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A numerical technique for solving the Oldroyd-B model for the whole range of viscosity ratios

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This work presents a technique for simulating time-dependent axisymmetric free surface flows of Oldroyd-B fluids that is capable of solving the Oldroyd-B model for any value of the ratio $\beta = \lambda_2/\lambda_1$, in the interval $[0, 1]$. Thus, it can solve the purely elastic UCM model when $\beta = 0$ and reduces to Newtonian flow if $\beta = 1$. We employ the EVSS transformation $\boldsymbol{\tau} = \mathbf{S} + 2\eta_0\mathbf{D}$ where the extra-stress tensor $\boldsymbol{\tau}$ is the solution of the Oldroyd-B constitutive equation while the non-Newtonian tensor $\mathbf{S}$ is calculated as a function of $\boldsymbol{\tau}$ and $2\eta_0\mathbf{D}$. The Oldroyd-B tensor is related to the conformation tensor $\mathbf{A}$ which is approximated implicitly by a system of finite difference equations that is solved exactly. The methodology developed is a Marker-and-Cell type method that uses a staggered grid and solves the momentum equations using primitive variables and a discrete non-symmetric Poisson equation to obtain a divergence-free velocity field and the pressure within the fluid and on the free surface. To verify this new technique, tube flow is solved and the numerical predictions are compared with the analytical solution for fully developed flow; the convergence of the method is demonstrated via mesh refinement. The performance of this method is demonstrated by solving the impacting drop problem for which a study of the parameters involved is provided and new phenomena are reported.