ERCIM "Alain Bensoussan" Fellowship Scientific Report

Fellow: Alfonso CAIAZZO
Visited location: INRIA Rocquencourt
Duration of Visit: 12 months (01.12.2008 - 30.11.2009)

I - Scientific activity

Research in collaboration with: M. Fernández, J.-F. Gerbeau, V. Martin, I.E. Vignon-Clementel.
Scientific contact: J.-F. Gerbeau, `jean-frederic.gerbeau@inria.fr`

During my visit I joined the team REO (focusing on simulation of biological flows), working in particular on numerical methods for hemodynamics, fluid-structure interaction in blood vessels and patient specific modeling.

Fluid-Structure Interaction in stented aneurysm In the first months I have been introduced to the software tools currently employed (and developed) at INRIA (the FE - based fluid solver, and several mesh processing routines). As first task, I set up simulations of Fluid-Structure interactions in a model of stented Abdominal Aortic Aneurysm (AAA). We worked both on an analytical model geometry and on a realistic porcine geometry obtained from medical imaging, performing numerical simulations in physiological conditions, reaching hydodynamical states comparable with the experimental data. The main issues have been to create a suitable computational mesh starting from the realistic geometry, and to extend to these cases a model previously proposed[1] for stented cerebral aneurysms.
Results of this work have been presented at the conference *Computational and Mathematical Biomedical Engineering* (CMBE 2009).

Stabilized FE methods for fluid through porous interfaces In parallel, to improve the efficiency of the numerical method, we derived a fractional step formulation for simulation of an incompressible fluid through a porous interface. From the mathematical point of view, the main difficulties concerned the treatment of the jump conditions and the resulting stability properties of the scheme. We set up a formulation combining the standard fractional step approach, the model of porous interface as additional dissipative term, and a penalization term to impose the jump relations at the interface in a weaker sense. From a more technical point of view, issues

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[1]M.Fernández, J.F.Gerbeau, V.Martin, M2AN (2008).

involving the implementation of non-standard terms in the finite element library had to be solved.

The application of the resulting scheme is not restricted to the particular case, but can be useful also in more general situations. A manuscript on the topic has been recently submitted, and the results will be presented at the next *Workshop on Numerical Analysis of Partial Differential Equations* (WONAPDE 2010).

II - Publications

- A.Caiazzo, M.Fernández, J.-F. Gerbeau, V.Martin.
  Finite element formulation for incompressible flows through porous interfaces, submitted to SIAM J. of Sci. Comp.
  Abstract. We propose and analyze different finite element formulations to simulate incompressible flow through a porous interface. From the mathematical point of view, the porous interface is treated as a surface measure term in the Navier-Stokes equations, characterized by a resistance parameter. We analyze first a simpler variant of a previously proposed monolithic approach, which is proved to be stable without any extra interface pressure stabilization. Then we consider a fractional step formulation based on the Chorin-Temam projection scheme. We show that an appropriate Nitsche interface treatment of the pressure interface conditions allows to derive uniform stability, independently on the resistance of the interface. The presented theoretical stability and convergence results will be illustrated via numerical experiments.

III - Attended seminars, workshops and conferences

- June 15th - 20th, 2009: Workshop on Computational Multiscale Methods, Oberwolfach Mathematics Research Center (MFO)

- June 29th - July 02nd, 2009: Conference on Computational and Mathematical Biomedical Engineering; talk presented: *Blood Flows through stents in Abdominal Aortic Aneurysms.*

- November 16th -19th, 2009: CEA-EDF-INRIA Schools on "Cardiac and brain electrophysiology: modeling and simulation", INRIA Rocquencourt.

- January 11th - 15th, 2010 (upcoming): Workshop on Numerical Analysis of Partial Differential Equations; talk to be presented: *Numerical schemes for incompressible flows through porous interfaces.*

IV - Research exchange program

1 Fraunhofer Institut für Rechner- und Softwaretechnik (FIRST),
May 05th - 09th;
contact: Dr. Steffen Unger (`steffen.unger@first.fraunhofer.de`).
Dr. Unger introduced me to the heads of the different projects at
FIRST. I had the opportunity to have discussions with experts in the
field of software architecture, in particular in connection with medical
applications. I presented a talk concerning the computational modeling of stented aneurysms.

2 University of Geneva, Department of Computer Science,
October 20th - 23rd;
contact: Prof. Bastien Chopard (`Bastien.Chopard@unige.ch`).
Part of the visit to Prof. Chopard was dedicated to an ongoing discussion on the analysis of lattice Boltzmann schemes. Furthermore, I
could discuss researchers of his group, who have several year of experience in computational modeling of thrombus formation in connection
with aneurysms. In a short talk, I presented our results concerning
the FE approaches for blood flow through a porous stent.