THREE-DIMENSIONAL FLOW RECONSTRUCTION IN A DISSECTED AORTA FROM 4D-MRI DATA

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Introduction

Advances in flow reconstruction techniques allow predicting the evolution of the blood flow using sparse measurements. In this study, we investigate the potential of applying a linear dynamic estimator to reconstruct the unsteady three-dimensional blood flow in a dissected aorta form 4-Dimensional Flow Magnetic Resonance Imaging (4D-MRI) measurement data in one plane.

Methodology

The training data used to identify the dynamic estimator is generated using a simulated flow field in a rigid-wall patient-specific luminal geometry. This was reconstructed by manual segmentation of CTA data using Simpleware ScanIP and Autodesk Meshmixer and non-rigidly registered to the 4D-MRI domain. The flow field is simulated using Reynolds Average Navier Stokes (RANS) and the K-Omega SST turbulence model [1]. The simulation results match well with the 4D-MRI data, providing improved spatial and temporal resolution of the flow field.

Three-dimensional Proper Orthogonal Decomposition (POD) is used to obtain a reduced order model of the fluctuating flow. The flow field is approximated using the first four most energetic POD modes, which carry 96% of the total kinetic energy.

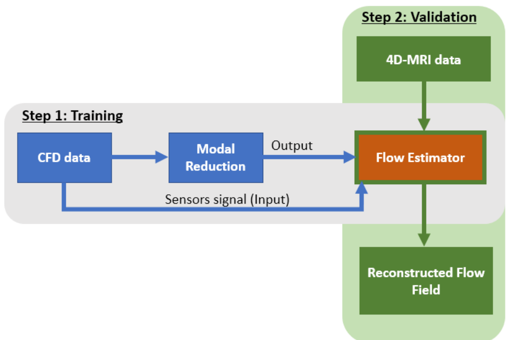

Figure 1: A schematic of the training and validation steps of the dynamic estimator

The dynamic estimator is identified using a subspace system identification algorithm, N4SID, with the fluctuated streamwise velocity upstream of the aorta arch as input and the time coefficients of the POD modes as output. Figure 1 shows a schematic of the training and validation steps used to design the dynamic estimator.

Results

The estimator performance is validated using 4D-MRI velocity data (figure 2). The reconstructed flow field is then compared to the CFD (Computational Fluid Dynamics) and the 4D-MRI data at other planes.

With reference to the training data from CFD, the average estimation accuracy is around 94%. This is the correlation coefficient between the fluctuating streamwise velocity at the different planes along the dissected aorta, part of which is shown in figure 2. When the reconstructed flow field is compared to the 4D-MRI data, the average estimation accuracy is around 90%, based on the maximum and minimum streamwise velocities on the planes.

The estimation accuracy looks very promising. Further investigations into improving it are currently being considered. To the best of the authors' knowledge, this represents the first study to reconstruct the three-dimensional blood flow patterns using a linear dynamic estimator from planar 4D-MRI data.

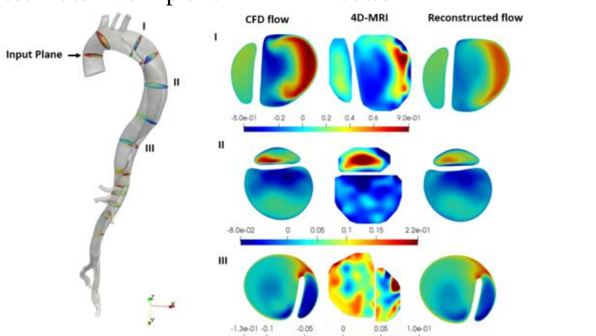

Figure 2: Dissected Aorta geometry with the input plane and selected validation planes (I, II and III) on the left and comparisons between the CFD, 4D-MRI and the reconstructed flow fields on the right.

References

1. C. Stokes, et al, J Biomech, 129, 110793, 20