DROPLET INTERNAL FLOW MEASUREMENT USING MICRO-PIV

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"PHYSICS OF DROPLETS"

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The micro-PIV technique represents a development of the general particle image velocimetry technique to applications in fluid mechanics phenomena at a micrometric scale. It takes advantage from the very small depth of field of long distance objectives with high magnification to carry out accurate measurements in the focusing plane. The typical configuration (figure 1) consists of a microscope coupled to a pulsed laser and a double exposure PIV camera. The flow in the transparent microchannel is seeded using sub-micrometric fluorescent particles. The laser light is directed on the investigated flow through the epifluorescent microscope objective. The light re-emitted with a stoke shift (figure 2) by the fluorescent particles is detected by the PIV camera equipped of an optical filter to select only the fluorescence wavelength. The micro-PIV technique presents a large interest in the validation of numerical codes developed in different micro-fluidic framework such as biological flows and in industrial application as the ink-jet print-head.

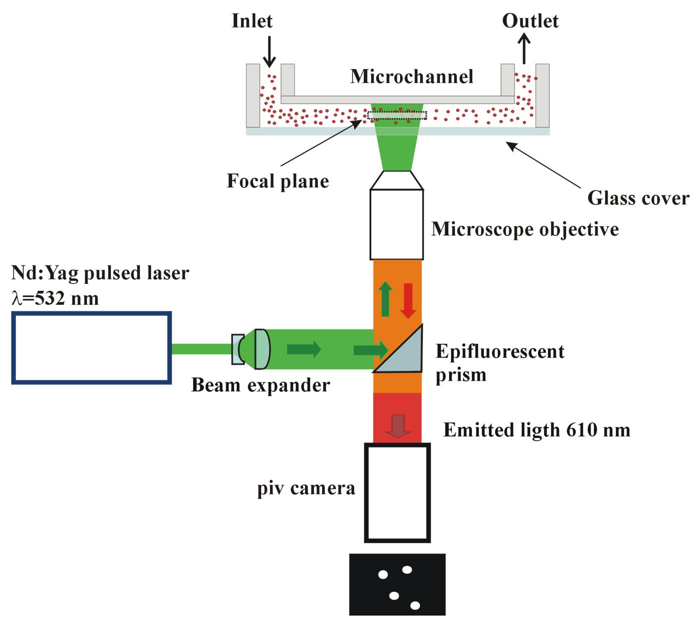

Figure 1: Sketch of a typical optical configuration for a micro-PIV system

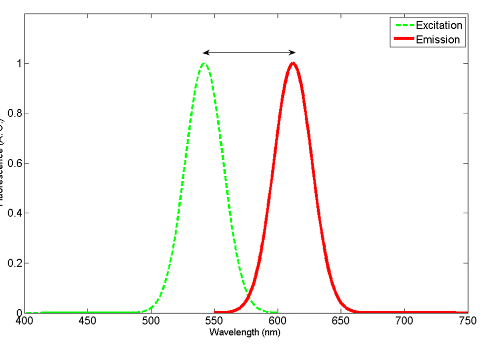

Figure 2 : Example Stoke shift

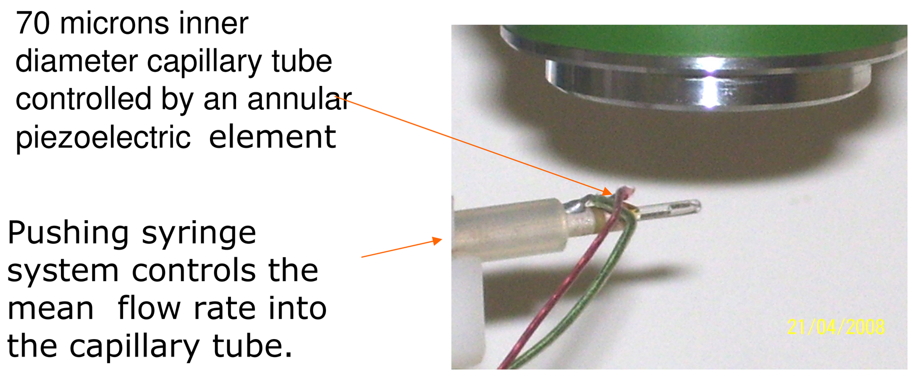

Figure 3: Sketch of a typical optical configuration for a micro-PIV system

To investigate the micro-PIV measurements capabilities for fast moving and deforming droplets, measurement of the flow inside a jet ejected by a piezo-driven capillary up to the droplet formation by Rayleigh instability (figure 4) are studied in combination with PTV in order to distinguish the main liquid movement from the bulk one. Liquids differing from each other for their viscosity and their surface tension as well as piezo-element frequency in the 1 to 8 KHz range are investigated. The flow rate of the jet is adjusted by means of a pushing syringe system. Low concentration of 0.86 microns fluorescent particles is employed as seeding in order to have good signal to noise ratios. The ensemble averaging method is used to increase the height of the correlation peaks (figure 5). Stroboscopic method (figure 6) is used to achieve several couples of frames (figure 7) taken in the same conditions thanks to high repeatability of piezo-driven instabilities. Moreover changing the of stroboscopic delay, all the droplet formation phases can be analyzed in detail (figure 8).

Figure 4: Piezo-driven Rayleigh instability droplet formation

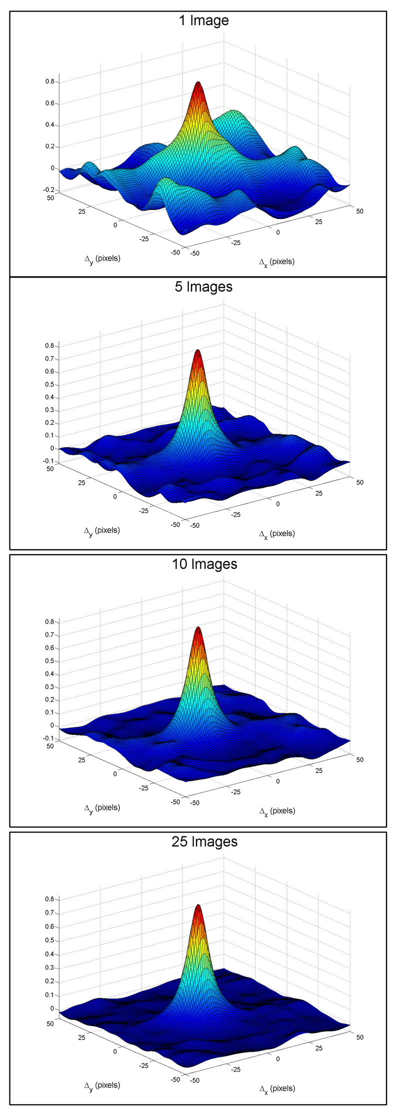

Figure 5: Signal to noise ratio improvement by means of the correlation peak ensemble average.

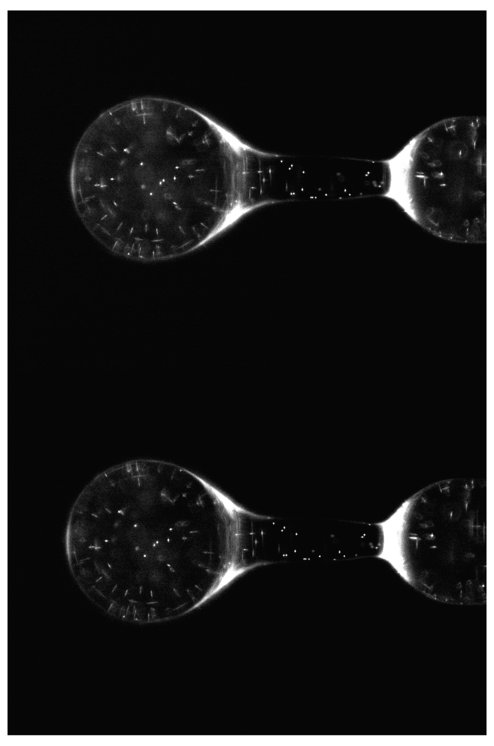

Figure 7: couple of frames using the μPIV equipment

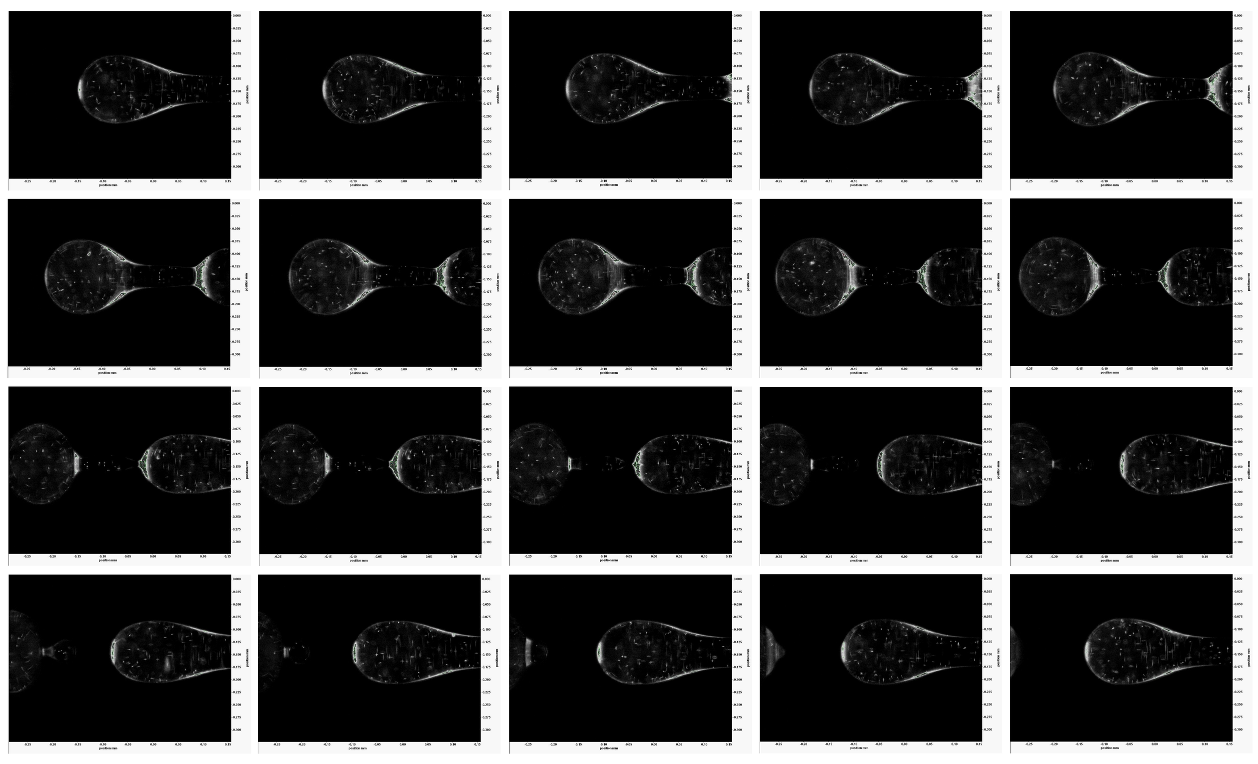

Figure 8: Stroboscopic sequence of droplet formation

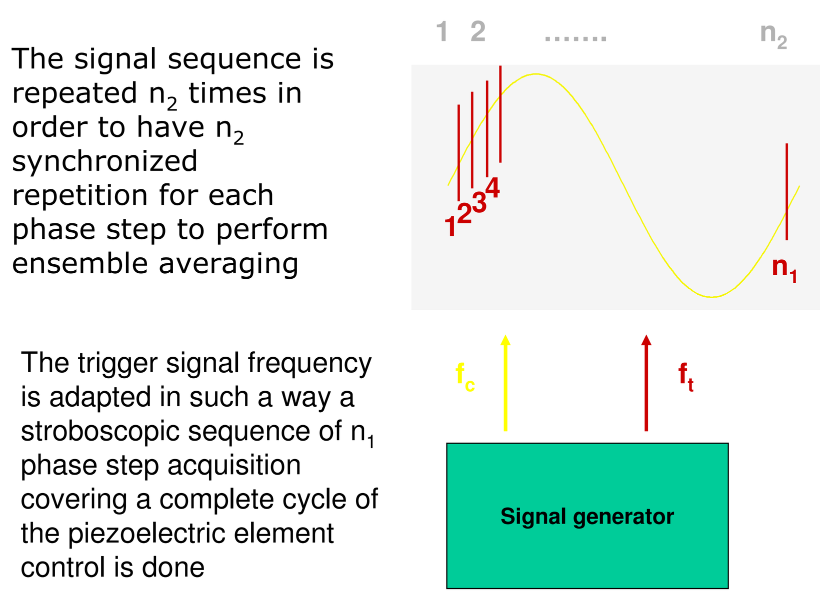

Figure 6: Stroboscopic image acquisition method

In the experimental configuration, optical aberrations play a role since they affect the position and shape of the particle images and as a consequence the velocity field . The two main optical aberration experienced are astigmatism (figure 9) and measurement plane deformation (figure 10). Astigmatism cannot be avoided in the experimental configuration, as it is clearly observed on droplet images were particles above and bellow the focalisation plane appear as perpendicular lines (Figure 11). Nevertheless cross correlation method is not sensitive on particle image shape. As the measurement plane defined by the focal plane of the microscope is located inside a curved transparent object, it deformed as it was passing through a lens. The deformation of the objective plane affects the measurements as a function of the optical configuration, droplet curvature and relative refractive index. However, in the studied configuration, deformed plane differs only from the straight one of about 8 μm.

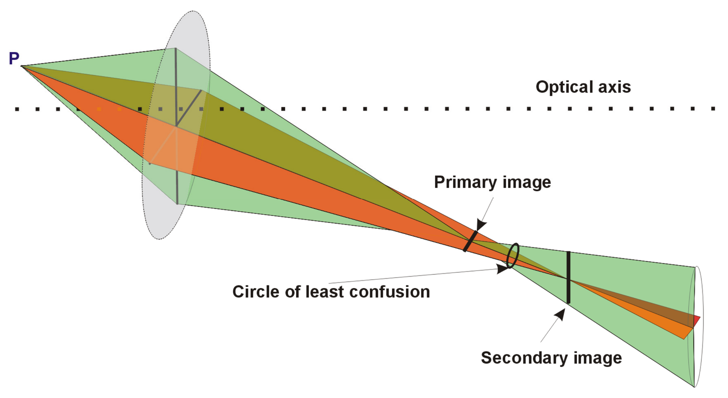

Figure 9: Schematic drawing of the astigmatic aberration

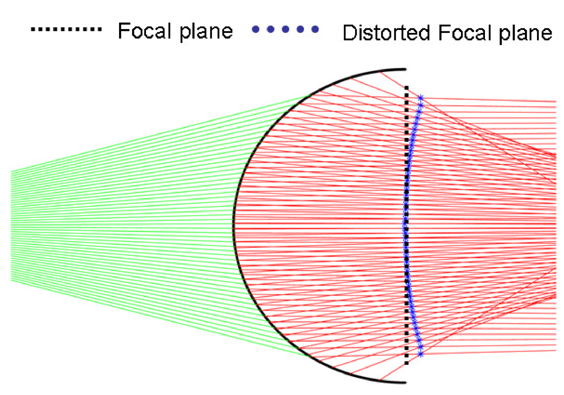

Figure 10 : Example of focal plane deformation due to the light rays through a droplet.

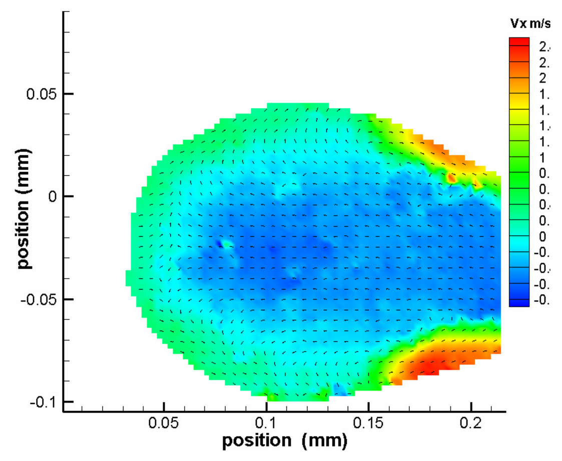

Figure 12: Relative velocity pattern inside the drop

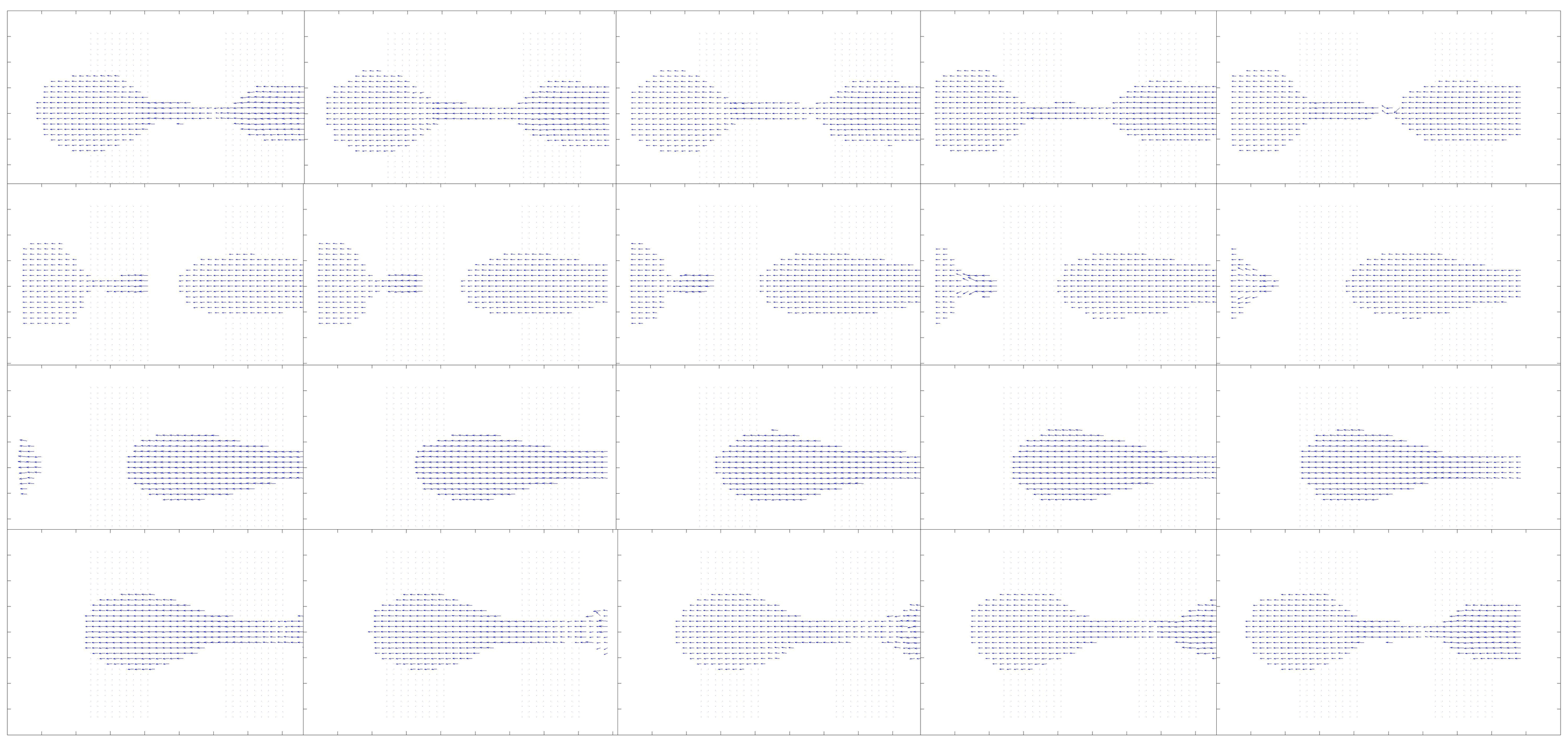

Figure 13: velocity vectors field sequence during drop formation

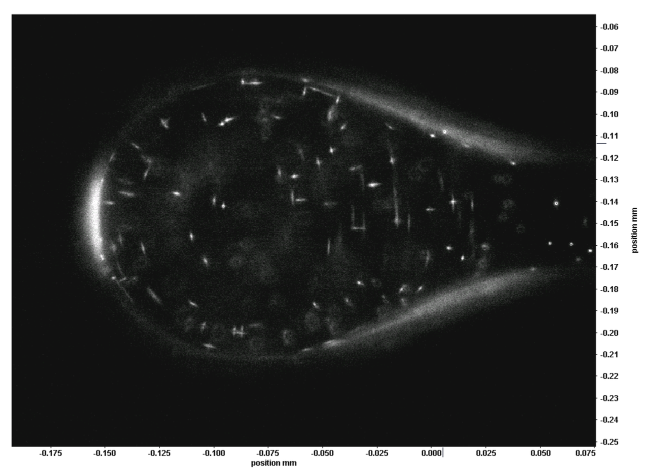

Figure 11: Image of a detaching drop at 40x magnification. The horizontal and vertical strips are images of the particles distorted by astigmatic aberration.

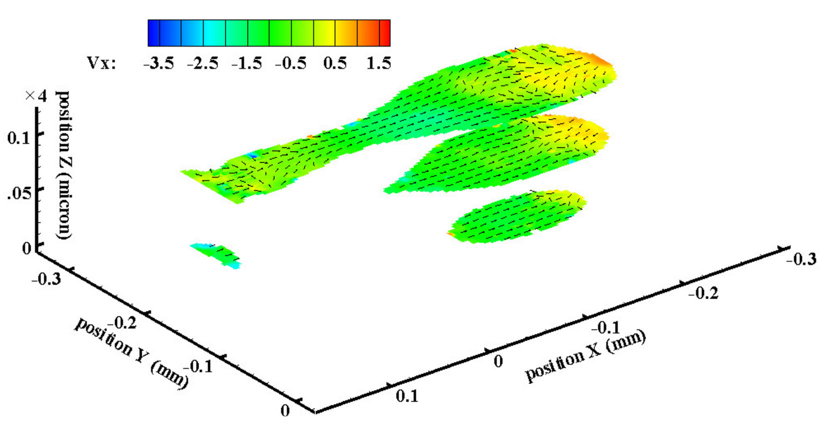

Figure 14: Micro-PIV measurement in different planes of a detaching droplet

As a conclusion, the micro-PIV method is therefore suited to measure the instantaneous vector field inside droplets through cross-correlation methods (figure 12 and 13). The internal flow recirculation is observed. Measurements can be also performed in different planes inside the droplet depending on the focalisation plane (figure 14).