The understanding of how flow-structure interaction influences the macroscopic behavior of multi-phase systems is of both fundamental and practical significance. This mini-symposium will be devoted to present advances in computational methods for interfacial and multi-component flows, flows with immersed boundaries, and complex (polymeric) fluids.

**Nano-Structure Computation with Momentum Phase Ordering Kinetics Models (2624)**

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Phase fields models offer a systematic physical approach for investigating complex multiphase systems such as near-critical interfacial behavior, phase separation under shear, and microstructure evolution during solidifications. However, because interfaces are replaced by thin transition regions (diffuse interfaces), phase field simulations require resolution of very thin layers to capture the physics of the problems studied. This demands robust numerical methods that can efficiently achieve high resolution and accuracy, especially in three dimensions. We present here an accurate and efficient numerical method to solve the coupled Cahn Hilliard/Navier-Stokes system, known as Model H that constitutes a phase field model for binary fluids with variable mobility and viscosity. The numerical method is a time-split scheme that combines a novel semi- implicit discretization for the convective Cahn-Hilliard equation with state-of-the-art high-resolution CFD schemes employed for direct numerical simulations of turbulence. This new semi-implicit discretization is simple but effective since it removes the stability constraint due to the nonlinearity of the Cahn-Hilliard equation at the same cost as that of an explicit scheme. The capabilities of the method are demonstrated with several examples including phase separation with and without, shear and isothermal turbulent phase separation. The method effectively resolves interfacial layers of as few as three mesh points. For spinodal decomposition the numerical examples show agreement with analytical solutions and scaling laws, where available, and the 3D simulations in the presence of shear reveal rich and complex structures, involving combinations of plates and strings.

**Computing Flows with Immersed Free Boundaries: Full Adaption and a Fast, Local Fluid Indicator (2423)**

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A novel numerical methodology for computing incompressible flows in the presence of free boundaries will be presented. The new method originates from the Immersed Boundary Method and makes also use of Level Set ideas to deal with different material fluid properties. Dynamic mesh adaption is performed both on the Eulerian grid with adaptive mesh refinements and on the Lagrangian (immersed boundary) grid via moving meshes. This dynamic adaption, crucial to accurately resolve the flow, is performed in concert with a semi-implicit strategy to successfully treat the well-known numerical difficulties associated with interfacial tension. Inspired by fast local level set methods and taking advantage of the availability of the explicitly tracked interface location a fast, local, geometry-based approach for computing a fluid indicator and thus for optimally updating fluid material quantities will be introduced. This new approach uses ideas from Computational Geometry to render at each time step the signed distance (level set) function with optimal computational cost and up to machine precision in a vicinity (tube) of the interface.

**Mathematical Models of Liquid Crystals (2531)**

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A statistical mechanical theory for the study of liquid crystals was introduced by Onsager in 1949. The theory explains the Isotropic-Nematic phase transition as a consequence of the balance between entropy and steric repulsion, represented by an excluded volume effect. However, the Onsager theory does not take into account spatial variations in the molecular orientation. We will present a molecular theory for the study of liquid crystals based on an inhomogeneous density functional approach, which extends the Onsager theory. This new theory predicts the Isotropic-Nematic-Smectic A-Solid transition as a function of temperature and concentration.

Viscous Fingering with in-situ Production of Surfactants (2180)

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Viscous fingering experiments are performed in a Hele-Shaw cell in the presence of a well-characterized interfacial reaction that produces a surfactant. The experiments are carried out at high capillary number for which the fingering patterns become fractal. We measure the effect of the chemical reaction rate, characterized by the Damkohler number, Da, on the fractal dimension and finger width. The effects are significant: in general both quantities increase when Da = O(1). A plausible mechanism is hypothesized in which tangential Marangoni stresses due to surfactant gradients lead to finger broadening. We discuss the challenges and difficulties in modelling and simulation of such systems, including the issue of how to incorporate Marangoni stresses into the lower order Hele-Shaw/Darcy equations.

Numerical Simulation of the Motion of Elliptic Bodies in a Viscous Fluid (2169)

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In this work we discuss the application of a methodology combining distributed Lagrange multiplier based fictitious domain techniques, finite element approximation, and operator splitting, to the numerical simulation of the motion of elliptic bodies in an incompressible viscous fluid. The interaction between the fluid and the rigid body is implicitly modeled by a global variational formulation, so that we do not compute the hydrodynamical forces explicitly during the simulation. In addition, the fictitious domain method allows the flow computation to be done on a fixed region without re-meshing. Examples of the sedimentation of an elliptic body, and of hydrodynamic pendula will be presented.

Enhanced Front Tracking Method for the Computation of Discontinuous Structures in Fluid Dynamic (2604)

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The use of liquid crystalline polymers (LCP) as high strength materials has been limited almost exclusively to the formation of fibers such as Kevlar. This is because processing flows, other than predominantly extensional flows (e.g., fiber spinning), disrupt long-range orientational order of these expensive materials. The mechanisms by which this occurs have remained elusive. In this study, we wish to explore this question in the context of the simplest of all possible flows, namely the flow between parallel, flat boundaries, one of which is translating in its own plane. One reason for studying this flow is that there is a large body of experimental observations available for qualitative comparison. Although we are still in an early state of realizing our overall objectives, the work I will discuss here seems to point in a positive direction.
Zhiliang Xu

The front tracking method is a high resolution method to study multiphase flow with discontinuous interfaces. In this paper we discuss three important developments of this method. The first development deals with the robust and high quality computation of dynamically moving front. We introduced a locally grid-based method which uses Lagrangian propagation and redistribution, but applies Eulerian reconstruction for the bifurcation of topology. This method maintains high quality surface mesh and confines geometrical diffusion only in the regions where topological bifurcations are needed. Secondly, we have made important changes to the coupling of finite difference interior solver and the front propagation. Global conservation is achieved by using dynamic flux in the finite difference stencil near the interface. The third enhancement is to add the Colella-Burger adaptive mesh refinement method to the FronTier code. This is accomplished by merging the FronTier code with the Overture code (Livermore) through the use of a common data model called the TSTT interface. We will demonstrate these features through application of the front tracking method to the computation of fluid interface instabilities.

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A Surfactant-Conserving Volume-of-Fluid Method for Interfacial Flows with Insoluble Surfactant (2539)

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A James

A numerical method to simulate interfacial surfactant mechanics within a volume of fluid method will be presented. Two important features of this new method are that it conserves surfactant mass exactly and the form of the equation of state is not restricted, i.e. the relation between surfactant concentration and surface tension can be linear or nonlinear. To conserve surfactant, the surfactant mass and the interfacial surface area are tracked as the interface evolves, and then the surfactant concentration is reconstructed. The algorithm is coupled to an incompressible Navier-Stokes solver that uses a continuum method to incorporate both the normal and tangential components of the surface tension force into the momentum equation.

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Numerical simulations demonstrate the effect of surfactant on the dynamics of several problems by comparison to surfactant-free simulations.

A Numerical Simulations of Inviscid Capillary Pinchoff (2546)

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Inviscid capillary pinchoff is studied numerically for an axisymmetric model problem in which a bubble pinches at two points on the symmetry plane, breaking into two symmetric end-bubbles and a satellite bubble in between. Results are presented for a range of density jumps across the bubble. The numerical method uses a formulation in terms of arclength and tangent angle, and incorporates a new procedure to redistribute the computational points dynamically, in order to maintain resolution in regions of high curvature. The results are compared with alternative computations by Lepinnen and Lister (Phys. Fluids 15, 2003), where available. New results include details about the cone-crater structure near pinchoff, and the dependence of satellite bubble volume and pinchoff time on the density ratio.

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The Immersed Interface Method for Elasticity Problems With Interfaces (2526)

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Bo Li

The motivation of this work is to develop an efficient algorithm that can be applied to moving interface or free boundary problems. An immersed interface method for solving linear elasticity problems with two phases separated by an interface has been developed in this work. For the problem of interest, the underlying elasticity modulus is a constant in each phase but vary from phase to phase. The basic goal here is to design an efficient numerical method using a fixed Cartesian grid. The application of such a method to problems with moving interfaces driving
by stresses has a great advantage: no re-meshing is needed. A local optimization strategy is employed to determine the finite difference equations at grid points near or on the interface. The bi-conjugate gradient method and the GMRES with preconditioning are both implemented to solve the resulting linear systems of equations and compared. Numerical results are presented to show that the method is second-order accurate.