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Adjoint-based Shape Sensitivities of Ducted Blood Flows with Non-Newtonian Fluid Properties

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The present contribution discusses the derivation and numerical implementation of an adjoint system, to the primal generalized Navier-Stokes equations, for the efficient computation of shape sensitivities of ducted flows considering non-Newtonian fluids. The ever-growing advancements in computational simulations of blood flows [1] are, naturally, accompanied by an increased interest in the optimization of related medical devices [2]. In the majority of the computational studies the Newtonian assumption is used to describe the rheology of blood. While this assumption has been shown to satisfactorily capture the flow when it is governed by high shear rates, it falls short when low shear rates are dominant. A rich variety of viscosity models have been proposed to tackle this shortcoming.

In this work we show how such models can be incorporated into the derivation of an adjoint system targeting to produce the shape sensitivity which can then be used by a gradient-based optimization method for the minimization of an objective functional. A general formulation of the adjoint field equations is proposed in which contributions of the non-Newtonian properties are explicitily identified. The numerical implementation is discussed, and the method is investigated by means of numerical experiments of steady blood flows in a 2D stenosed ducted geometry. Results are compared against second-order finite-difference (FD) studies. The influence of the adjoint non-Newtonian terms on the shape sensitivity is discussed on the basis of numerical deviations from the FD studies. Flows with different ranges of shear rate are considered, to highlight the conditions under which the adjoint non-Newtonian contributions become relevant.

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