Optimization Module Enables Hybrid Experimental-Numerical Algorithm for 3D Particle Image Velocimetry

M. Sigurdson[1], C. Meinhart[1], I. Mezic[1]

[1]Department of Mechanical Engineering, University of California - Santa Barbara, Santa Barbara, CA, USA

Abstract

2D particle image velocimetry (PIV) is a well developed technique for measuring microscale flows, but 3D PIV has proven more difficult, requiring extensive imaging, extra expensive equipment, and resulting in lower data quality than 2D methods. We present here a hybrid experimental-numerical technique which uses the Optimization Module with COMSOL Multiphysics® software, together with experimental measurements and an imperfect numerical model to generate a 3 dimensional velocity field.

This research effort studies chaotic mixing, following the numerical algorithm developed by (1). To apply this mixing predictive algorithm to real experimental flows, measurement of a 3D velocity field that can be used to generate fluid trajectories is required. We are using a programmable blinking AC electrokinetic flow as a mixing testbed (Figure 1a; electrodes in orange). We start by measuring 2D velocity fields of a steady flow at several z-planes in the mixing chamber, following (2) (Fig 1b). Then, in order to use, for example, the 3D POD PIV technique developed by (3), 16 x-y velocity regions would be required to span the mixing chamber, each with 20 z-levels, of 100 image pairs per level. Such a large experiment introduces problems such as drift from various sources, as well as error involved in stitching together the data.

Instead we use a hybrid technique. The physics underlying AC electrothermal flow have been explained by (4), but uncertainty regarding simplifying assumptions and physical parameters mean it is often - as here - difficult match model to measurements. The quasi-steady electric field is modeled with the Electrostatics interface; the heat transfer problem is modeled with the Heat Transfer in Fluids interface; the fluid flow, subject to buoyancy and electrothermal volume forces are modeled with a Laminar Flow interface. Because our purpose is a measurement, rather than development of a physically accurate and predictive model, it not necessary that parameters match actual conditions, only that the flow is represented. With this in mind we identify parameters that can be used as handles to shape and scale the flow field. We use an Optimization Module to import experimental velocity fields, and the Optimization Solver to fit values of chosen parameters to the experimental data.

First results have shown that scaling parameters for the two volume forces, buoyancy force and electrothermal force, as well as the directional conductivity components of the base material are effective shaping parameters, and can be used to fit the flow. Figure 2(a) shows one plane of experimental velocity field (blue) and numerical velocity field (red), with optimized scaling parameters. Then, a time dependent ("blinked") BC is applied to electrodes, and the fit parameters are used for a time dependent solution. The particle tracing mode allows the calculation of fluid trajectories: Figure 2 (b) "unblinked" and (c) "blinked".

Although we are still working to identify the best few fitting parameters, by using the highest signal measurements for the fitting, and evaluating the goodness of fit with checks at other regions, this Hybrid 3D PIV technique promises to be helpful for generation of experimentally accurate 3D velocity fields.

Reference

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Figures used in the abstract

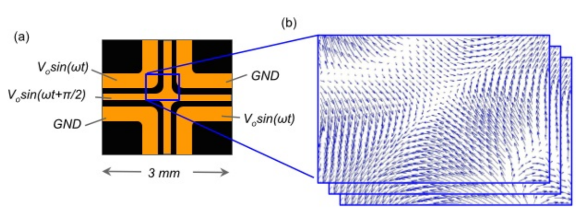

Figure 1: (a) Top view of 3mm x 3mm x 450 um mixing chamber. Typical applied voltage for each of five electrodes (orange) is shown. (b) Velocity field measured experimentally through PIV. u and v components of velocity are measured for several (up to 20) z-planes.

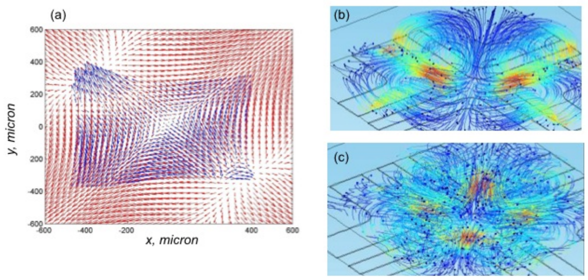

Figure 2: (a) Experimentally measured velocity field (blue) and model velocity field (red), matched through the Optimization Module using fitting parameters. A time dependent model is then run, “blinking” or swapping the voltage boundary conditions in Figure 1 among the electrodes. Particle trajectories for the unblinked case (a) and blinked case (b) will be used to quantify mixing.