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Particle Image Velocimetry for validation of aneurysm blood flow simulations – comparison of planar and stereo technique

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Experimental validation of computational fluid dynamic (CFD) simulations in the broad field of hemodynamics is still an indispensible requirement to foster acceptance among medical experts. Often, a detailed flow field analysis in different vessel geometries is necessary to understand the impact of involved variables onto the overall system. Simulations are able to deliver such detailed data, however, up to now, in vivo validation is difficult, not very precise or even not possible at all. Therefore, in vitro experiments are conducted where state of the art measurement technologies of fluid dynamical research can be applied and from which highly resolved data for comparison with numerical simulations can be derived.

Particle Image Velocimetry (PIV) is a well established imaging method for investigation of flow fields [1]. It is based on illumination of markers given to the flow and recording of the scattered particle light by appropriate cameras. Typically, double pulsed lasers allow for recording of two consecutive images separated by a short time delay. Velocities of particle ensembles can then be derived by correlation techniques.

The standard PIV approach (referred to as planar PIV) requires only a single camera observing illuminated particles inside a thin laser light sheet. From this technique, two components of the velocity vector in a two dimensional measurement domain can be derived. As this method is relatively simple and robust it is often used as first investigation tool. However, this technique is questionable in flows featuring a highly three dimensional character or in situations where the main velocity component is normal to the light sheet plane. In these cases, the perspective imaging from standard lenses can introduce a significant error to the in-plane velocity components (so called perspective error)[2]. This error influence can be mitigated by a stereoscopic PIV setup, where two cameras observe the measurement domain and all three components of velocity can be obtained [3]. It comes with increased complexity of the measurement itself, particularly in enclosed liquid flows, as cameras have to be aligned and calibrated carefully.

In the present contribution, a comparison of the standard PIV technique and the stereoscopic technique will be presented by means of flow measurements inside a phantom model of a cerebral aneurysm. A dedicated setup was constructed involving all relevant components for accurate measurements. The fluidic cycle was driven by a constant head tank ensuring steady blood flow monitored by an ultrasonic flow meter. The blood analogous liquid was a mixture of water, glycerine, sodium chloride and xanthan gum featuring non Newtonian behaviour and a refractive index of 1.41 which enables index matching with the silicone model of the aneurysm phantom [4]. The model geometry was reconstructed from three dimensional digital subtraction angiography data (3D-DSA) out of which the silicone block was manufactured. For the stereoscopic PIV, a tank featuring a tapered wall section to reduce optical aberrations was constructed in which the model was positioned and which was filled with the index matching fluid. Two PIV cameras each with a viewing direction normal to the oblique walls of the tank were used for recording of fluorescent light emitted by tracer particles doped with Rhodamin B to suppress noisy scatter light. Camera calibration was conducted by means of a two-plane calibration target positioned inside the liquid filled tank.

For the confrontation of the techniques, the laser light sheet was placed at several planes inside the aneurysm sac and at each position and with each method sequences of statistically independent image pairs were recorded for averaging purposes. The resulting mean vector fields of the in-plane velocity components will be presented, compared and discussed with respect to possible measurement errors. A comparison to results of steady numerical simulations of the same aneurysm geometry will complete the contribution to the mini-symposium.

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