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Phase Separated PIV Measurements Using Phase Boundary Detection

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ABSTRACT

PIV measurement accuracy in two-phase flows is often lower along the phase boundaries, i.e. in interrogation windows that contain information from both phases. This is because different seeding density, velocity magnitude and flow direction conditions often exist across the boundary, and the selected correlation peak is either biased towards the wrong phase, or the calculated displacement is erroneously detected as an outlier and is subsequently replaced. Phase separated PIV measurements often minimize this problem, and increase accuracy along the boundary by treating each phase separately. This technique requires for each time step (i) the accurate detection of the phase boundary in consecutive frames, (ii) generation of dynamic masks, (iii) an accurate PIV evaluation of each phase and (iv) recombination of the flow fields. In this paper, we test a novel hybrid phase boundary detection algorithm in two different two-phase flow configurations where the phase definition could be challenging: First configuration is the mixing of two liquids in a magnetic micromixer (Fig. 1), and the second is a combustion experiment where air-fuel mixture and the combustion products form the two gas phases (Fig. 2). The first application is the magnetic micromixer experiment performed in collaboration with University of Latvia [1-2], where a magnetic fluid (the darker phase in Fig. 1a) is mixed with water (the brighter phase in Fig. 1a) in a micro Hele-Shaw cell. Both phases are seeded with 1µm-diameter particles and phase separation is performed using the concentration information visible in the background (Fig. 1a). Results of the phase separated PIV evaluation (Fig. 1b) reveal many regions with very sharp velocity gradients and with different flow directions across the boundary, which cannot be detected using a conventional PIV evaluation; observe vectors across the boundary f.ex. the 3rd finger from the bottom right, within the green rectangle in Fig. 1b. The difference between PIV results with and without phase separation shows that the phase separated PIV evaluation improves the results not only in the phase boundary (Fig. 1c) but surprisingly also in the magnetic fluid where the image contrast is lower (top right corner in Fig. 1c).

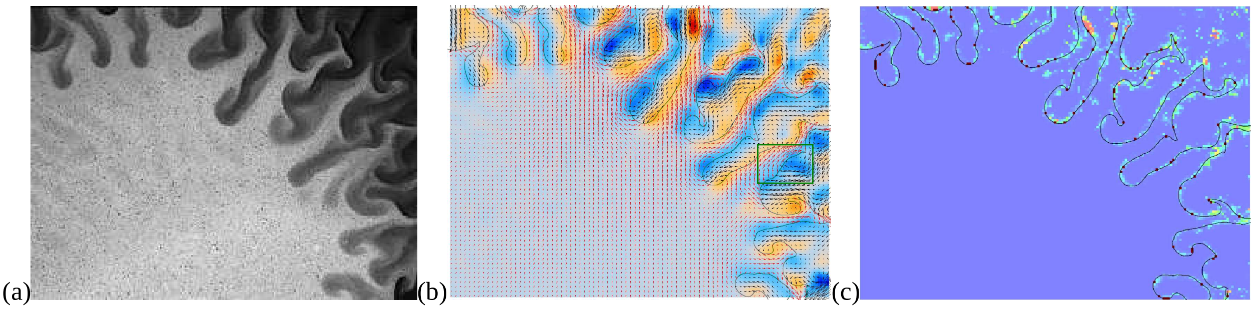
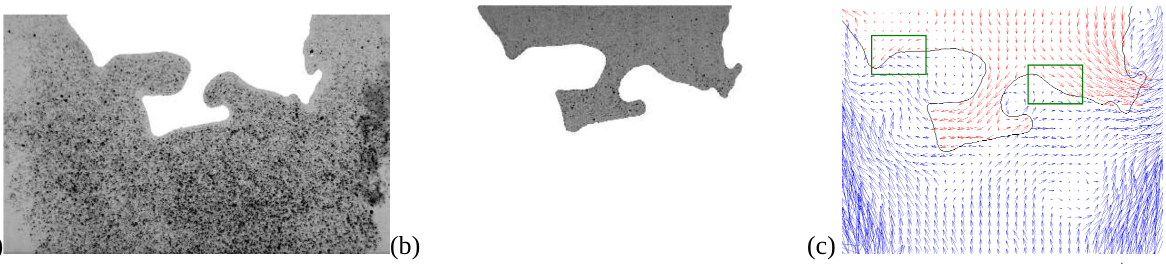


Figure 1 Application of phase separated PIV measurements in a micromixer. (a) First frame of the raw particle image pair, (b) Phase Separated PIV measurement results where red vectors are in water, black vectors are in the magnetic fluid, black continuous line is the phase boundary, and the blue and orange colors represent vorticity. (c) Magnitude of the difference between PIV results with and without phase separation shown with the phase boundary.

The second application of the phase boundary detection tool is a turbulent, premixed, low-swirl gas flame experiment performed in collaboration with Lund University [3], where similar improvements are observed (Fig. 2). The experimental setup is a combination of a high-speed PIV system and a high-speed OH-LIF (Laser Induced Fluorescence) system (See Fig. 1 in Ref. 3) where flow fields and OH concentration is measured simultaneously at a 4kHz-sampling rate. The flow is seeded with 1µm-sized $ZrSiO_4$ particles and phase separation and boundary detection is performed using the OH-species concentration information obtained from the LIF processing. In order to achieve an accurate phase separation, a good overlap of field of view is essential and this is achieved by image calibration. Different seeding concentrations are immediately visible in Fig. 2a and 2b due to sudden gas expansion after combustion. This is because the main heat release occurs at the flame front, resulting in a sudden temperature increase of the gases on the products phase. As the flame experiment is done at ambient pressure, the temperature increase causes the gas to expand, resulting in a lower seeding density on the burnt side. As a consequence, the PIV seeding density is significantly lower in the combustion products phase (Fig. 2b) than in the fuel phase (Fig. 2a), and this is often a major challenge for PIV analysis. Results of the phase separated PIV evaluation (Fig. 2c), once again reveal many regions with very sharp velocity gradients and with different flow directions across the boundary, which cannot be detected using a conventional PIV evaluation; observe the velocity magnitude and direction jumps across the boundary within the green rectangles in Fig. 2c.



(a) (b) (c)

Figure 2 Application of phase separated PIV measurements in a swirling flame (t=5ms in Ref. 3). (a) 1st frame of the fuel phase of the raw particle image pair, (b) same for the combustion products phase (c) Close up of the phase-separated PIV measurement results at the same instant. Red vectors are in the products phase, blue vectors are in the fuel phase, and the black continuous line is the phase boundary.

The new phase boundary detection tool provides numerous advantages in multiphase flow diagnostics; (i) accurate detection of phase boundary location and length in a time resolved fashion (f. ex. flame front position in combustion diagnostics), (ii) separation of phases in multi-phase flow applications in a systematic fashion, (iii) dynamic masking of PIV raw images and vector fields to perform phase-separated PIV measurements, and thereby (iv) providing accuracy improvements in PIV results in the vicinity of phase boundaries.

REFERENCES

[1] Ergin FG, Watz BB, Erglis K and Cebers A "Planar velocity & concentration measurements in a magnetic micromixer with interface front detection" Proc. 10th International Symposium on Particle Image Velocimetry, Delft, The Netherlands, July 1-3, 2013

[2] Ergin FG, Watz BB, Erglis K and Cebers A "Poor-contrast particle image processing in Micro scale mixing" Proc. 10th Biennial Conference on Engineering Systems Design and Analysis, Istanbul, Turkey, July 12-14, 2010

[3] Petersson P, Wellander R, Olofsson J, Carlsson H, Carlsson C, Watz BB, Boetkjaer N, Richter M, Aldén M, Fuchs L and Bai XS "Simultaneous high-speed PIV and OH PLIF measurements and modal analysis for investigating flame-flow interaction in a low swirl flame" (2012) Proc. 16th Int Symp on Applications of Laser Techniques to Fluid Mechanics Lisbon, Portugal, 09-12 July, 2012