Modeling hyperelastic solids in OpenFOAM

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Understanding physiological processes is key to treat patients, especially in emergency situations. For this reason the understanding of the creation of aneurysms in the human brain has been the study of research for decades. With a better understanding of the processes involved the treatment of patients can be improved.

Modeling as well as hardware capabilities have improved in the last years to a level, where it is possible to model the fluid-structure interaction between the fluid dynamics of the blood flow as well as the structural behaviour of the blood vessel in a reasonable simulation runtime [1,2]. For certain applications the solid behaviour can be modelled in a simple linear way [2], however in some cases the material behaviour of the blood vessels is more complex. These cases are especially interesting as aneurysm creation is more likely.

For this reason it is important to model the tissue of the blood vessel with more realistic hyperelastic material models instead of assuming linear elasticity. In this work the widely used hyperelastic structural mechanical models "*Mooney-Rivlin*" as well as "*Ogden*" are implemented in the framework of OpenFOAM (v1812) within the user library solids4Foam [1].

Structural mechanic simulations are performed in order to verify compatibility between the models themselves. Additionally, a comparison between OpenFOAM models and the commercial structural mechanics software Abaqus as well as analytic results [3] is conducted. Therefore an infinitely long cylindrical pressure vessel is loaded on the inside with a pressure of 100 MPa, thus creating a large deformation of the wall. The displacement (see figure 1) as well as the arising stress values (see figure 2) are evaluated. Good agreement is found between both models in OpenFOAM as well as Abaqus and the analytical solution.

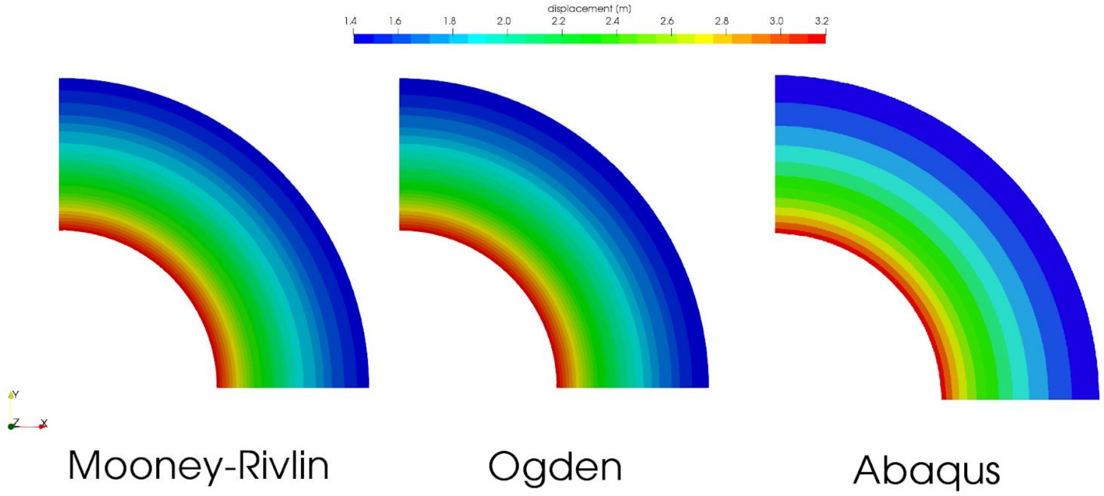

Figure 1: Comparison of displacement in m; left: Mooney-Rivlin model in OpenFOAM, center: Ogden model in OpenFOAM, right: Mooney-Rivlin model in Abaqus

With this verification of the model implementation it is possible to utilize these models in future fluid-structure interaction simulations of aneurysm creation. This way better estimation of large deformations of blood vessels can be performed.

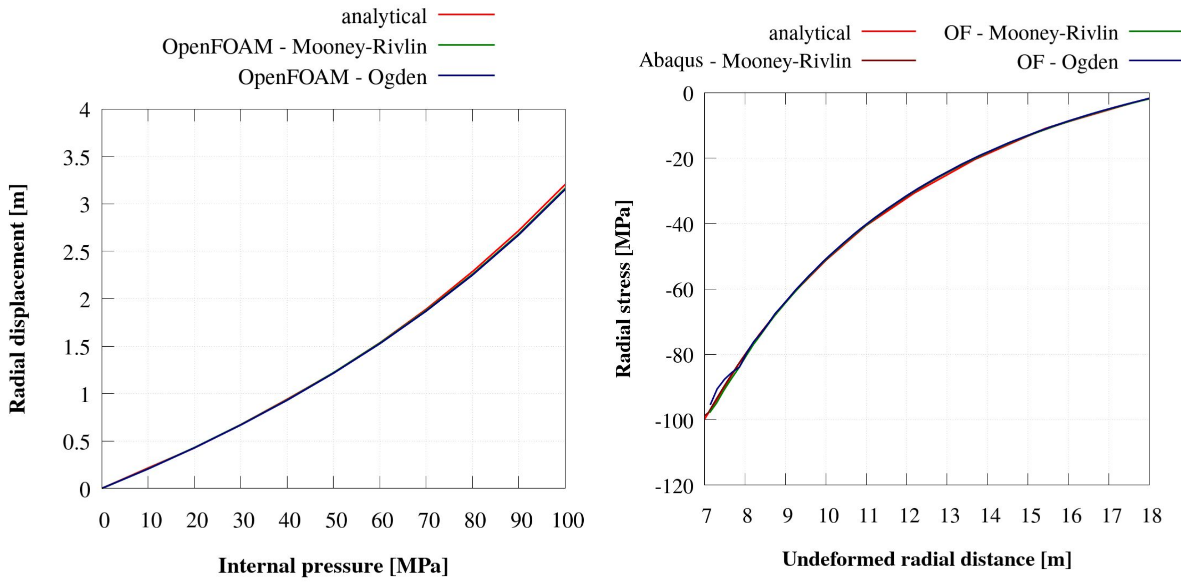

Figure 2: Left: radial displacement of the cylindrical pressure vessel as a function of internal pressure; right: radial stress as a function of undeformed distance in the wall

Literature

[1] P. Cardiff, A. Karač, P. De Jaeger, H. Jasak , J. Nagy, A. Ivanković and Ž. Tuković: An open-source finite volume toolbox for solid mechanics and fluid-solid interaction simulations, arXiv:1808.10736v2, 2018, available at https://arxiv.org/abs/1808.10736

[2] J. Nagy, P. Cardiff: Numeric investigation of Fluid-Structure Interaction for internal flow processes - Aneurysm modeling, 7th OpenFOAM conference 2019, Berlin, Germany

[3] I. Bijelonja, I. Demirdzic, S. Muzaferija: A finite volume method for large strain analysis of incompressible hyperelastic materials, Int. J. Numer. Meth. Engng 2005; 64:1594–1609