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# Two-phase viscoelastic jetting

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**Abstract**

A coupled finite difference algorithm on rectangular grids is developed for viscoelastic ink ejection simulations. The ink is modeled by the Oldroyd-B viscoelastic fluid model. The coupled algorithm seamlessly incorporates several things: (1) a coupled level set-projection method for incompressible immiscible two-phase fluid flows; (2) a higher-order Godunov type algorithm for the convection terms in the momentum and level set equations; (3) a simple first-order upwind algorithm for the convection term in the viscoelastic stress equations; (4) central difference approximations for viscosity, surface tension, and upper-convected derivative terms; and (5) an equivalent circuit model to calculate the inflow pressure (or flow rate) from dynamic voltage.
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## 1. Introduction

The goal of this work is to develop computational techniques which can be applied to two-phase viscoelastic flows in complex geometries. The fluid model considered in this work is the Oldroyd-B viscoelastic fluid model, in which both the dynamic viscosity and relaxation time are constant. Our purpose is to simulate two-phase immiscible incompressible flows in the presence of surface tension and density jump across the interface separating a viscoelastic fluid from air, incorporated with a macroscopic slipping contact line model which describes the air–fluid–wall dynamics. The fluid interface between the air and the fluid is treated as an infinitely thin immiscible boundary, separating regions of different but constant densities and viscosities. The flow is axisymmetric, and for boundary conditions on solid walls we assume that both the normal and tangential components of the fluid velocity vanish; this is amended by the contact model at places where the interface meets walls. Here, we wish to be able to simulate air/wall/fluid interactions and such effects as interactions

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between geometry and viscoelastic forces. The computational model and algorithm are general enough to handle problems in which either of the two fluids is either viscoelastic or Newtonian.

Applications involving viscoelastic fluid jets are quite broad, and include such areas as microdispensing of bioactive fluids through high throughput injection devices, creation of cell attachment sites, scaffolds for tissue engineering, coatings and drug delivery systems for controlled drug release, and viscoelastic blood flow past valves.

We test and apply these algorithms in the context of ink jet plotters. Regular dye-based inks used in desktop printers are Newtonian, which means the relation between the stress tensor and the rate of deformation tensor at an instant is linear and not related to any other instant. The use of pigment-based inks at the end of the 1990's improved the color durability of an ink jet printout. Pigment-based inks and inks used in industrial printing applications are usually viscoelastic, i.e. the relation between the stress tensor and the rate of deformation tensor at an instant depends on the deformation history.

The typical structure of an ink jet nozzle is shown in Fig. 1. The actual geometry is axisymmetric and is not drawn to scale. Ink is stored in a cartridge, and driven through the nozzle in response to a dynamic pressure at the lower boundary (nozzle inflow). The dynamics of incompressible viscoelastic fluid flow through the nozzle, coupled to surface tension effects along the ink–air interface and boundary conditions along the wall, act to determine the shape of the interface as it moves. A negative pressure at the nozzle inflow induces a backflow, which together with the capillary instability causes the bubble to pinch off. The bubble moves through the domain and usually separates into a major droplet and at least one small droplet (satellite).

### 1.1. Background

Several different numerical simulations of the Newtonian ink jet process have been performed in recent years, see, for example, Aleinov et al. [1], Sou et al. [22], and Yu et al. [28,29]. Our methods make use of level set methods for tracking the fluid interface boundaries, coupled to projection methods to solving the associated fluid flows. A large number of background references for projection methods and level set methods are given in [28]; here we briefly mention the original paper on projection methods for incompressible flow by Chorin [8], second-order Godunov-type improvements by Bell et al. [4], the finite-element approximate projection by Almgren et al. [2], and the extension of these techniques to quadrilateral grids (see for example [6]) and to moving quadrilateral grids (see [26]). On the interface tracking side, level set methods, introduced in [15], rely in part on the theory of curve and surface evolution given in [18,19] and on the link between front

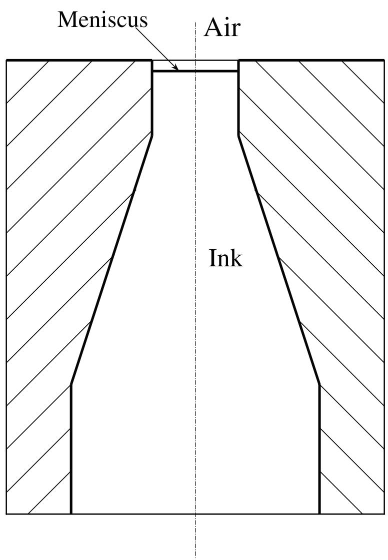


Fig. 1. The cross-section view of an ink jet nozzle.

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