Computational fluid dynamics of the left heart with variational multiscale LES modeling

Filippo Menghini[a*], **Luca Dedé**[b], **Davide Forti**[a] **and Alfio Quarteroni**[a]

[a] Chair of Modeling and Scientific Computing
École Polytechnique Fédérale de Lausanne
Av. Piccard, Station 8, 1015 Lausanne, Vaud, Switzerland

[b] Dipartimento di Matematica
Politecnico di Milano
Piazza L. da Vinci 32, 20133 Milano, Italy

ABSTRACT

The study of hemodynamics has received great attention during the last years because of the possibility of gaining deep insights into physiological and pathological mechanisms due to the blood fluid dynamics such as formation of aneurysms, bypass interactions with the blood flow, thrombi dynamics and many others. In this work, we consider the mathematical modeling and numerical simulation of the blood dynamics in an idealized human left heart. Since the domain is moving we solve the Navier-Stokes equations in an Arbitrary Lagrangian Eulerian (ALE) framework by assigning the domain velocity on the boundary and by extending it in the interior with a standard harmonic extension. The volume variation in time and the inlet and outlet flows are modeled based on physiological data. The blood flow in the left atrium and ventricle experiences strong accelerations and decelerations due to the pulsatile nature of the flow and to the rapid changes of the chambers shape. This eventually involves the transition to a turbulent regime. To deal with this problem, we use a variational multiscale (VMS) modeling for large eddy simulation (LES) that can be used in laminar, transitional and turbulent flows. We simulate several heart cycles and we perform a phase-averaging of the results. With this approach, we obtain physically meaningful time dependent indicators of the flow such as the total kinetic energy, the fluctuating kinetic energy and the enstropy as well as local indicators as the root mean square of the velocity and of the pressure. By analyzing these results we locate the space and time of occurrence of turbulence transition and we check the suitability of the variational multiscale LES model compared to a more simple Streamwise Upwind Petrov Galerkin (SUPG) stabilization method.

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