1. FINAL PUBLISHABLE SUMMARY REPORT

The characterisation of the aneurysm flow is highly relevant. According to the World Health Organisation (WHO), around 17 million people around the world die of cardiovascular disease (CVD) every year. Effective diagnostics and treatment of certain types of CVD require the characterization of the geometry and mechanic properties of the tissue involved, as well as the local haemo-dynamics. A cardio-vascular simulation specific for each case is a necessary step to improve the diagnostic and treatment of CVD. This is why it is important to develop software models that evaluate the mechanics behaviour of the blood, the arterial wall and the devises designed to alleviate the different pathologies. This project aims to improve numerical simulations with the instantaneous 3C-3D velocity field measurements in brain aneurysms.

Holographic Particle Image Velocimetry (HPIV) provides a means to make simultaneous three component three-dimensional (3C-3D) measurements of a seeded fluid flow. Implicit in the analysis of HPIV recordings is the assumption that light scattered from a laser source is recorded directly by the hologram such that multiple scattering is negligible. In practice, however, multiple scattering effects increase background noise, thereby decreasing the SNR and ultimately limiting the number of velocity vectors that can be retrieved from a given flow field. Tomographic methods using several recordings from different observation directions have been proposed in the last years to mitigate this problem.

In this project, the temporal evolution of the velocity fields during each pulsatile cycle of the flow inside an aneurysm model with and without endovascular has been considered. To obtain an appropriate sampling of the velocity measurements a relatively high seeding concentration will be required, and therefore the application of Optical Diffraction Tomography (ODT) in HPIV was proposed by the researcher.

Consequently the objectives of the project were as follows:

<u>1.- ODT set-up for the characterization of biological flows</u>. A working ODT set-up has been implemented. Furthermore, several configurations have been considered and built during the first year of the project. For a dynamic experiment such in the case of the aneurysm flow, a double cavity Nd:YAG pulsed laser has been used and in consequence several parts of the initial set-up were re-arranged. In addition the position of the system aperture has been moved to the focal plane of the imaging lens. This ensures that the depth of field and the spatial resolution will be uniform in the whole studied volume.

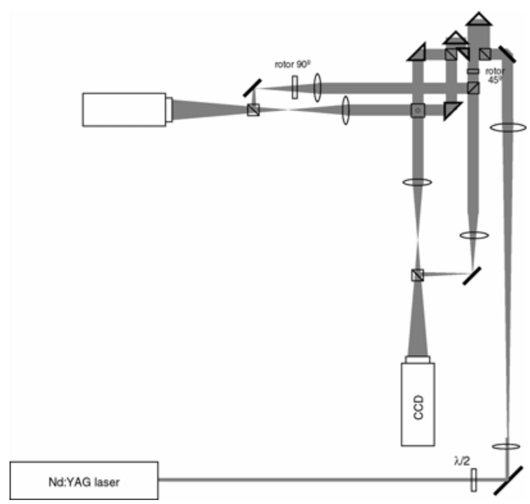


Figure 1 ODT working set-up.

2. Implementation of linear ODT in HPIV. Some preliminary ODT experiments were recorded in order to determine and implement in Matlab the required image processing steps, such as removing the background illumination or calibrating the camera positions. For this purpose a home-made test-object consisting on seeding particles in a flat box of 0.1mm width has been built. The 3D particle position can be assumed as the 3D maximum location of the small blobs. A better result can be obtained by adjusting the intensity value to a quadratic dependence with the three coordinates. In some measurements obtained from only one hologram, the error or spatial resolution of the in-plane coordinates is roughly 12 μm, while the on-axis position can be obtained with an error of 2mm. To reduce this on-axis error the combination of the particle images obtained from both cameras will be needed, as expected. These experiments have been also used to perform some preliminary calibration of both cameras positions.

It has been also settled that a Particle Tracking Velocimetry approach could be more suitable for the resultant ODT images than a standard PIV analysis. For that reason a Matlab implementation of several intermediate algorithms has been done so far: they include a 3D particle location as shown above, and a 3D image particle correlation for displacement measurements. Furthermore, a comparison of several methods to perform the 3D correlation has been done. These algorithms have been applied to recover the 3D position and velocity of particles inside an oscillating droplet (fig. 2). The results have been presented in the B&D 2009 conference and will be reported in a paper currently on preparation.

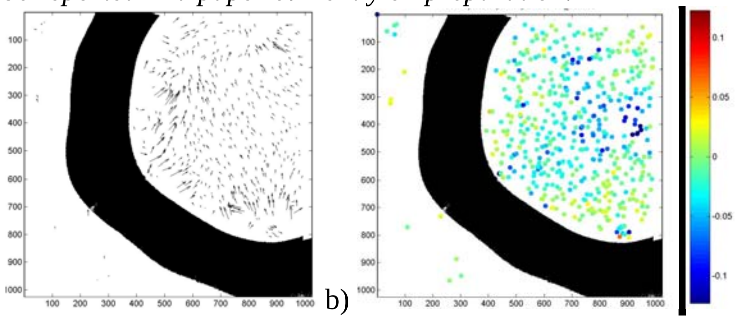
a) 

Figure 2 3D velocity field inside an oscillating droplet: a) in-plane velocity vectors, b) out of plane component.

3. Characterization of the flow inside an aneurysm with and without coils. Some preliminary ODT experiments of a transparent model of an aneurism have been done (fig. 3). The previously validated particle tracking algorithms did locate a great amount of dust and bubbles on the wall of the silicone model. As a consequence the aneurism wall deformation can be studied just following the displacement of these features instead of the distortion of the phase map. However the seeding particles of the flow were obscured. Some experiments were carried out to find the appropriate tracer size and concentration. We can conclude that a significant reduction on the concentration and special care to remove any other source of noise are needed.

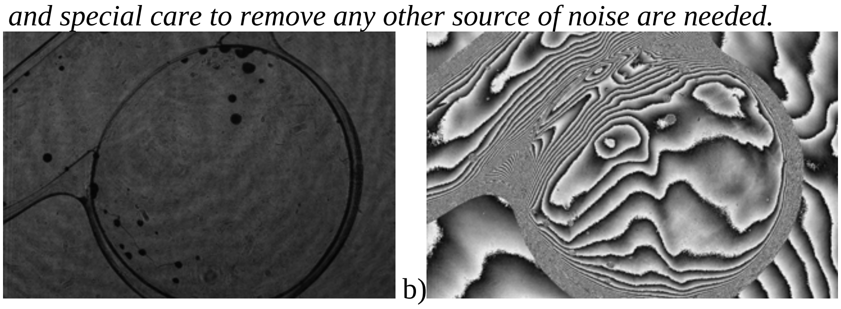
a) 

Figure 3 Modulus (a) and phase map (b) obtained from an aneurism model.

4. Image correction of the particle field. The previous image (figure 3b), also shows the numerous fringes obtained in the phase map even when the aneurism is immersed in a index liquid fairly matched (within 0.5%). Though, as far as the fringe pattern can be resolved for successful background elimination, the particle position can be retrieved. Experiments show that the particle location will not differ in these cases from the expected position within the *resolution for the numerical aperture of the system. Thus no image correction of the particle field is needed.*

5. Implementation of non-linear ODT in HPIV. *It has been clear during the first part of the project that the introduction of High Performance Computing (HPC) techniques could be critical to reach the last and more important objective. Thus, intensive work has been done towards this goal. A new non-linear ODT algorithm has been recently proposed by the researcher that would allow a significant reduction on the computational requirements and a 3D implementation for the case of the aneurysm model. Also this task has been selected as a pilot project in the national E-ciencia network, and a new collaboration for the parallel computing implementation of the non-linear ODT algorithm with a HPC research group of the University of Almería (Spain) has been started.*