Organization(s): **University of Illinois at Urbana-Champaign; Massachusetts Institute of Technology; Brown University; Oregon State University; and Stanford University**

MTO Composite CAD

Title: Efficient Computational Prototyping of Mixed-Technology Microfluidic Components and Systems

Duration of Effort: June 1998 - May 2001

Principal Investigator(s): N. R. Aluru, UIUC
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Web: www.staff.uiuc.edu/~aluru

Objectives:

To develop fast, accurate and efficient design tools for rapid computational prototyping of microfluidics and MEMS.

Major Accomplishments:

- Developed FASTSTOKES, which can be three orders of magnitude faster than existing tools. Algorithmic innovations included: a new polynomial projection/interpolation algorithm, a new approach to vector convolution, and a new approach to compute integrals over curved panels; used Fast Stokes compute Drag on Comb and correlated results to measured data; extended FASTSTOKES for analysis of unsteady and mildly compressible Stokes flow.
- Developed flexible meshless methods for microfluidics and MEMS. Algorithmic innovations included: development of new approaches for computing interpolation functions, finite cloud method for microflows and MEMS and boundary cloud method for exterior electrostatics; developed Monte Carlo methods for atomistic modeling of microflows; developed multiscale methods combining Monte Carlo and continuum theories; simulated complicated microfluidic filters using multiscale tools; developed new reduced-order models.
- Developed force coupling method for particulate flows; developed inverse problems for bioparticulate flows; developed unified formulations for stochastic modeling of microflows.
- Developed a coupled circuit/fluidic environment for simulation of microfluidic systems; demostrated applications to micropumps and electroosmotic flows.
- Developed microfabrication and packaging technologies for microfluidic systems based on silicon, glass, elastomer, biodegradable polymer, and liquid crystal polymer materials; Demonstrated a micromachined elastomer micropump for remote, wireless operations; Developed an on-demand, remotely operated, magnetic micro bar mixer for mixing fluids in channels and reaction chambers; Designed a micro central fluid processing unit, for biological fluid processing and diagnosis

DOD Impact:

- Public domain codes for DoD use; invited talks at several DoD and National Laboratories.

Technology Transfer/Products:

- Several commercial companies have started using our tools; research led to several journal papers, conference papers and a text book on microfluidics; techniques developed as part of this project are currently being implemented into commercial tools.

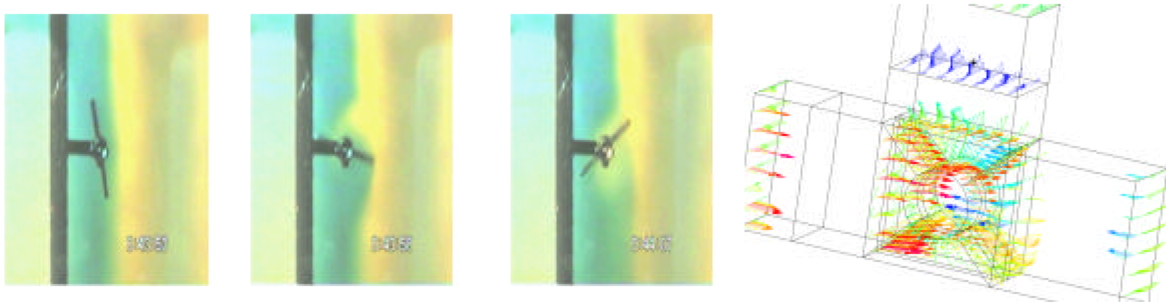

Figure 1: Images of mixing in a microfluidic channel (extreme right) micromixer design is aided by CAD

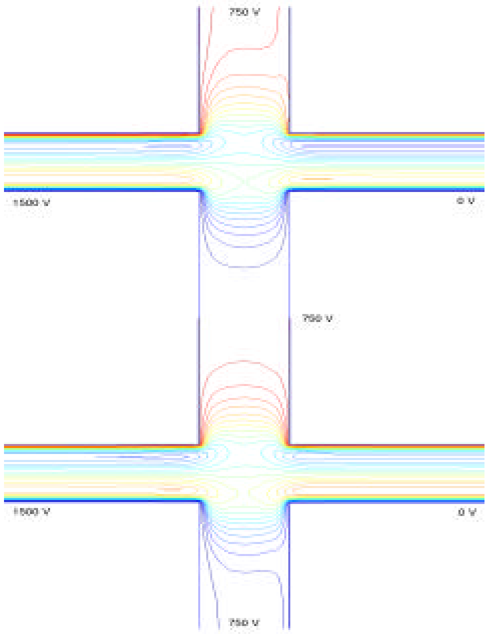

Figure 2: Demonstration of coupled circuit/microfluidic approach. Application to two cross-channel structures

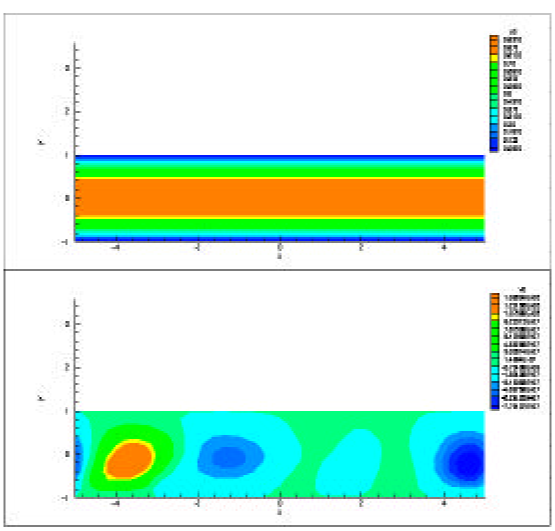

Figure 3: Simulation of non-uniform uncertainty at wall using NEKTAR.

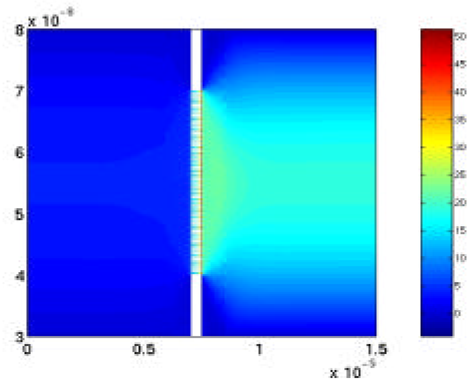

Figure 4: Multiscale analysis of a complex array of microfluidic filters. A combined DSMC/meshless technique is used to simulate 60 microfilters in a membrane.

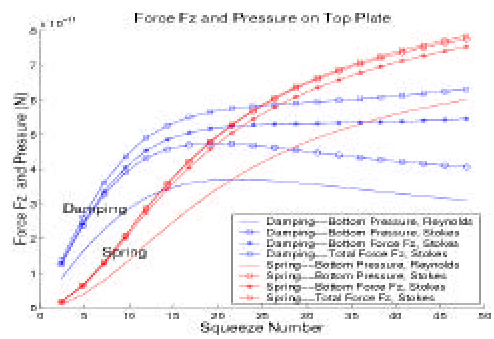

Figure 5: We extended faststokes for compressible Stokes equations. Spring and damping force calculations are shown.

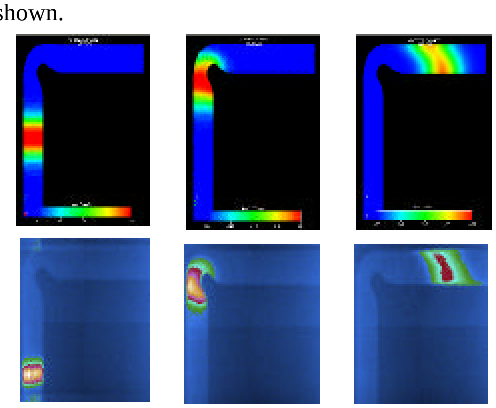

Figure 6: Low dispersion turns in electrokinetic flows. (top) simulation performed with MEMCAD (bottom) experiments

Organization(s): CFD Research Corporation; and Sarnoff Corporation

Title: An Integrated CAD Tool for Thermo-Fluidic-Mechanical-ElectrostaticDesign of MEMS Devices

MTO **Composite CAD**

Duration of Effort: April 1997 - June 1999

Principal Investigator(s): Phillip Stout, PhD
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Web: www.cfdrc.com

Objective

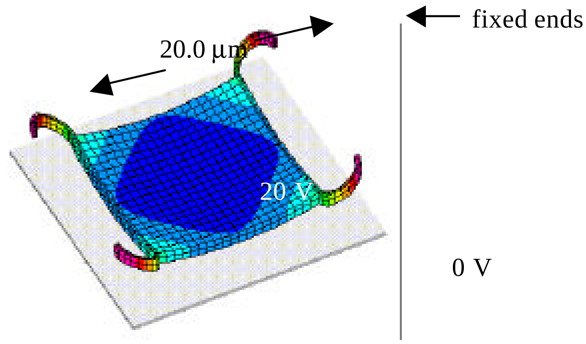
To develop a high fidelity computational simulation capability for integrated design of microsystems and components.

Progress/Results

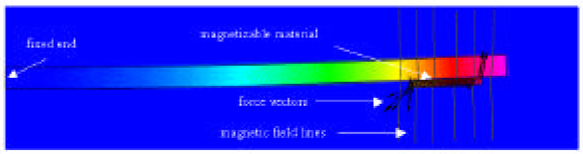
- A flow, thermal, mechanical CAD tool, has been modified to include electric (FVM/BEM) and magnetic (FVM) physical models.
- Structural mechanics model is now supplied with additional forces such as the electrostatic pressure forces, magnetic moment forces, and the Lorentz force on a conducting body.
- Heat model has additional heat sources due to joule heating both from conduction currents in resistive materials and inductive heating due to time varying magnetic/ electric fields.
- The flow module has an additional Lorentz force on flows of (electrically) conducting fluids.
- The volume of fluids (VOF) model is supplied with an electrostatic force that opposes the surface tension on the free surface.
- The electric model also calculates source currents for use by the magnetic model.
- Electric/mechanical coupling has been made implicit using a multi-level Newton approach.
- The models are integrated into a CAD environment (CFD-ACE+) which supplies grid generation, problem set-up, solution monitoring, and data visualization.
- The simulation abilities of the CAD tool have been demonstrated on many well-characterized microsystems and test cases: doubly clamped beam, accelerometer, high frequency resonator, electrostatic torsional micromirror, micromotor, linear lateral resonator comb drive, angular resonator comb drive, fluid damped beam, magnetic shielding of bus bar, magnetic field due to circular and square planar coils, magnetic actuation of a beam with high permeability material, magnetic field damping of a buoyancy-driven conductive flow.
- Through experimental measurements conducted at Sarnoff Corporation (subcontractor), the CAD tool has been verified using measured flow field and mechanical displacements.
- CAD tool has been demonstrated, tested, and applied to industrial MEMS or microsystems.
- A Communication protocol has been established to exchange microtomography and radiography data from Sarnoff with CFDRC Software.

Status

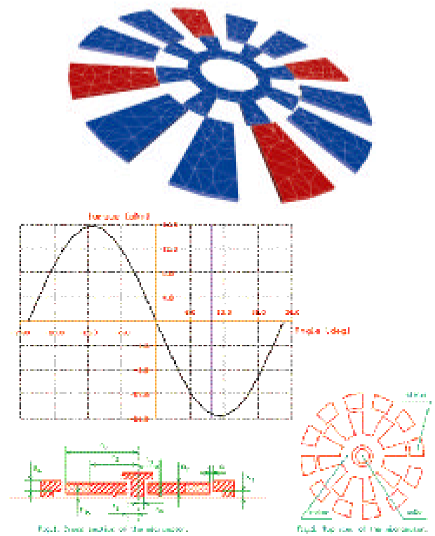
- The project is complete. A CAD tool has been developed to aid in the design of microsystems. The modified CFD-ACE+ MEMS is now commercially available from CFDRC.



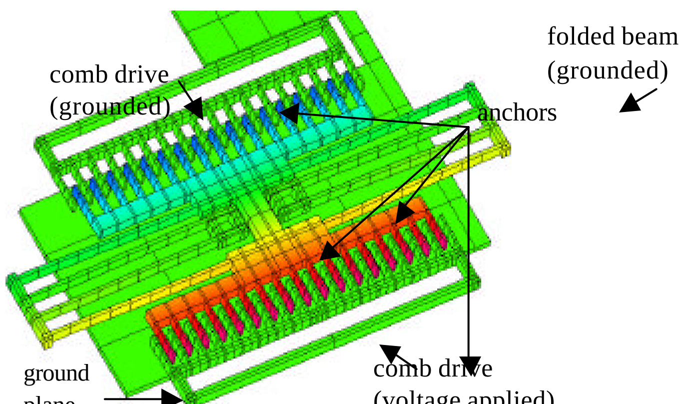
Calculated Displacement (Contours) of an Accelerometer Under an Electrostatic Load



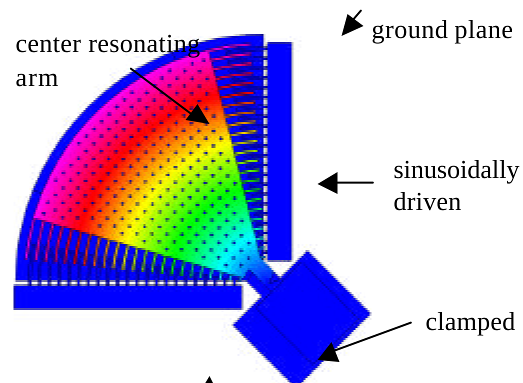
Displacement Field Contours, Magnetic Field Lines, and Force Vectors on a Magnetically Actuated Beam



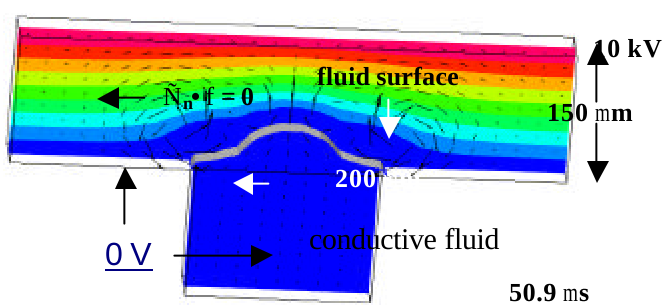
Geometry and Computed Torque-Angle Relationship for an Electric Micromotor



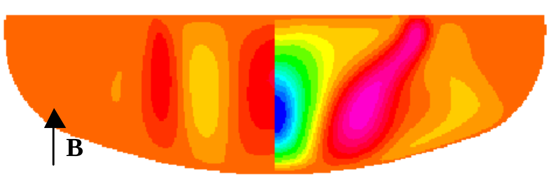
Linear Lateral Resonator Comb Drive with an Applied Sinusoidal Drive Voltage. Vertical Displacement (Contours)



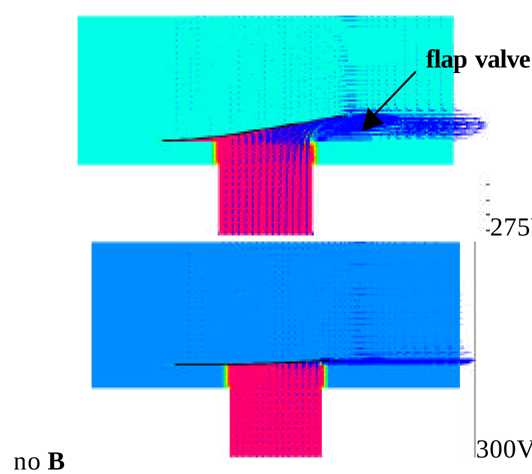
Calculated Lateral Displacement of the Angular Resonator



Time Evolution of the Electrostatic Extraction of a Conductive Fluid from a Bath. Voltage (Color Contours), Flow (Arrows)



Vertical Velocity Contours for Coupled Flow/Magnetics Solution. Right Half is without the Magnetic Field, Left Half is with the Magnetic Field



Flow (Arrows) Across a Flap for Two Different Applied Voltages