Viscous Entrainment from a Nozzle: Singular Liquid Spouts.

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Recommended and a Commentary by Raymond Goldstein, University of Arizona, Tucsan.

Several years ago, Cohen and Nagel described an intriguing example of a topological transition which occurs when fluid is withdrawn through a tube placed slightly above the two-fluid interface bounding immiscible fluids. As the withdrawal rate is increased, the lower fluid becomes increasingly deformed into a roughly conical bump by the extensional flow in the upper fluid, until eventually the flow topology changes and a slender axisymmetric spout emerges. The spout can be extremely narrow, orders of magnitude smaller than the nozzle radius. For this reason, all sorts of applications come to mind, and as well this enormous separation of length scales provides a challenge for theorists to explain. Existing experiments indicate that the approach to this transition proceeds through a sequence of steady-state shapes, so that for any given flow rate into the nozzle there is a stationary interface between the two fluids, even as the fluid is flowing. This is quite unlike the more commonly encountered behavior near topological transitions, such as the familiar one leading to droplet breakup, in which explicit time-dependence appears. These steady states were found experimentally to persist until a very small cutoff length, then giving way to a weakly discontinuous transition. The origin of this saturation in the curvature has been a mystery, with existing theories (e.g. in 2d) suggesting subtleties associated with the viscosity contrast between the fluids, but no clear answer regarding existence and stability of solutions in 3d.

The recent paper by Wendy Zhang confronts this issue, which is important for both conceptual and practical reasons. Can the entrainment transition be continuous, characterized by an arbitrarily small spout near threshold? Using a long-wavelength description of the kind now rather standard in the study of topological transitions, she finds that by suitable control of the large-scale flow characteristics this continuous behavior can be realized through a sequence of steady-state shapes rendered stable through a combination of surface tension and extensional flow. The sensitivity of the behavior to those far-field boundary conditions suggests an explanation for the weak discontinuity observed, and now puts the ball back in the experimentalists' court. It also serves as an elegant illustration of the role of scale-invariant solutions in the description of topological transitions.