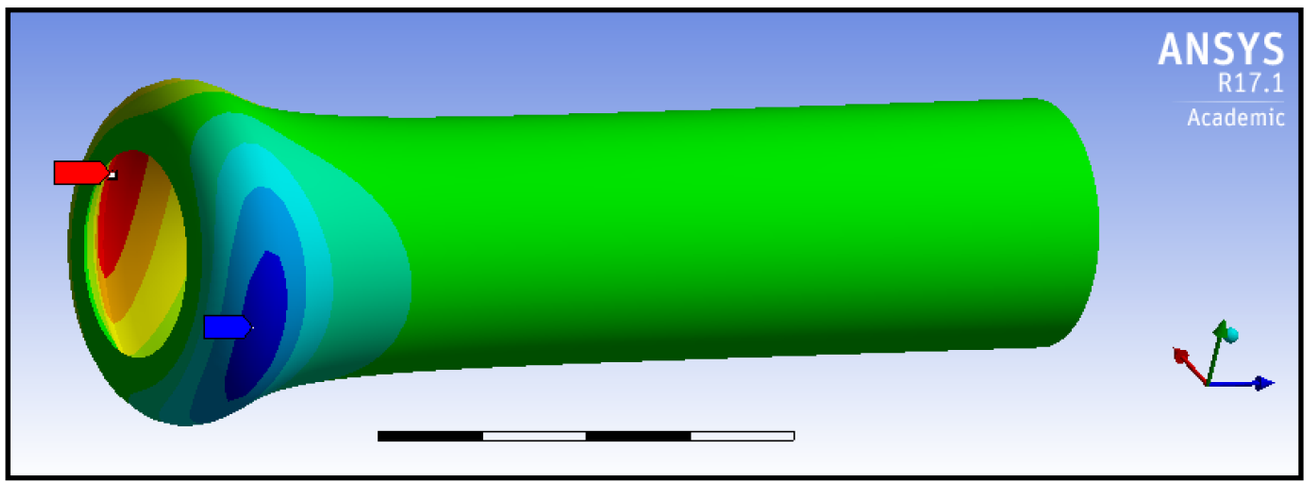
- The NFSI(**base solver**) was verified with well known benchmarks FSI [Tukovic - 2014]
- Simulation
- Classical pulse-in-vessel case, but with non-Newtonian fluid
- Very unstable
- During the first 0.003s, a uniform overpressure of 1333.2 N/m2 is applied at the inlet.
- The same simulation run both using OpenFOAM and ANSYS



a) The mesh



b) Deformed domain

Continuous model

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- Fluid Model:
  - Transient and Isothermal
  - Shape of the domain is time-dependent ⇒ ALE ⇒ GCL
  - Incompressible and non-Newtonian
  - Based on mass and momentums conservation equations

- Solid Model:
  - Transient and Isothermal
  - Hyperelastic material
  - Based on momentums conservation equations

ALE: Arbitrary Lagrangian-Eulerian [Erwin Stein - 2004]
GCL: Geometrical Conservation Law [Demirdzic - 1987]

Numerical model

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- Fluid and Solid models
  - FVM - Unstructured grid
  - Fluid mesh deformation governed by Laplacian mesh motion equation
  - PISO and GAMG for fluid
  - PCG for solid
  - Colocated grid for fluid using Rhie-Chow
  - Backward time integration (2nd order and three time levels)

FVM: Finite Volume Method
PISO: Pressure Implicit with Splitting of Operator
GAMG: Generalised geometric-Algebraic Multi-Grid
PCG: Preconditioned Conjugate Gradient

Numerical model

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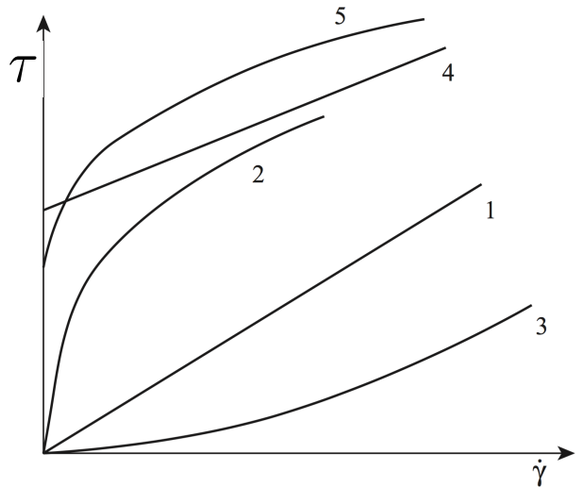
- FSI model
  - Partitioned, Strongly and Implicit coupling
  - Decomposed using Dirichlet-Neuman
  - Fluid solver uses displacement of the FSI
  - Solid solver uses pressure force on the interface
  - Coupling scheme is the IQN-ILS

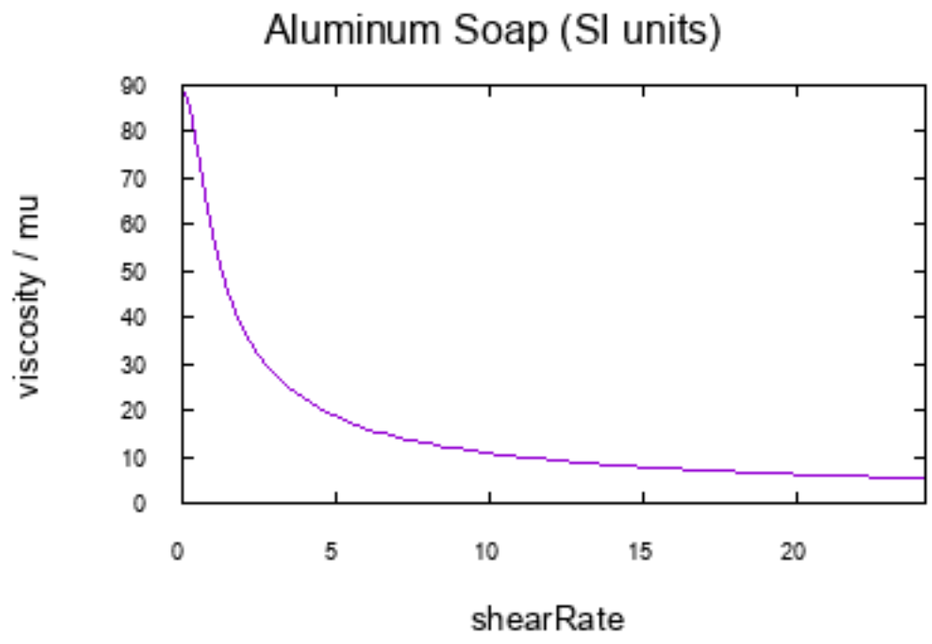
IQN-ILS: interface quasi-Newton technique with an approximation for the inverse of the Jacobian from a least-squares model [Degroote - 2010]

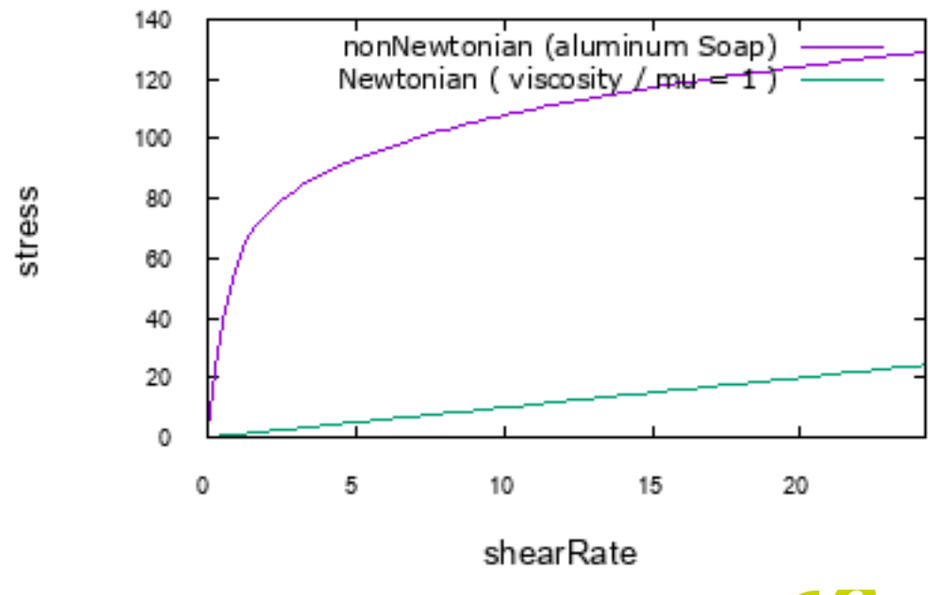
Results

$$\tau = \mu(\dot{\gamma})\dot{\gamma}$$

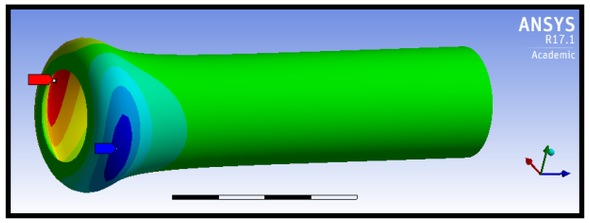


1 - Newtonian : Water
2 - Shear thinning : Silicone coatings
3 - Shear thickening : Corn starch in water
4 - Bingham plastic : Toothpaste
5 - Bingham pseudoplastic : Paints





Results



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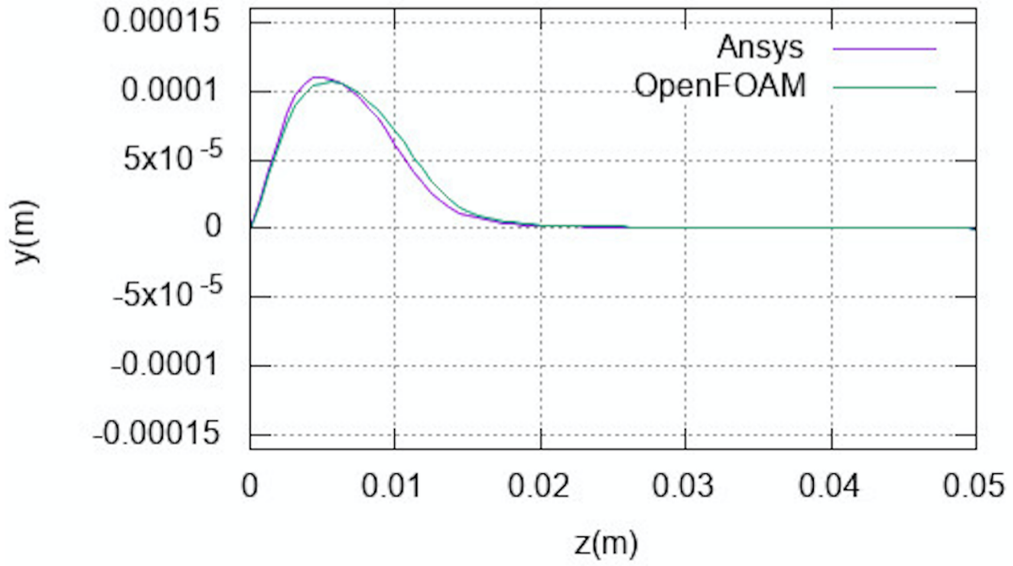
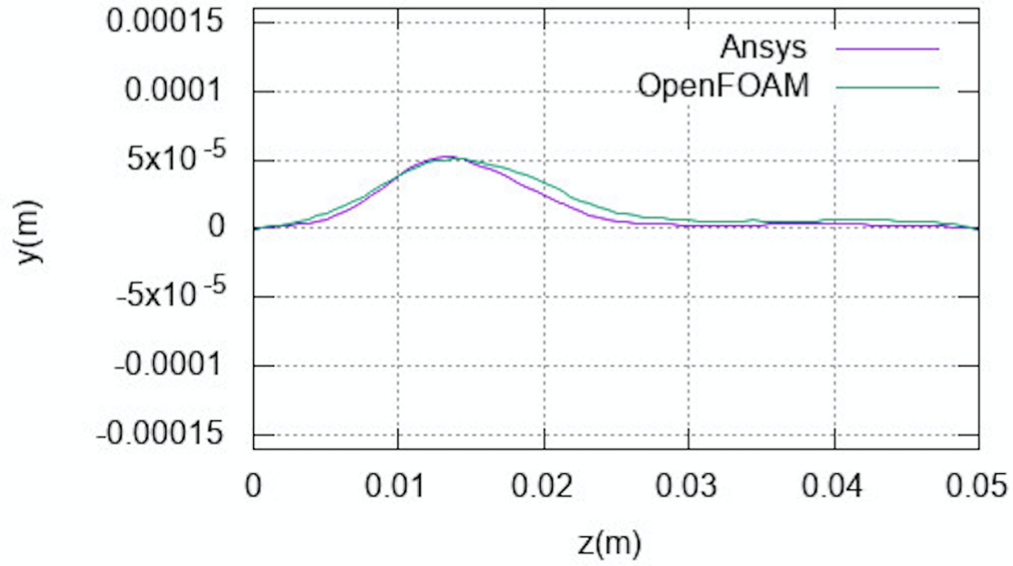
Aluminum soap and Hyperelastic

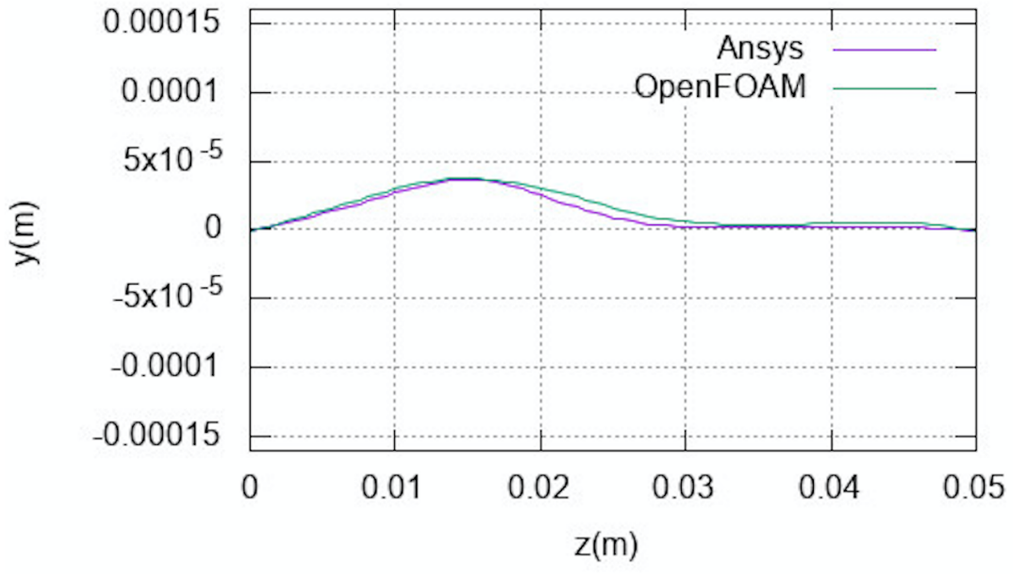
Time = 0.003s



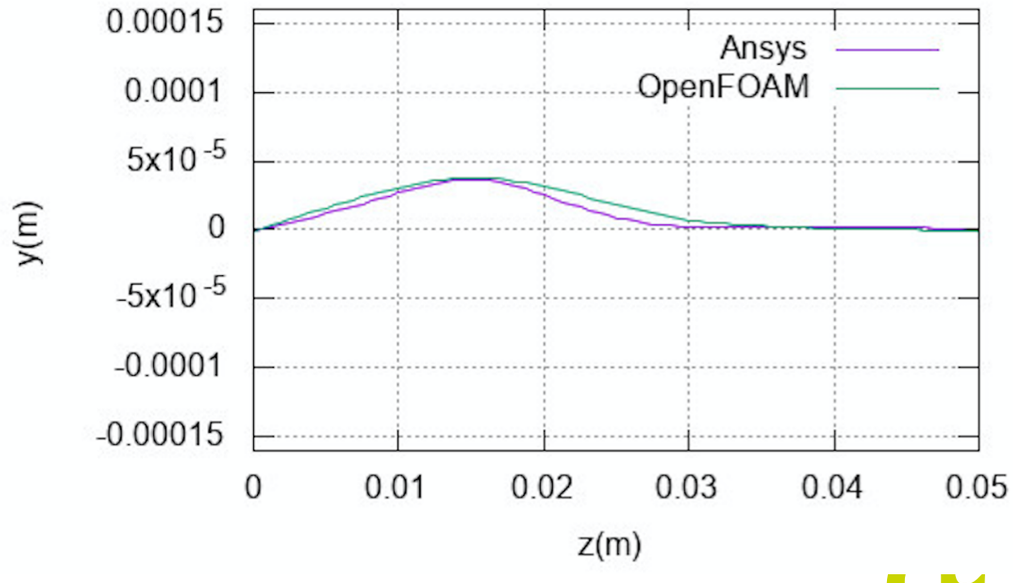
Time = 0.006s



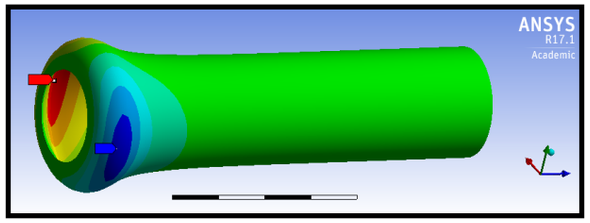
Time = 0.009s



Time = 0.012s



Results



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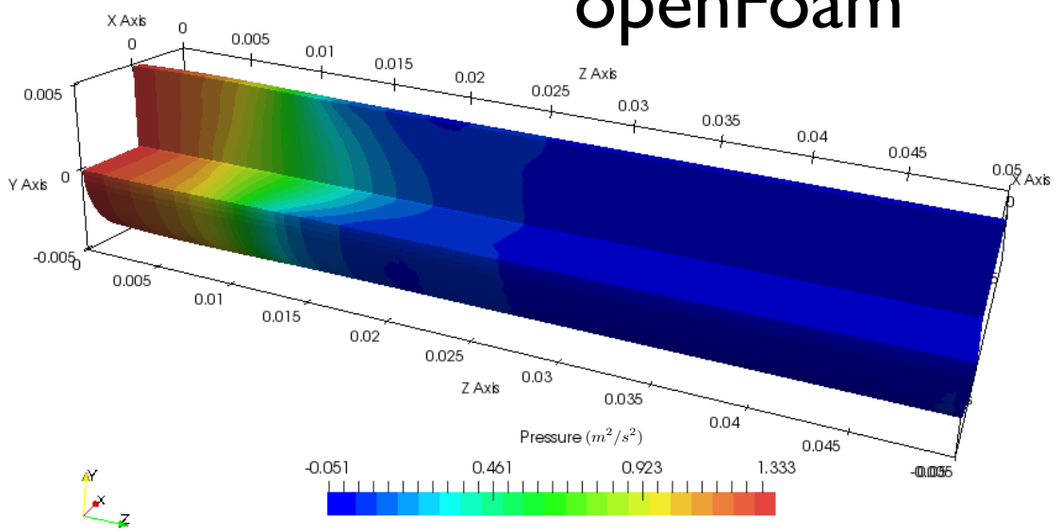
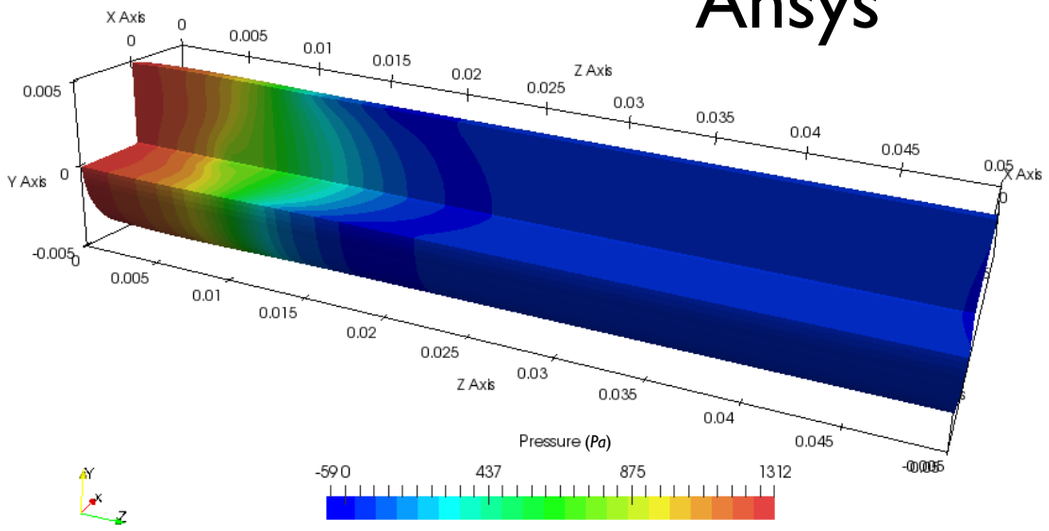
Pressure field

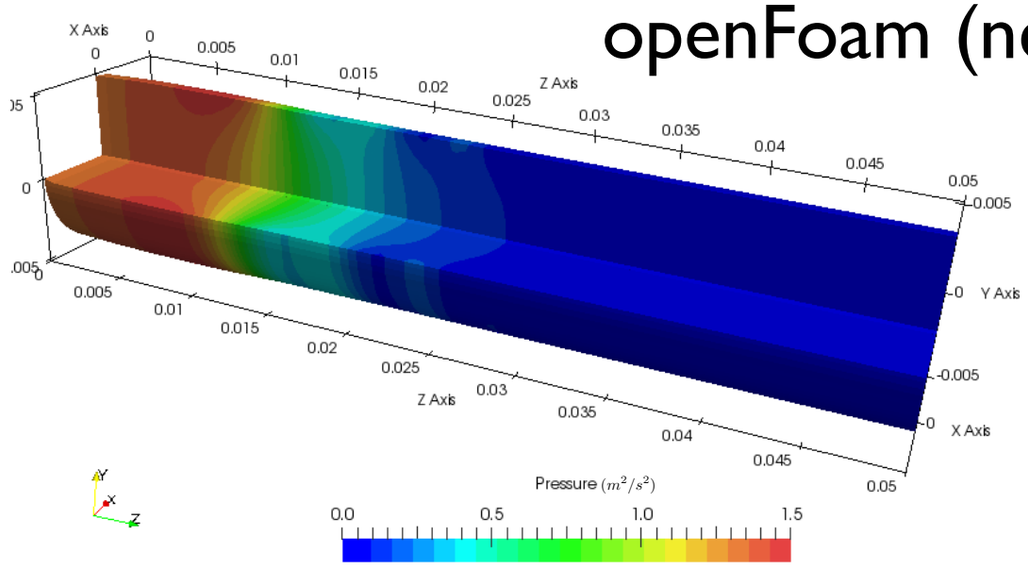
openFoam



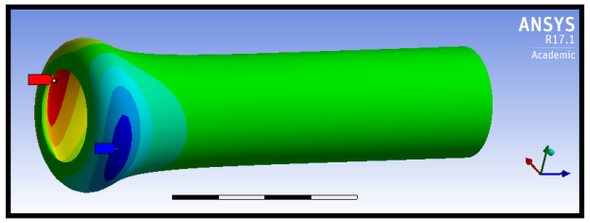
Ansys



openFoam (newtonian)



Results



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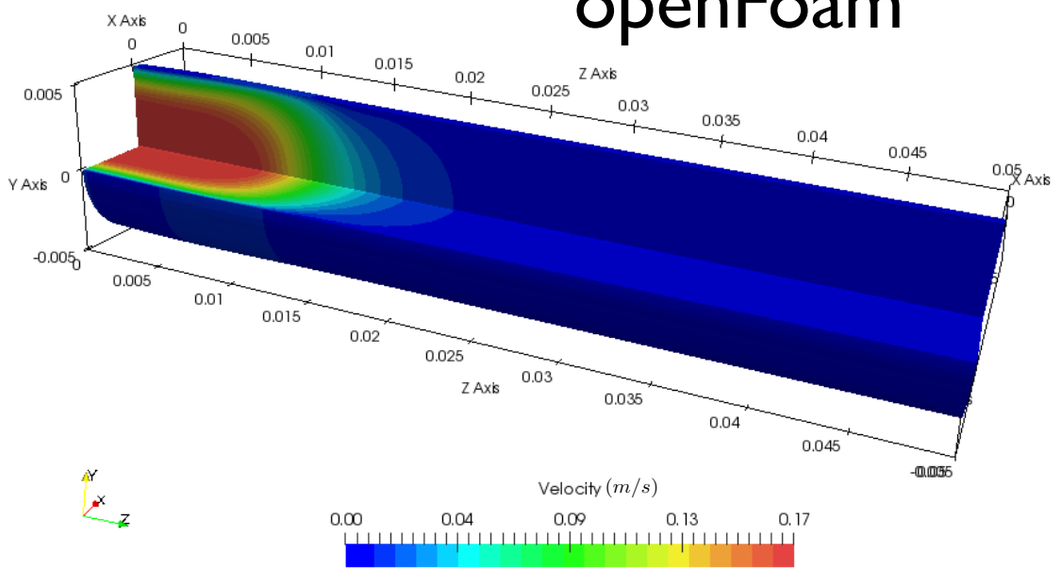
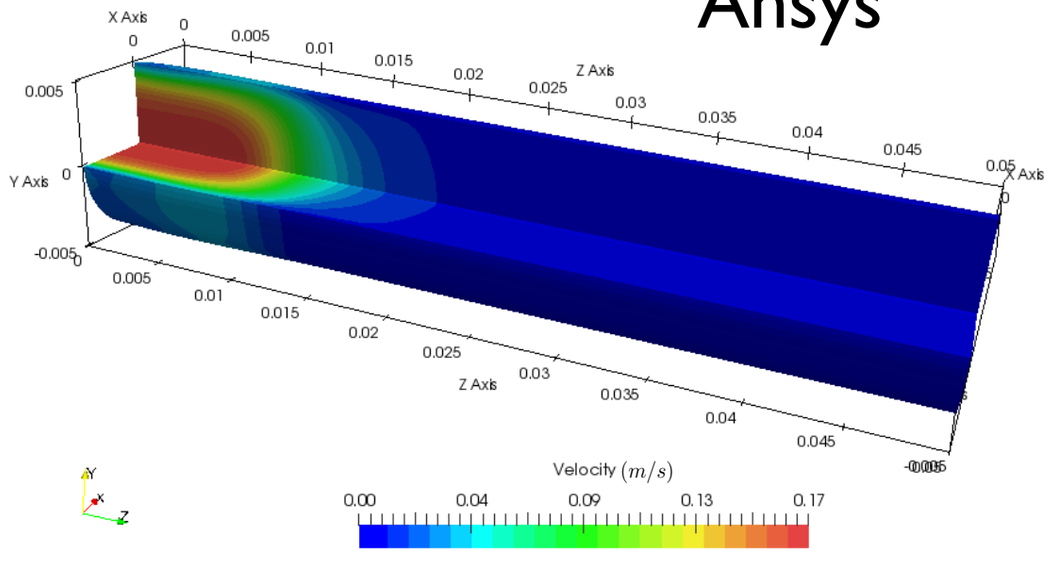
Axial velocity field

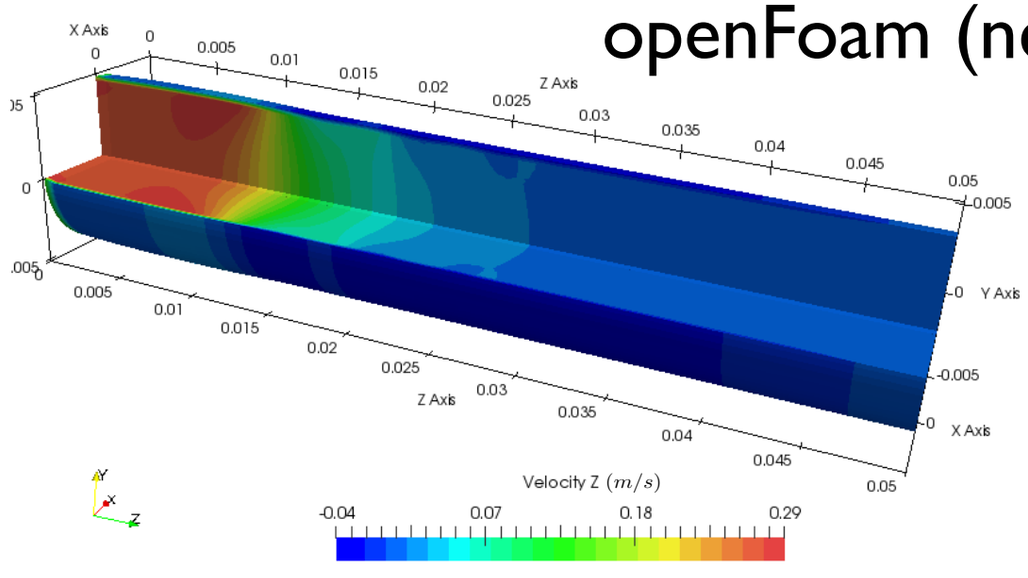
openFoam



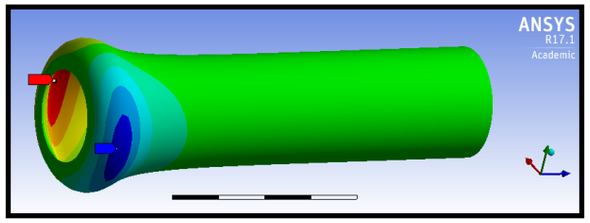
Ansys



openFoam (newtonian)



Results



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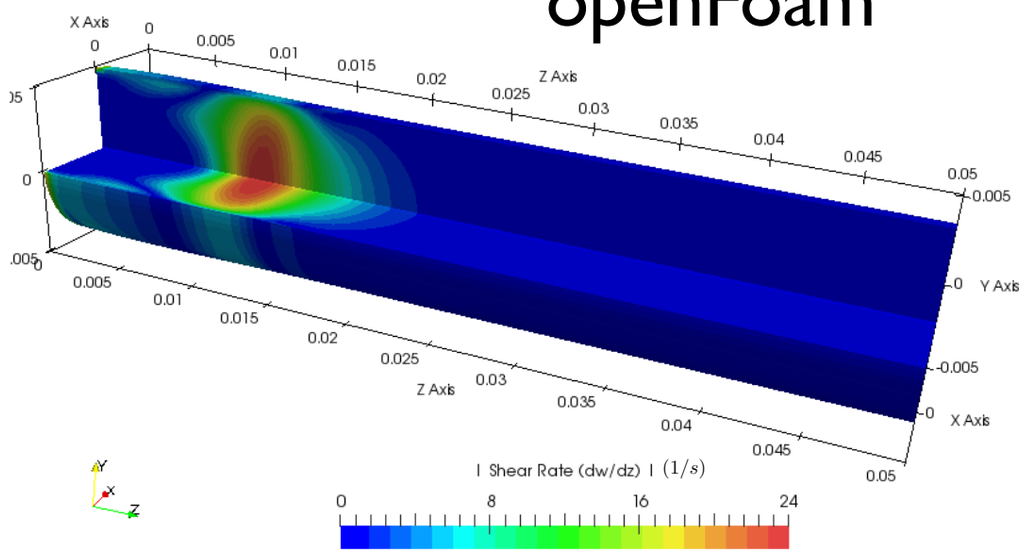
Shear Rate

openFoam



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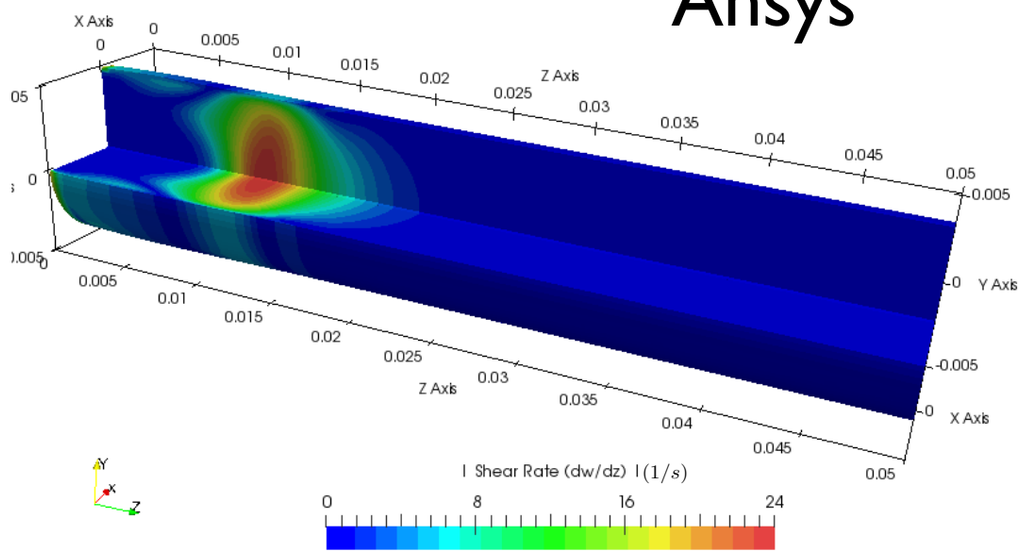
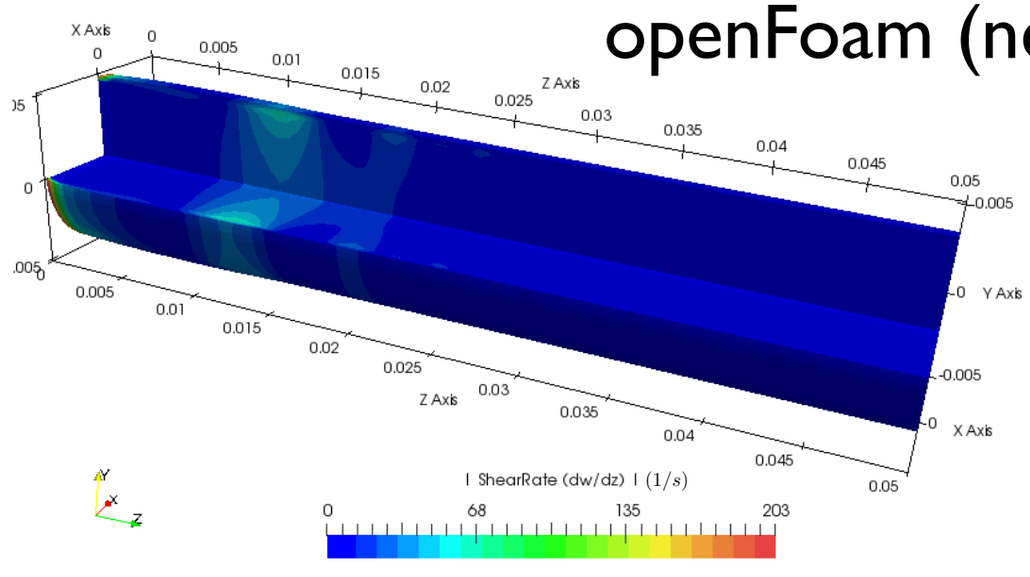
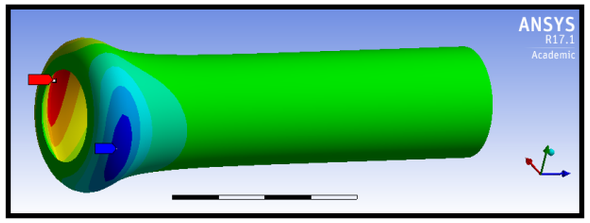


openFoam (newtonian)



Results



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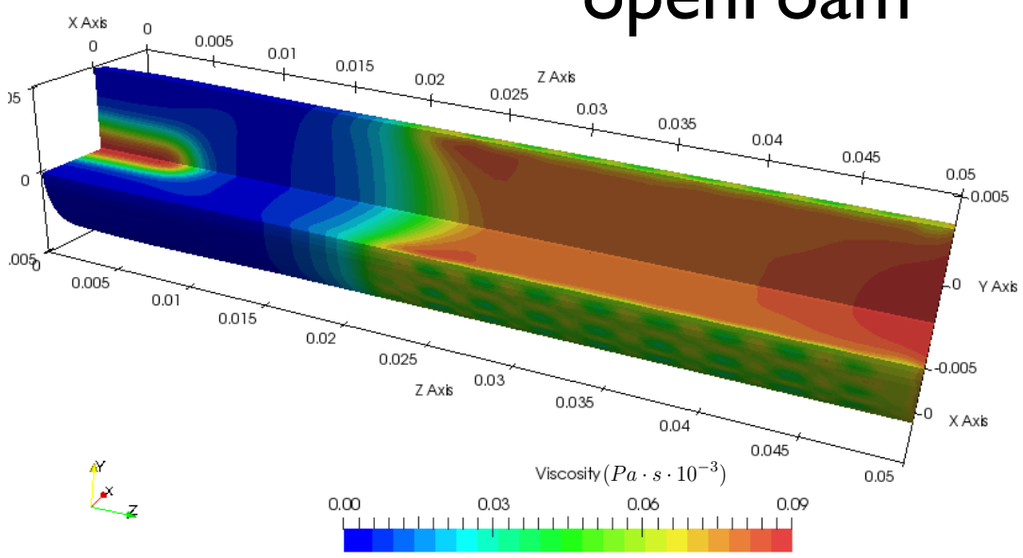
Viscosity

openFoam



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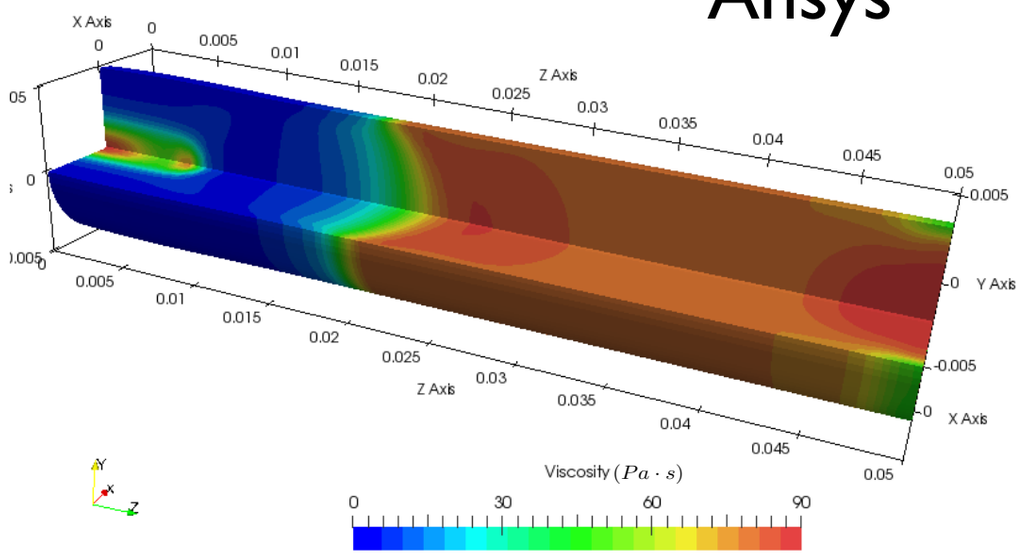

Conclusion

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- General purpose nNFSI solver
- “Unified” approach
- Objected-oriented approach
- All old non-Newtonian models can be used
- Easy to extend to new models
- Solver is verified

Next steps

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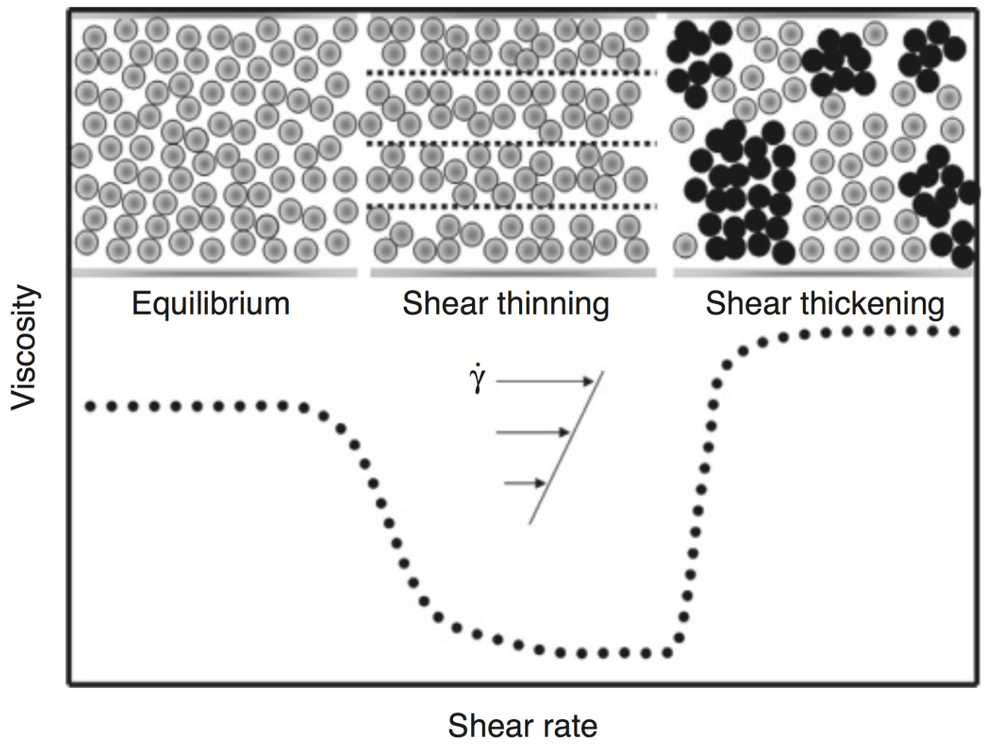
- Implement the Ogden hyperelastic model
- Implement a viscoelastic fluid model
- Implement a shear thickening fluid model



Acknowledgements

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Thank you!

References

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