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Project-Team REO

Numerical simulation of biological flows

IN COLLABORATION WITH: Laboratoire Jacques-Louis Lions

RESEARCH CENTER
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THEME
Observation, Modeling, and Control for Life Sciences

Table of contents

Project-Team REO

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2. Overall Objectives

2.1. Introduction

REO is a joint project of the Inria Research Center of Paris-Rocquencourt and the Jacques-Louis Lions Laboratory (LJLL) of the Pierre and Marie Curie University (Paris 6) and CNRS (UMR7598). Its research activities are aimed at

- modeling some aspects of the cardiovascular and respiratory systems, both in normal and pathological states;
- developing and analyzing efficient, robust and reliable numerical methods for the simulation of those models;
- developing simulation software to guide medical decision and to design more efficient medical devices.

2.2. Highlights of the Year

- Marc Thiriet et al. were awarded the "JBSE Paper of the Year 2010" for their article [6].
- New european project (FP7-PEOPLE Marie-Curie Action: "Initial Training Networks") REVAMMAD about Retinal Modeling, Measurement and Diagnosis (Jean-Frédéric Gerbeau, Working Package leader)
- New ANR project EXIFSI (ANR JCJC) about fluid-structure interaction (Miguel Fernández, Principal Investigator)

3. Scientific Foundations

3.1. Multiphysics modeling

In large vessels and in large bronchi, blood and air flows are generally supposed to be governed by the incompressible Navier-Stokes equations. Indeed in large arteries, blood can be supposed to be Newtonian, and at rest air can be modeled as an incompressible fluid. The cornerstone of the simulations is therefore a Navier-Stokes solver. But other physical features have also to be taken into account in simulations of biological flows, in particular fluid-structure interaction in large vessels and transport of sprays, particles or chemical species.

3.1.1. Fluid-structure interaction

Fluid-structure coupling occurs both in the respiratory and in the circulatory systems. We focus mainly on blood flows since our work is more advanced in this field. But the methods developed for blood flows could be also applied to the respiratory system.

Here “fluid-structure interaction” means a coupling between the 3D Navier-Stokes equations and a 3D (possibly thin) structure in large displacements.

The numerical simulations of the interaction between the artery wall and the blood flows raise many issues: (1) the displacement of the wall cannot be supposed to be infinitesimal, geometrical nonlinearities are therefore present in the structure and the fluid problem have to be solved on a moving domain (2) the densities of the artery walls and the blood being close, the coupling is strong and has to be tackled very carefully to avoid numerical instabilities, (3) “naive” boundary conditions on the artificial boundaries induce spurious reflection phenomena.

Simulation of valves, either at the outflow of the cardiac chambers or in veins, is another example of difficult fluid-structure problems arising in blood flows. In addition, very large displacements and changes of topology (contact problems) have to be handled in those cases.

Because of the above mentioned difficulties, the interaction between the blood flow and the artery wall has often been neglected in most of the classical studies. The numerical properties of the fluid-structure coupling in blood flows are rather different from other classical fluid-structure problems. In particular, due to stability reasons it seems impossible to successfully apply the explicit coupling schemes used in aeroelasticity.

As a result, fluid-structure interaction in biological flows raise new challenging issues in scientific computing and numerical analysis : new schemes have to be developed and analyzed.

We have proposed over the last few years several efficient fluid-structure interaction algorithms. We are now using these algorithms to address inverse problems in blood flows (for example, estimation of artery wall stiffness from medical imaging).

3.1.2. Aerosol

Complex two-phase fluids can be modeled in many different ways. Eulerian models describe both phases by physical quantities such as the density, velocity or energy of each phase. In the mixed fluid-kinetic models, the biphasic fluid has one dispersed phase, which is constituted by a spray of droplets, with a possibly variable size, and a continuous classical fluid.

This type of model was first introduced by Williams [77] in the frame of combustion. It was later used to develop the Kiva code [67] at the Los Alamos National Laboratory, or the Hesione code [72], for example. It has a wide range of applications, besides the nuclear setting: diesel engines, rocket engines [70], therapeutic sprays, *etc.* One of the interests of such a model is that various phenomena on the droplets can be taken into account with an accurate precision: collision, breakups, coagulation, vaporization, chemical reactions, *etc.*, at the level of the droplets.

The model usually consists in coupling a kinetic equation, that describes the spray through a probability density function, and classical fluid equations (typically Navier-Stokes). The numerical solution of this system relies on the coupling of a method for the fluid equations (for instance, a finite volume method) with a method fitted to the spray (particle method, Monte Carlo).

We are mainly interested in modeling therapeutic sprays either for local or general treatments. The study of the underlying kinetic equations should lead us to a global model of the ambient fluid and the droplets, with some mathematical significance. Well-chosen numerical methods can give some tracks on the solutions behavior and help to fit the physical parameters which appear in the models.

3.2. Multiscale modeling

Multiscale modeling is a necessary step for blood and respiratory flows. In this section, we focus on blood flows. Nevertheless, similar investigations are currently carried out on respiratory flows.

3.2.1. Arterial tree modeling

Problems arising in the numerical modeling of the human cardiovascular system often require an accurate description of the flow in a specific sensible subregion (carotid bifurcation, stented artery, *etc.*). The description of such local phenomena is better addressed by means of three-dimensional (3D) simulations, based on the numerical approximation of the incompressible Navier-Stokes equations, possibly accounting for compliant (moving) boundaries. These simulations require the specification of boundary data on artificial boundaries that have to be introduced to delimit the vascular district under study. The definition of such boundary conditions is critical and, in fact, influenced by the global systemic dynamics. Whenever the boundary data is not available from accurate measurements, a proper boundary condition requires a mathematical description of the action of the reminder of the circulatory system on the local district. From the computational point of view, it is not affordable to describe the whole circulatory system keeping the same level of detail. Therefore, this mathematical description relies on simpler models, leading to the concept of *geometrical multiscale* modeling of the circulation [73]. The underlying idea consists in coupling different models (3D, 1D or 0D) with a decreasing level of accuracy, which is compensated by their decreasing level of computational complexity.

The research on this topic aims at providing a correct methodology and a mathematical and numerical framework for the simulation of blood flow in the whole cardiovascular system by means of a geometric multiscale approach. In particular, one of the main issues will be the definition of stable coupling strategies between 3D and reduced order models.

To model the arterial tree, a standard way consists of imposing a pressure or a flow rate at the inlet of the aorta, *i.e.* at the network entry. This strategy does not allow to describe important features as the overload in the heart caused by backward traveling waves. Indeed imposing a boundary condition at the beginning of the aorta artificially disturbs physiological pressure waves going from the arterial tree to the heart. The only way to catch this physiological behavior is to couple the arteries with a model of heart, or at least a model of left ventricle.

A constitutive law for the myocardium, controlled by an electrical command, has been developed in the CardioSense3D project [1]. One of our objectives is to couple artery models with this heart model.

A long term goal is to achieve 3D simulations of a system including heart and arteries. One of the difficulties of this very challenging task is to model the cardiac valves. To this purpose, we plan to mix arbitrary Lagrangian Eulerian and fictitious domain approaches, or simplified valve models based on an immersed surface strategy.

3.2.2. Heart perfusion modeling

The heart is the organ that regulates, through its periodical contraction, the distribution of oxygenated blood in human vessels in order to nourish the different parts of the body. The heart needs its own supply of blood to work. The coronary arteries are the vessels that accomplish this task. The phenomenon by which blood reaches myocardial heart tissue starting from the blood vessels is called in medicine perfusion. The analysis of heart perfusion is an interesting and challenging problem. Our aim is to perform a three-dimensional dynamical numerical simulation of perfusion in the beating heart, in order to better understand the phenomena linked to perfusion. In particular the role of the ventricle contraction on the perfusion of the heart is investigated as well as the influence of blood on the solid mechanics of the ventricle. Heart perfusion in fact implies the interaction between heart muscle and blood vessels, in a sponge-like material that contracts at every heartbeat via the myocardium fibers.
Despite recent advances on the anatomical description and measurements of the coronary tree and on the corresponding physiological, physical and numerical modeling aspects, the complete modeling and simulation of blood flows inside the large and the many small vessels feeding the heart is still out of reach. Therefore, in order to model blood perfusion in the cardiac tissue, we must limit the description of the detailed flows at a given space scale, and simplify the modeling of the smaller scale flows by aggregating these phenomena into macroscopic quantities, by some kind of "homogenization" procedure. To that purpose, the modeling of the fluid-solid coupling within the framework of porous media appears appropriate.
Poromechanics is a simplified mixture theory where a complex fluid-structure interaction problem is replaced by a superposition of both components, each of them representing a fraction of the complete material at every point. It originally emerged in soils mechanics with the work of Terzaghi [76], and Biot [68] later gave a description of the mechanical behavior of a porous medium using an elastic formulation for the solid matrix, and Darcy's law for the fluid flow through the matrix. Finite strain poroelastic models have been proposed (see references in [69]), albeit with *ad hoc* formulations for which compatibility with thermodynamics laws and incompressibility conditions is not established.

3.2.3. Tumor and vascularization

The same way the myocardium needs to be perfused for the heart to beat, when it has reached a certain size, tumor tissue needs to be perfused by enough blood to grow. It thus triggers the creation of new blood vessels (angiogenesis) to continue to grow. The interaction of tumor and its micro-environment is an active field of research. One of the challenges is that phenomena (tumor cell proliferation and death, blood vessel adaptation, nutrient transport and diffusion, etc) occur at different scales. A multi-scale approach is thus being developed to tackle this issue. The long term objective is to predict the efficiency of drugs and optimize therapy of cancer.

[1] http://www-sop.inria.fr/CardioSense3D/

3.2.4. Respiratory tract modeling

We aim to develop a multiscale modeling of the respiratory tract. Intraprenchymal airways distal from generation 7 of the tracheabronchial tree (TBT), which cannot be visualized by common medical imaging techniques, are modeled either by a single simple model or by a model set according to their order in TBT. The single model is based on straight pipe fully developed flow (Poiseuille flow in steady regimes) with given alveolar pressure at the end of each compartment. It will provide boundary conditions at the bronchial ends of 3D TBT reconstructed from imaging data. The model set includes three serial models. The generation down to the pulmonary lobule will be modeled by reduced basis elements. The lobular airways will be represented by a fractal homogenization approach. The alveoli, which are the gas exchange loci between blood and inhaled air, inflating during inspiration and deflating during expiration, will be described by multiphysics homogenization.

4. Application Domains

4.1. Blood flows

Cardiovascular diseases like atherosclerosis or aneurysms are a major cause of mortality. It is generally admitted that a better knowledge of local flow patterns could improve the treatment of these pathologies (although many other biophysical phenomena obviously take place in the development of such diseases). In particular, it has been known for years that the association of low wall shear stress and high oscillatory shear index give relevant indications to localize possible zones of atherosclerosis. It is also known that medical devices (graft or stent) perturb blood flows and may create local stresses favorable with atherogenesis. Numerical simulations of blood flows can give access to this local quantities and may therefore help to design new medical devices with less negative impacts. In the case of aneurysms, numerical simulations may help to predict possible zones of rupture and could therefore give a guide for treatment planning.

In clinical routine, many indices are used for diagnosis. For example, the size of a stenosis is estimated by a few measures of flow rate around the stenosis and by application of simple fluid mechanics rules. In some situations, for example in the case a sub-valvular stenosis, it is known that such indices often give false estimations. Numerical simulations may give indications to define new indices, simple enough to be used in clinical exams, but more precise than those currently used.

It is well-known that the arterial circulation and the heart (or more specifically the left ventricle) are strongly coupled. Modifications of arterial walls or blood flows may indeed affect the mechanical properties of the left ventricle. Numerical simulations of the arterial tree coupled to the heart model could shed light on this complex relationship.

One of the goals of the REO team is to provide various models and simulation tools of the cardiovascular system. The scaling of these models will be adapted to the application in mind: low resolution for modeling the global circulation, high resolution for modeling a small portion of vessel.

4.2. Respiratory tracts

Breathing, or “external” respiration (“internal” respiration corresponds to cellular respiration) involves gas transport though the respiratory tract with its visible ends, nose and mouth. Air streams then from the pharynx down to the trachea. Food and drink entry into the trachea is usually prevented by the larynx structure (epiglottis). The trachea extends from the neck into the thorax, where it divides into right and left main bronchi, which enter the corresponding lungs (the left being smaller to accommodate the heart). Inhaled air is then convected in the bronchus tree which ends in alveoli, where gaseous exchange occurs. Surfactant reduces the surface tension on the alveolus wall, allowing them to expand. Gaseous exchange relies on simple diffusion on a large surface area over a short path between the alveolus and the blood capillary under concentration gradients between alveolar air and blood. The lungs are divided into lobes (three on the right, two on the left) supplied by lobar bronchi. Each lobe of the lung is further divided into segments (ten segments of the right lung and eight of the left). Inhaled air contains dust and debris, which must be filtered, if possible, before they reach the alveoli. The tracheobronchial tree is lined by a layer of sticky mucus, secreted by the epithelium. Particles which hit the side wall of the tract are trapped in this mucus. Cilia on the epithelial cells move the mucous continually towards the nose and mouth.

Each lung is enclosed in a space bounded below by the diaphragm and laterally by the chest wall and the mediastinum. The air movement is achieved by alternately increasing and decreasing the chest pressure (and volume). When the airspace transmural pressure rises, air is sucked in. When it decreases, airspaces collapse and air is expelled. Each lung is surrounded by a pleural cavity, except at its hilum where the inner pleura give birth to the outer pleura. The pleural layers slide over each other. The tidal volume is nearly equal to 500 ml.

The lungs may fail to maintain an adequate supply of air. In premature infants surfactant is not yet active. Accidental inhalation of liquid or solid and airway infection may occur. Chronic obstructive lung diseases and lung cancers are frequent pathologies and among the three first death causes in France.

One of the goals of REO team in the ventilation field is to visualize the airways (virtual endoscopy) and simulate flow in image-based 3D models of the upper airways (nose, pharynx, larynx) and the first generations of the tracheobronchial tree (trachea is generation 0), whereas simple models of the small bronchi and alveoli are used (reduced-basis element method, fractal homogenization, multiphysics homogenization, lumped parameter models), in order to provide the flow distribution within the lung segments. This activity has been carried out in the framework of successive research programs: RNTS "R-MOD" until 2005, ACI "le-poumon-vous-dis-je" until 2007 and ANR M3RS until 2013.

4.3. Cardiac electrophysiology

The purpose is to simulate the propagation of the action potential in the heart. A lot of works has already been devoted to this topic in the literature (see *e.g.* [71], [75], [74] and the references therein), nevertheless there are only very few studies showing realistic electrocardiograms obtained from partial differential equations models. Our goal is to find a compromise between two opposite requirements: on the one hand, we want to use predictive models, and therefore models based on physiology, on the other hand, we want to use models simple enough to be parametrized (in view of patient-specific simulations). We are now working on using our ECG simulator to address the inverse problem of electrocardiology. In collaboration with the Macsproject-team, we are working on the electromechanical coupling in the myocardium. We are also interested in various clinical and industrial issues related to cardiac electrophysiology. In particular, we collaborated with ELA Medical company (pacemaker manufacturer, Sorin group).

5. Software

5.1. LiFE-V library

Participants: Miguel Ángel Fernández Varela [correspondant], Jean-Frédéric Gerbeau.

LiFE-V [2] is a finite element library providing implementations of state of the art mathematical and numerical methods. It serves both as a research and production library. LiFE-V is the joint collaboration between three institutions: Ecole Polytechnique Fédérale de Lausanne (CMCS) in Switzerland, Politecnico di Milano (MOX) in Italy and Inria (REO) in France. It is a free software under LGPL license.

5.2. Mistral library

Participants: Cristóbal Bertoglio Beltran, Jean-Frédéric Gerbeau [correspondant], Vincent Martin.

Mistral is a finite element library which implements in particular fluid-structure interaction algorithms (ALE and Fictitious domain formulations), fluid surface flow (ALE) and incompressible magnetohydrodynamics equations. Mistral results from a collaboration between Inria and ENPC (CERMICS).

[2] http://www.lifev.org/

5.3. FELiScE

Participants: Grégory Arbia, Cesare Corrado, Miguel Ángel Fernández Varela, Justine Fouchet-Incaux, David Froger, Jean-Frédéric Gerbeau [correspondant], Damiano Lombardi, Elisa Schenone, Saverio Smaldone, Marina Vidrascu, Irène Vignon-Clementel.

FELiScE – standing for "Finite Elements for Life Sciences and Engineering" – is a new finite element code which the MACS and REO project-teams have decided to jointly develop in order to build up on their respective experiences concerning finite element simulations. One specific objective of this code is to provide in a unified software environment all the state-of-the-art tools needed to perform simulations of the complex cardiovascular models considered in the two teams – namely involving fluid and solid mechanics, electrophysiology, and the various associated coupling phenomena. FELISCE is written in C++, and may be later released as an opensource library. https://gforge.inria.fr/projects/felisce/

5.4. SHELDDON

Participant: Marina Vidrascu [correspondant].

SHELDDON (SHELls and structural Dynamics with DOmain decomposition in Nonlinear analysis) is a finite element library based on the Modulef package which contains shell elements, nonlinear procedures and PVM subroutines used in domain decomposition or coupling methods, in particular fluid-structure interaction. (https://gforge.inria.fr/projects/shelddon)

6. New Results

6.1. Mathematical and numerical analysis of fluid-structure interaction problems

Participants: Cristóbal Bertoglio Beltran, Muriel Boulakia, Miguel Ángel Fernández Varela, Sébastien Martin, Jean-Frédéric Gerbeau, Jimmy Mullaert, Marina Vidrascu.

- In [26], we study a three-dimensional fluid-structure interaction problem. The motion of the fluid is modeled by the Navier-Stokes equations and we consider for the elastic structure a finite-dimensional approximation of the equation of linear elasticity. The time variation of the fluid domain is not known a priori, so we deal with a free boundary value problem. Our main result yields the local in time existence and uniqueness of strong solutions for this system.
- In [31], a robust finite volume method for the solution of high-speed compressible flows in multi-material domains involving arbitrary equations of state and large density jumps is presented. One of the main contributions of this paper is a tabulation method based on a sparsegrid approximation to solve very efficiently two-phase Riemann problems for arbitrary equations of state. The proposed computational method is illustrated with the three-dimensional simulation of the dynamics of an underwater explosion bubble.
- In [52] we analyze the performances of several Luenberger observers to estimate the state of a fluid-structure interaction model for hemodynamics, when the measurements are assumed to be restricted to displacements or velocities in the solid. The present framework establishes that these methods are very attractive strategies (compared, e.g., to classical variational techniques) to perform state estimation.
- In [51] we analyze two 3D-0D coupling approaches in which a fractional-step projection scheme is used in the fluid. We introduce and analyze an implicitly 3D-0D coupled formulation with enhanced stability properties and which requires a negligible additional computational cost. The theoretical stability results are confirmed by meaningful numerical experiments in patient specific geometries coming from medical imaging.

- In [55] we introduce a class of explicit Robin-Neumann schemes for the explicit coupling of a general thin-structure (e.g., viscoelastic and non-linear) with an incompressible fluid. These methods generalize the displacement correction schemes introduced in [32]. A priori stability and convergence error estimates show that optimal first-order accuracy can be achieved with appropriate extrapolation and without compromising stability. A deep numerical study confirms the theoretical findings.
- In [64] we present two-dimensional simulations of chemotactic self-propelled bacteria swimming in a viscous fluid. Self-propulsion is modelled by a couple of forces of same intensity and opposite direction applied on the rigid bacterial body and on an associated region in the fluid representing the flagellar bundle. The orientations of the individual bacteria are subjected to random changes, with a frequency that depends on the surrounding oxygen concentration, in order to favor the direction of the concentration gradient.
- In [40] we propose a method of modeling sail structures which captures the wrinkling behavior of such structures. The method is validated through experimental and analytical test cases, particularly in terms of wrinkling prediction. An enhanced wrinkling index is proposed as a valuable measure characterizing the global wrinkling development on the deformed structure. The method is based on a pseudo-dynamic finite element procedure involving non-linear MITC shell elements. The major advantage compared to membrane models generally used for this type of analysis is that no ad hoc wrinkling model is required to control the stability of the structure. We demonstrate our approach to analyse the behavior of various structures with spherical and cylindrical shapes, characteristic of downwind sails over a rather wide range of shape constitutive parameters. In all cases convergence is reached and the overall flying shape is most adequately represented, which shows that our approach is a most valuable alternative to standard techniques to provide deeper insight into the physical behaviour. Limitations appear only in some very special instances in which local wrinkling-related instabilities are extremely high and would require specific additional treatments.

6.2. Numerical methods for fluid mechanics and application to blood flows

Participants: Grégory Arbia, Jean-Frédéric Gerbeau, Sébastien Martin, Saverio Smaldone, Marc Thiriet, Irène Vignon-Clementel.

- In [18], a procedure for modeling the heart valves is presented. Instead of modeling complete leaflet motion, leaflets are modeled in open and closed configurations. This method enables significant computational savings compared to complete fluid-structure interaction and contact modeling, while maintaining realistic three-dimensional velocity and pressure distributions near the valve, which is not possible from lumped parameter modeling. To illustrate the versatility of the model, realistic and patient-specific simulations are presented, as well as comparison with complete fluid-structure interaction simulation.
- [37] paves the way for a complete patient-specific fluid-structure vascular modeling in which all types of available measurements could be used to estimate uncertain parameters of biophysical and clinical relevance. We propose a complete methodological chain for the identification of the parameters involved in a model for external tissue support of blood vessels, using patient image data. We demonstrate the use of this framework in a realistic application case involving hemodynamics in the thoracic aorta. The estimation of the boundary support parameters proves successful, in particular in that direct modeling simulations based on the estimated parameters are more accurate than with a previous manual expert calibration.
- In [27] we study the image-based blood flow in the first generation of the pulmonary arterial tree. This patient-specific study is aimed at assessing effects of lung deformation and vascular resistance on the pulmonary blood flow, especially during the acute phase of a pneumothorax and after recovery. Arterial geometry was extracted up to the fifth generation from computed tomography images, and reconstructed. An unsteady laminar flow with a given set of resistances at outlets was modeled. Adaptation is set to match perfusion to ventilation.

- In [44], [36] we study the reciprocal effect of blood circulation and high-intensity focused ultrasound on the temperature field in the liver. High-intensity focused ultrasound (HIFU) is used as a thermal ablation process to eliminate tumors in different body's organs. Blood flow has a cooling effect. Conversely, ultrasounds are responsible for acoustic streaming. A three-dimensional acoustics-thermal-fluid coupling model is carried out to compute the temperature field a given hepatic cancerous region.
- The use of elaborate closed-loop lumped parameter network (LPN) models of the heart and the circulatory system as boundary conditions for 3D simulations can provide valuable global dynamic information, particularly for patient specific simulations. In [30], we have developed and tested a numerical method to couple a 3D Navier-Stokes finite-element formulation and a reduced model of the rest of the circulation, keeping the coupling robust but modular. For Neumann boundaries, implicit, semi-implicit, and explicit quasi-Newton formulations are compared within the time-implicit coupling scheme. The requirements for coupling Dirichlet boundary conditions are also discussed and compared to that of the Neumann coupled boundaries. Both these works were key for applications where blood flows in different directions during the cardiac cycle and where coupling with the rest of the circulation is instrumental (see the shunt optimization application [29]).
- Boundary conditions in patient-specific blood flow simulations is key because pressure and flow within the modeled domain are driven by the interplay between the local 3D hemodynamics and the rest of the circulation. However, these boundary conditions are rarely the measured variables. In [45], we showed how one can go from patient-specific clinical data (MRI and catheterization) to simulation input parameters, including modeling assumptions and the impact of both on simulation results. We explained how Windkessel models and more involved LPN can be calibrated.

  In [34], we developed two multi-scale models, each including the 3D model of the surgical junction constructed from MRI, and a closed-loop LPN derived from pre-operative data obtained from two patients prior to Stage 2 Fontan palliation of single ventricle congenital heart disease. "Virtual" surgeries were performed and a corresponding multi-scale simulation predicted the patient's post-operative hemodynamic conditions, tested under different physiological conditions. The impact of the surgical junction geometry on the global circulation was contrasted with variations of key physiological parameters.
- In [19], a similar 3D multiscale model was used but for the Stage 3 Fontan palliation. Several studies have been done to optimize the geometry of the surgical connection, to minimizing energy losses and improving surgical outcomes, but usually without taking into account respiration or exercise. A respiration model that modulates the extravascular pressures in the thoracic and abdominal cavities was implemented. Results showed that the preoperative model is able to realistically capture cardiac and respiratory oscillations compared to the venous Doppler velocity tracings. Three virtual surgical alternatives were coupled to the LPN and then investigated under rest and exercise conditions.
- In [29], such a 3D-closed loop LPN model was integrated with an automated derivative-free optimization algorithm in an idealized systemic-to-pulmonary shunt anatomy (Stage 1 Fontan palliation). The goal was to optimize shunt geometries. Clinicians selected three objective functions to be maximized: (1) systemic, (2) coronary, and (3) combined systemic and coronary oxygen. Results showed the geometries associated with the favored delivery, the origin of coronary artery flow being driven by the shunt position as well. The results made only sense when the 3D domain was connected to a closed-loop model of the circulation.
- A novel Y-shaped baffle was proposed for the Stage 3 Fontan operation achieving overall superior hemodynamic performance compared with traditional designs. Previously, we investigated if and how the inferior vena cava flow (which contains an important biological hepatic factor) could be best distributed among both lungs. In [41] we proposed a multi-step method for patient-specific optimization of such surgeries to study the effects of boundary conditions and geometry on hepatic factor distribution (HFD). The resulting optimal Y-graft geometry largely depended on the patient left/right pulmonary flow split. Unequal branch size and constrained optimization on

energy efficiency were explored. Two patient-specific examples showed that optimization-derived Y-grafts effectively improved HFD.

6.3. Numerical methods for cardiac electrophysiology

Participants: Muriel Boulakia, Miguel Ángel Fernández Varela, Jean-Frédéric Gerbeau, Vincent Martin, Elisa Schenone.

- In [62], we propose a surface-based electrophysiology formulation, motivated by the modeling of thin structures such as cardiac atria, which greatly reduces the size of the computational models. Our model is specifically devised to retain the key features associated with the anisotropy in the diffusion effects induced by the fiber architecture, with rapid variations across the thickness which cannot be adequately represented by naive averaging strategies. The model relies on a detailed asymptotic analysis in which we identify a limit model and establish strong convergence results. We also provide detailed numerical assessments which confirm an excellent accuracy of the surface-based model – compared with the reference 3D model – including in the representation of a complex phenomenon, namely, spiral waves.

6.4. Lung and respiration modeling

Participants: Laurent Boudin, Paul Cazeaux, Bérénice Grec, Muriel Boulakia, Anne-Claire Egloffe, Benoit Fabreges, Miguel Ángel Fernández Varela, Jean-Frédéric Gerbeau, Céline Grandmont, Stéphane Liwarek, Sébastien Martin, Ayman Moussa.

- [59], [60]:We are concerned here with identifiability, stability properties and estimates for the inverse problem of identifying a Robin coefficient on some non accessible part of the boundary from available data on the other part of boundary corresponding to solutions of the Stokes equations. In [59], we first consider a steady state two-dimensional Stokes problem and study the identifiability of Robin coefficient and then we establish a stability estimate of logarithm type using a global Carleman inequality. We then consider the unsteady problem. In [60]:We prove hölderian and logarithmic stability estimates associated to the unique continuation property for the Stokes system. The proof of these results is based on local Carleman inequalities. In the second part, these estimates on the fluid velocity and on the fluid pressure are applied to solve the inverse problem of identifying a Robin coefficient. For this identification parameter problem, we obtain a logarithmic stability estimate under the assumption that the velocity of a given reference solution stays far from 0 on a part of the boundary where Robin conditions are prescribed.
- In [61] we are interested in the mathematical modeling of the propagation of sound waves in the lung parenchyma, which is a foam–like elastic material containing millions of air– filled alveoli. In this study, the parenchyma is governed by the linearized elasticity equations and the air by the acoustic wave equations. The geometric arrangement of the alveoli is assumed to be periodic with a small period $\varepsilon > 0$. We consider the time–harmonic regime forced by vibrations induced by volumic forces. We use the two–scale convergence theory to study the asymptotic behavior as ε goes to zero and prove the convergence of the solutions of the coupled fluid–structure problem to the solution of a linear–elasticity boundary value problem.
- In [53] we develop and study numerically a model to describe some aspects of sound propagation in the human lung, considered as a deformable and viscoelastic porous medium (the parenchyma) with millions of alveoli filled with air. Transmission of sound through the lung above 1 kHz is known to be highly frequency–dependent. We pursue the key idea that the viscoelastic parenchyma structure is highly heterogeneous on the small scale ε and use two–scale homogenization techniques to derive effective acoustic equations for asymptotically small ε. This process turns out to introduce new memory effects. The effective material parameters are determined from the solution of frequency–dependent micro–structure cell problems. We propose a numerical approach to investigate the sound propagation in the homogenized parenchyma using a Discontinuous Galerkin formulation. Numerical examples are presented.

- In [22], we consider the Maxwell-Stefan model of diffusion previously introduced. We provide a qualitative and quantitative mathematical and basic numerical analysis of the model.
- In [65] we propose an integrated model for oxygen transfer into the blood, coupled with a lumped mechanical model for the ventilation process. We aim at investigating oxygen transfer into the blood at rest or exercise. The first task consists in describing nonlinear effects of the oxygen transfer under normal conditions. We also include the possible diffusion limitation in oxygen transfer observed in extreme regimes involving parameters such as alveolar and venous blood oxygen partial pressures, capillary volume, diffusing capacity of the membrane, oxygen binding by hemoglobin and transit time of the red blood cells in the capillaries. The second task consists in discussing the oxygen concentration heterogeneity along the path length in the acinus.
- In [43] we presented preliminary work on a multiscale 3D-0D airflow model to study differences between healthy and emphysema rats. The 0D model parameters were estimated from experimental data. 3D Navier-Stokes simulations were performed in healthy lungs, and in homogenous and heterogeneous emphysema lungs.

6.5. Miscellaneous

Participants: Laurent Boudin, Jean-Frédéric Gerbeau, Damiano Lombardi, Sébastien Martin, Marina Vidrascu, Irène Vignon-Clementel.

- In [56], a reduced-order model algorithm, based on approximations of Lax pairs, is proposed to solve nonlinear evolution partial differential equations. Contrary to other reduced-order methods, like Proper Orthogonal Decomposition, the space where the solution is searched for evolves according to a dynamics specific to the problem. It is therefore well-suited to solving problems with progressive waves or front propagation. Numerical examples are shown for the KdV and FKPP (nonlinear reaction diffusion) equations, in one and two dimensions.
- In [21], we investigate the asymptotic behaviour of the solutions to the non-reactive fully elastic Boltzmann equations for mixtures in the diffusive scaling. We deal with cross sections such as hard spheres or cut-off power law potentials. We use Hilbert expansions near the common thermodynamic equilibrium granted by the H-theorem. The lower-order non trivial equality obtained from the Boltzmann equations leads to a linear functional equation in the velocity variable which is solved thanks to the Fredholm alternative. Since we consider multicomponent mixtures, the classical techniques introduced by Grad cannot be applied, and we propose a new method to treat the terms involving particles with different masses. The next-order equality in the Hilbert expansion then allows to write the macroscopic continuity equations for each component of the mixture.
- In [58], we discuss some numerical properties of the viscous numerical scheme introduced in [23] to solve the one-dimensional pressureless gases system, and study in particular, from a computational viewpoint, its asymptotic behavior when the viscosity parameter $\varepsilon > 0$ used in the scheme becomes smaller.
- In [33] we study a network-based model for rubber. Since the pioneering work by Treloar, many models based on polymer chain statistics have been proposed to describe rubber elasticity. Recently, Alicandro, Cicalese, and the first author rigorously derived a continuum theory of rubber elasticity from a discrete model by variational convergence. The aim of this paper is twofold. First we further physically motivate this model, and complete the analysis by numerical simulations. Second, in order to compare this model to the literature, we present in a common language two other representative types of models, specify their underlying assumptions, check their mathematical properties, and compare them to Treloar's experiments.
- In [63] our aim is to demonstrate the effectiveness of the matched asymptotic expansion method in obtaining a simplified model for the influence of small identical heterogeneities periodically distributed on an internal surface on the overall response of a linearly elastic body. The results of some numerical experiments corroborate the precise identification of the different steps, in particular of the outer/inner regions with their normalized coordinate systems and the scale separation, leading to the model.

- In cancer modeling, to be able to capture the full in-vivo scale, tumors have to be modeled with continuum models. An important step consists in qualitatively and quantitatively comparing agent-based models (which parameters can generally be identified by experiments in vitro) and continuum models. We derived a first 1D continuum model for tumor growth from the cell based model (Drasdo and Hoehme, 2005): it results in a fluid-type model which capture tumor expansion in both diffusive and compact phenotypes. The tumor expands based on the pressure gradient generated by cell proliferation, the latter being hindered by high density or pressure. In [39] this modeled is analyzed mathematically, showing the existence of traveling waves in the different regimes (with or without internal friction and diffusion due to active movement). In particular the incompressible cells limit is very singular and relates to the Hele-Shaw equation. Numerical results confirm the analysis.

7. Partnerships and Cooperations

7.1. National Initiatives

7.1.1. ANR

7.1.2. ANR Project "M3RS"

Participants: Laurent Boudin, Muriel Boulakia, Paul Cazeaux, Anne-Claire Egloffe, Céline Grandmont [Principal Investigator], Bérénice Grec, Sébastien Martin, Irène Vignon-Clementel.

Period: 2008-2013.
This project, coordinated by C. Grandmont, aims at studying mathematical and numerical issues raised by the modeling of the lungs.

7.1.3. ANR Project "Epsilon"

Participants: Marina Vidrascu, Sofiene Hendili.

Period: 2009-2013
This project, coordinated by Jean-Jacques Marigo (LMS-Ecole polytechnique) aims to study Domain decomposition and multi-scale computations of singularities in mechanical structures.

7.1.4. ANR Project "EXIFSI"

Participants: Miguel Ángel Fernández Varela, Mikel Landajuela Larma, Vincent Martin, Marina Vidrascu.

Period: 2012-2016
The aim of this project, coordinated by Miguel Ángel Fernández Varela is to study mathematically and numerically new semi-explicit fluid-structure interaction schemes.

7.2. European Initiatives

7.2.1. FP7 Projects

7.2.1.1. EUHEART

Title: euHeart

Type: COOPERATION (ICT)

Defi: Virtual Physiological Man

Instrument: Integrated Project (IP)

Duration: June 2008 - September 2012

Coordinator: Philips Technologie GmbH Forschungslaboratorien (Germany)

Others partners: Philips Technologie GmbH (DE), The University of Oxford (UK), Universitat Pompeu Fabra (SP), The University of Sheffield (UK), Inria, French National Research Institute in Informatics and Mathematics (FR), King's College London (UK), Academisch Medisch Centrum bij de Universiteit van Amsterdam (NL), Universität Karlsruhe (TH) (DE), Institut National de la Santé et de la Recherche Médicale, INSERM (FR), Philips Medical Systems Nederland BV (NL), Berlin Heart GmbH (DE), HemoLab BV (NL), Universitätsklinikum Heidelberg (DE), Volcano Europe SA / NV (BE), Hospital Clínico San Carlos de Madrid (SP), Philips Ibérica S.A. (SP)

See also: http://www.euheart.eu/

Abstract: The euHeart project (Ref 224495), is a 4-year integrated European project which aims at developing personalized, and clinically validated multi-physics, multi-level models of the heart and great vessels.

7.3. International Initiatives

7.3.1. Inria Associate Teams

Participants: Grégory Arbia, Cristóbal Bertoglio Beltran, Miguel Ángel Fernández Varela, Jean-Frédéric Gerbeau, Céline Grandmont, Irène Vignon-Clementel [coordinator].

Period: 2008-2014

CARDIO: The aim of this project is to foster the collaboration between the Cardiovascular Biomechanics Research Laboratory (CVBRL) of C.A. Taylor (Stanford University, USA) and colleagues such as Dr. Feinstein, and the project-team REO, through research on cardiovascular and respiratory related topics (boundary conditions for complex flow, patient-specific modeling of congenital heart disease, image-based fluid solid interaction, postprocessing of numerical simulations). The associated team has been extended to other partners: team-project MACS at Inria, the Marsden group at USCD and the Flow physics group at IIT. CA Figueroa is now at KCL, UK.

7.3.2. Inria International Partners

7.3.3. Trans-Atlantic Network of Excellence for Cardiovascular Research

Participants: Grégory Arbia, Jean-Frédéric Gerbeau, Irène Vignon-Clementel [correspondant].

Period: 2010-2014

This network, funded by the Leducq fondation, is working on the multi-scale modeling of single ventricle hearts for clinical decision support [3].

7.3.4. German BMBF national project Lungsys II

Participant: Irène Vignon-Clementel.

"Systems Biology of Lung Cancer "Dynamic Properties of Early Spread and Therapeutic Options". In collaboration with Dirk Drasdo EPI Bang, Inria & Paris 6 UPMC

ICI Vous pouvez ecrire du texte

[3] http://modelingventricle.clemson.edu/home

7.4. International Research Visitors

7.4.1. Visits of International Scientists

- André Garon, Département Génie Mécanique de l'Ecole Polytechnique de Montréal, 10-18 may, 2012
- Michel Delfour, Département de Mathématiques et Statistiques, Université de Montréal, 12-16 may, 2012
- C. Alberto Figueroa, KCL, London, UK, Feb 7-8th 2012
- Maxim Solovchuk, Taida Institute of Mathematical Sciences, National Taiwan University, 15–30 july, 2012
- Chang-Shou Lin, Taida Institute of Mathematical Sciences, National Taiwan University, 22-24 november, 2012
- Jessica Oakes, University of California at San Diego, USA, 17-21 december, 2012

7.4.1.1. Internships

- Frédéric Jamin, MS student, Imperial College, London, UK, May 15th-Sept 14th 2012

8. Dissemination

8.1. Scientific Animation

- Laurent Boudin
  - Member of the Board of Mathematics Licence (*EFU de Licence de mathématiques*), UPMC.
  - Co-organizer of the monthly workgroup "Humaniste" focusing on mathematics applied to humanities, alternatively taking place at UPMC, UP7D and Orléans and jointly handled by LJLL, MAPMO and CAMS.
- Miguel Ángel Fernández Varela
  - Member of the Postdocs Selection Committee, Inria Paris-Rocquencourt, 2012
- Jean-Frédéric Gerbeau
  - Member of the editorial boards of Mathematical Modelling and Numerical Analysis (M2AN), International Journal for Numerical Methods in Biomedical Engineering (IJNMBE), Communications in Applied and Industrial Mathematics.
  - Service activity at Inria: Délégué Scientifique / Chairman of the project-teams' committee of Inria Paris-Rocquencourt research center; Member of the evaluation committee of Inria
  - Service activity in Universities: Member of the Mathematics Faculty Concil of University P. & M. Curie Paris 6 (conseil de l'UFR 929); member of the scientific committee of the Faculty of Science, University Versailles Saint-Quentin; member of the Reference Committee of the PhD program Mathematical Models and Methods in Engineering (Politecnico di Milano, Italy);
- Céline Grandmont
  - Member of the CNU 26 (2011–2015)
- Elisa Schenone
  - Co-organizer of the monthly Junior Seminar of Inria Paris-Rocquencourt
- Marc Thiriet

  - President of thematic comittee CT3 (Biomedical Simulation and Applications to Health) of GENCI (Grand Equipement National de Calcul Intensif – National Large Equipement for Intensive Computation)
  - PRACE peer review staff member (Panel 4 [Biochemistry, Bioinformatics and Life Sciences])
  - Member of the Mechanical Engineering Evaluation Group of the Canadian Granting Agency NSERC
  - Member of the Scientific Committee of the PME DiscInNet
- Marina Vidrascu
  - Member of the Postdocs Selection Committee, Inria Paris-Rocquencourt, 2011
- Irène Vignon-Clementel
  - Organizing the monthly seminar at Inria Paris-Rocquencourt on "modeling and scientific computing"
  - Inria: member of the "Conseil d'orientation scientifique et technologique" (scientific and technologic orientation council) of l'Inria, in the subgroup "GT Actions Incitatives" (incentive action working group), PhD grant committee
  - Mediator between PhD students and their supervisors for Inria Paris-Rocquencourt
  - Coordinator of the associated team CARDIO between REO and Prof. Taylor's lab at Stanford University, USA and colleagues both at Inria and in the USA (2008-present)

Conferences

- Grégory Arbia
  - Poster, 3rd annual conference on engineering frontiers in pediatric and congenital heart disease, Stanford University, May 2012.
  - Seminar, Laboratoire de Mathématiques appliquées, Univ. Paris 5, June 2012.
- Cristóbal Bertoglio Beltran
  - Contributed talk at 10th International Symposium Computer Methods in Biomechanics and Biomedical Engineering, April 11- 14th, 2012, Berlin, Germany
- Laurent Boudin
  - Seminar, Mapmo, Univ. Orléans, France, February 2012.
  - Seminar, ACSIOM, Univ. Montpellier-II, France, March 2012.
  - Seminar, LAGA, Univ. Paris-Nord, France, March 2012.
  - Colloquium, MAP5, Univ. Paris-Descartes, France, June 2012.
  - Contributed talk, HYP'2012, Padova, Italy, June 2012.
- Muriel Boulakia
  - Seminar, Univ. Metz, march 2012
  - Seminar, Univ. Paris-sud, may 2012
  - Invited speaker, Workshop Control of fluid-structure systems,Toulouse, june 2012
  - Invited speaker, Congrès Random Models in Neurosciences, Paris, july 2012
  - Evaluation talk, AERES evaluation, november 2012
- Paul Cazeaux
  - Seminar, REO team, Inria Paris-Rocquencourt, April 2012
  - Poster, CANUM 2012, Superbesse, Mai 2012
  - Contributed talk, ECCOMAS conference, Vienna, Austria, September 2012
  - Seminar, Homogenization and multiple scales, UPMC Paris 6, November 2012

  - PhD students Seminar, LJLL, UPMC Paris 6, November 2012
- Cesare Corrado
  - Contributed talk at Bioengineering 2012, Oxford, 6-7 September 2012 (with J-F. Gerbeau, P. Moireau),
- Anne-Claire Egloffe
  - PASI-CIPPDE 2012, Inverse problems and PDE control. Santiago, Chili, January 2012.
  - Seminar, University of Besanon, May, 2012.
  - Seminar, Institut Elie Cartan, Nancy, May, 2012.
- Miguel Ángel Fernández Varela
  - Seminar, Basque Country University, March 12, Bilbao, Spain
  - Seminar, Weierstrass Institute, April 19, Berlin, Germany
  - Invited talk at minisymposium, CANUM 2012, May 21-25, Superbesse, France
  - Keynote speaker at minisymposium, ECCOMAS 2012, September 10-14, 2012, Vienna, Austria
  - Seminar, University of Besanon, September, 2012, France
  - Seminar, University of Granada, October 16, 2012, Spain
  - Seminar, University of Sevilla, October 17, 2012, Spain
  - Seminar, University of Zaragoza, October 18, 2012, Spain
  - Seminar, Polytechnic University of Madrid, October 19, 2012, Spain
- Justine Fouchet-Incaux
  - Contributed talk Rencontres doctorales de l'IMREDD, Institut Mé diterranéen du Risque, de l'Environnement et du Développement Durable, Nice, oct. 2012
  - PhD students seminar, Orsay, nov. 2012
  - CEMRACS'12, Marseille, juil. 2012
- Jean-Frédéric Gerbeau
  - Invited conference, Rencontre iDySCo (Institut Dynamique des Systèmes Complexes), Villard de Lans, January 9-10, 2012
  - Invited conference, Printemps de la cardiologie, Bordeaux, April 12-13, 2012
  - Invited conference, 1st Usergroup Workshop of the Notocord company, Paris, June 7-8, 2012
  - Invited conference, CECAM Workshop: Reduced Order Methods for modeling and computational reduction, Switzerland, May 14-16, 2012
  - Invited minisymposium talk, UK Bioengineering conference, Oxford, September 24-25, 2012
  - Seminar, Journée Calcul Scientifique et Modélisation Mathématique d'Amiens, 2012
  - Seminar, Groupe Medisys, Philips, Jan 3, 2012
- Céline Grandmont
  - Invited speaker, Journées MIRES EDP, October 2012
  - Plenary conference, XIème colloque franco-roumain de mathématiques appliquées, August 2012
  - Invited speaker, Workshop Control of fluid-structure systems and inverse problems, June 2012
  - Plenary conference, CANUM 2012, Super Besse, May 2012
  - Seminar, Lyon, January 2012

- Bérenice Grec
  - Seminar, Applied Mathematics, Univ. Blaise Pascal, March 15, 2012, Clermont-Ferrand, France
  - Journée Mathématiques et Biologie du PRES Sorbonne Paris Cité, April 5, 2012, Paris, France
  - Seminar, PDEs, Univ. Strasbourg, June 19, 2012, Strasbourg, France
- Sébastien Martin
  - Poster, Congrès National de Physiologie Pharmacologie et Thérapeutique, Dijon 2012
  - Seminar, DAMTP: Applied and Computational Analysis, University of Cambridge, UK, 2012
  - Contributed talk, CANUM 2012, Superbesse, France.
  - Contributed talk, Softflow 2012: Biological complex fluids, Cargèse, 2012.
  - Invited talk, Workshop on Complexity in Fluid Mechanics, Vienna, Austria 2012.
- Ayman Moussa
  - Contributed talk at the Spring School on Kinetic Theory and Fluid Mechanics, March 26-30th 2012 Université Claude Bernard, Lyon.
  - Workshop on Kinetic Equations, 21th June 2012, ENS Cachan
- Elisa Schenone
  - Poster, CANUM 2012, Superbesse, May 2012
  - CEMRACS 2012, Cirm-Marseille, 16/07-24/08, 2012
- Saverio Smaldone
  - Contributed talk 10th World Congress on Computational Mechanics (WCCM 2012) 8 -13 July 2012, São Paulo, Brazil
  - Contributed talk 6th European Congress on Computational Methods in Applied Sciences and Engineering (ECCOMAS 2012) 10-14 September 2012, University of Vienna, Austria.
  - Seminar, Inria-Rocquencourt, November 20th, Le Chesnay, France
- Marc Thiriet
  - Plenary Conference, CMMBE 2012, 10th International Symposium on Computer Methods in Biomechanics and Biomedical Engineering, 11–14 april 2012, Berlin, Germany
  - Contributed talk International Union of Theoretical and Applied Mechanics (IUTAM) Symposium on Particle Methods in Fluid Mechanics, October 15–17, 2012 Lyngby, Denmark (with Chatelin R, Poncet P, Didier A, Murris-Espin M, Anne-Archard D)
  - Contributed talk 12TH International Symposium on Therapeutic Ultrasound, , 10–13 June, 2012, Heidelberg, Germany, (with Maxim A. Solovchuk, Tony W. H. Sheu)
- Marina Vidrascu
  - Contributed talk 10th World Congress on Computational Mechanics (WCCM 2012) 8 -13 July 2012, São Paulo, Brazil
  - Invited conference, XIème colloque franco-roumain de mathématiques appliquées, August 2012
  - Contributed talk 21st International Conference on Domain Decomposition Methods, 25-29 June, Inria Rennes-Bretagne
  - Seminar, Univ Caen (France)
- Irène Vignon-Clementel

- Seminar, Mathematical modeling in Medicine workshop, Laboratoire de Mathématique, March 12th 2012, U. Versailles Saint Quentin, France
- Invited lecture at the Spring school 2012 on systems biology, March 30th 2012, HelmholzZentrum München, Germany
- Contributed talk, 10th International Symposium on Biomechanics and Biomedical Engineering, April 11th-14th, Berlin, Germany
- Invited poster, 3rd International Conference on Engineering Frontiers in Pediatric and Congenital Heart Disease, May 1rst-2nd 2012, Stanford University, USA
- Invited talk, BIS'2012 workshop, May 22nd, Paris, France
- Contributed talk co-authored N. Jagiella and D. Drasdo, SBMC conference, July 9th-11th, Leipzig, Germany
- Invited keynote at a minisymposium, ECCOMAS, 10th-14th September, Vienna, Austria [cancelled due to personal reasons]
- Invited talk, Cancersys kickoff meeting, PI presentation of Lungsys consortium, October 8th-9th 2012, Heidelberg, Germany
- Seminar, Laboratoire Jacques Louis Lions, Paris 6 UPMC, November 19th, 2012, France

8.2. Teaching - Supervision - Juries

8.2.1. Teaching

DUT :

- Justine Fouchet-Incaux Algorithmiques et langages, 36h, IUT d'Orsay, département informatique, Université Paris-Sud
- Justine Fouchet-Incaux Mathématiques S2, 25,5h, IUT d'Orsay, département Mesures-Physiques, Université Paris-Sud
- Justine Fouchet-Incaux Mathématiques S1, 24h, IUT d'Orsay, département Chimie, Université Paris-Sud

Licence :

- Grégory Arbia Algèbre 1: calcul vectoriel, 36h, L1, UPMC.
- Grégory Arbia Calcul matriciel numérique, 24h, L3, UPMC.
- Laurent Boudin: Series and integrals (15h), L2, UPMC.
- Laurent Boudin: Multivariable calculus and multiple integrals (72h), L2, UPMC.
- Laurent Boudin: Hilbert analysis (16h), L3, Polytech'Paris.
- Paul Cazeaux Algebra 1, vectorial calculus, 72h, L1, UPMC Paris 6
- Paul Cazeaux Analysis 1, Functions, 36h, L1, UPMC Paris 6
- Anne-Claire Egloffe: Fonctions de plusieurs variables et intégrales multiples, L2, (36 h), UPMC
- Anne-Claire Egloffe: Khôlles Séries et intégrales, L2 (20 h), UPMC
- Ayman Moussa, Numerical Methods for differential equations (36h), L3, UPMC.
- Ayman Moussa, Introduction to Numerical Analysis oral exams, (15h), L3, UPMC.
- Miguel A. Fernández Scientific computing, 30h, level L3, École des Ponts ParisTech, France.
- Muriel Boulakia Vector calculus (24h), L1, UPMC, France
- Muriel Boulakia Linear optimization and convexity (36h), L3, UPMC, France.
- Muriel Boulakia Hilbertian analysis (30h), L3, Polytech'Paris, France

- Irène Vignon-Clementel Mathematics for biology, 64h ETD, L1 - undergraduate, Univ. de Versailles Saint Quentin

Master :

- Laurent Boudin: Numerical analysis (8h), M1, Polytech'Paris.
- Laurent Boudin: Basics for numerical methods (32h), M1, UPMC.
- Ayman Moussa, Real Analysis (72h), M1, UPMC.
- Ayman Moussa, Numerical analysis (38h), M1, Polytech'Paris.
- Ayman Moussa, Revision lecture on analysis and linear algebra (50h), M1, AIMS-Sénégal.
- Marc Thiriet Biofluid flows, 12 h. M2, UPMC
- Miguel A. Fernández Numerical methods in bio-fluids, 6h, level M2, University of Vigo, Spain.
- Miguel A. Fernández Inverse problems, 44h, level M1, Ecole Supérieure d'Ingénieurs Léonard de Vinci
- Muriel Boulakia Approximation methods for partial differential equations (72h, taught in english), M1, UPMC, France
- Muriel Boulakia Preparatory course for teaching admission examination Agrégation (15h), M2, UPMC, France
- Irène Vignon-Clementel Modeling Techniques, 24h ETD, M1, Univ de Versailles Saint Quentin.
- Irène Vignon-Clementel Different types of model for blood flow simulations, within the course Mathematics modeling for biology, 5h ETD, M1, Ecole Centrale Paris
- Apport des mathématiques appliquées (30min) "Diplôme universitaire de Médicine" on percutaneous valvular replacement, May 25th, Paris, France.

Others

- Ecole de printemps - Marrakech (LAMAI, FST) : Marc Thiriet Mathématiques & Interactions (6h)
- Ecole d'été - Roscoff (ICS, UPMC) : Marc Thiriet Biomathematics & Bioinformatics (12h)
- Biomathematical and Biomechanical Modeling and Simulation, Marc Thiriet (L3) Dpts of Mathematics, Computer Sciences, Physics, and Biology, 20h, Tbilisi State University (TSU)
- Laurent Boudin Supervisor (for mathematics) of the bidisciplinary computer science / applied mathematics licence program and of the joint program UPMC-Brown on computer science / applied mathematics at the licence level (18h).
- Irène Vignon-Clementel Numerical simulations of blood flow, 1h30, as part of the undergraduate continuum mechanics class at AgroParisTech, France

8.2.2. Supervision

PhD : Cristóbal Bertoglio Beltran, *Forwar and Inverse problems in fluid-structure interaction. Application in hemodynamics*, 23 November 2012. Supervisors: J-F. Gerbeau & M.A. Fernández Varela.

PhD : Paul Cazeaux, *Homogenization and lungs modelling*,12 December 2012 Supervisors: C. Grandmont & Y. Maday

PhD : Anne-Claire Egloffe, *Inverse problems in lungs modelling*, 19 October 2012. Supervisors: C. Grandmont & M. Boulakia.

PhD : Sofiene Hendili, *Structures élastiques comportant une fine couche d'hétérogénéités : étude asymptotique et numérique*, 4 July 2012. Supervisors: F. Krasucki & M. Vidrascu.

PhD in progress : Grégory Arbia, *Multi-scale Modeling of Single Ventricle Hearts for Clinical Decision Support*, since October 2010. Supervisors: J-F. Gerbeau & I. Vignon-Clementel.

PhD in progress : Justine Fouchet-Incaux, *Mathematical and numerical modeling of the human breathing*, since October 2011. Supervisors: C. Grandmont & B. Maury.

PhD in progress :Stéphane Liwarek, *Air flow in the nasal cavity*, since October 2010. Supervisors: M.A. Fernández & J-F. Gerbeau

PhD in progress : Jimmy Mullaert, *Fluid-structure interaction*, since September 2009. Supervisors: M.A. Fernández & Y. Maday

PhD in progress : Elisa Schenone, *Inverse problems in electrocardiology*, since October 2011. Supervisors: J-F. Gerbeau & M. Boulakia.

PhD in progress : Saverio Smaldone, *Numerical methods for cardiac hemodynamics*, since October 2010, Supervisors: J-F. Gerbeau & M.A. Fernández.

8.2.3. Juries

- Laurent Boudin
  - Member of the PhD committees of Phung Thanh-Tam (University Orléans, July 2012).
- Muriel Boulakia
  - Hiring committees: Univ. Caen, Univ. Versailles, Univ. P. & M. Curie (MCF positions)
- Miguel Ángel Fernández Varela
  - Member of the PhD committees of M. Pozzoli ((referee), Politecnico di Milano, Italy); A. Fumagalli (Politecnico di Milano, Italy), M. Pischiutta (Politecnico di Milano, Italy), V. Vitelli (Politecnico di Milano, Italy) and C. Bertoglio (University Paris VI) and B. Fabrèges (University Orsay Paris-Sud)
- Jean-Frédéric Gerbeau
  - Member of the PhD committees of Alistair Brown (Sheffield university (referee)) , Cristóbal Bertoglio (University Paris VI)
  - Hiring committees: Univ Montpellier (Professor position), Inria (DR2).
- Céline Grandmont
  - Member of the PhD committees of S. Court ((president of the jury) University Toulouse); A.-C. Egloffe (University Paris VI) and P. Cazeaux (University Paris VI)
  - Member of the HDR committees: of O. Saut ((referee) University Bordeaux Univ.); S. Martin (University Orsay Paris-Sud)
  - Hiring committees: Bordeaux Univ. (President of the hiring committee for an Assistant Professor position in Scientific computing), Bordeaux Univ. (Professor position), Dauphine (Assistant Professor position).
- Bérenice Grec
  - Hiring committee: Univ. Orléans (MCF position)
- Sébastien Martin
  - Hiring committee: École Nationale Supérieure des Arts et Métiers (mechanics).
- Marc Thiriet
  - Member of the selection comittee of HPC projects in the framework of HPC-Europa2 – Pan-European Research Infrastructure for High Performance Computing supported by the European Commission Capacities Area - Research Infrastructures Initiative

  - Member of the PhD committees of Referee of Bruno Tayllamin ((referee) University Montpellier 2); Edmund G. Lobb, (Aeronautics Dpt., Imperial College of London)
- Marina Vidrascu
  - Member of the PhD committees of Sofiene Hendili (University Montpellier)
  - Hiring committe: Univ Grenoble (MCF position)
- Irène Vignon-Clementel
  - Member of the PhD committees of: Yiyi Wei (University Lilles); Nick Jagiella (University Paris 6 UPMC)
  - Hiring committee for assistant professor positions at Grenoble University

8.3. Popularization

- Jean-Frédéric Gerbeau
  - Mediation and popularization of sciences: talk for "Fête de la science" Inria Paris-Rocquencourt
- Irène Vignon-Clementel
  - Journée "Filles et Mathématiques", High-school students, February 2nd & December 12th, 2012, Paris, France

9. Bibliography

Major publications by the team in recent years

[1] L. BOUDIN, L. DESVILLETTES, R. MOTTE. *A modeling of compressible droplets in a fluid*, in "Commun. Math. Sci.", 2003, vol. 1, n^{o} 4, p. 657–669.

[2] M. BOULAKIA, S. GUERRERO. *Regular solutions of a problem coupling a compressible fluid and an elastic structure*, in "Journal de Mathématiques Pures et Appliquées", 2010, vol. 94, n^{o} 4, p. 341-365 [*DOI :* 10.1016/J.MATPUR.2010.04.002], http://hal.inria.fr/hal-00648710/en/.

[3] E. BURMAN, M. A. FERNÁNDEZ VARELA. *Galerkin Finite Element Methods with Symmetric Pressure Stabilization for the Transient Stokes Equations: Stability and Convergence Analysis*, in "SIAM Journal on Numerical Analysis", 2008, vol. 47, n^{o} 1, p. 409–439.

[4] E. BURMAN, M. A. FERNÁNDEZ VARELA. *Stabilization of explicit coupling in fluid-structure interaction involving fluid incompressibility*, in "Comput. Methods Appl. Mech. Engrg.", 2008.

[5] P. CAUSIN, J.-F. GERBEAU, F. NOBILE. *Added-mass effect in the design of partitioned algorithms for fluid-structure problems*, in "Comp. Meth. Appl. Mech. Engng.", 2005, vol. 194, n^{o} 42-44.

[6] J.-J. CHRISTOPHE, T. ISHIKAWA, N. MATSUKI, Y. IMAI, K. TAKASE, M. THIRIET, T. YAMAGUCHI. *Patient-specific morphological and blood flow analysis of pulmonary artery in the case of severe deformations of the lung due to pneumothorax*, in "Journal of Biomechanical Science and Engineering", 2010, vol. 5, n^{o} 5, p. 485-498, http://hal.inria.fr/inria-00543090.

[7] M. A. FERNÁNDEZ VARELA, J.-F. GERBEAU, C. GRANDMONT. *A projection semi-implicit scheme for the coupling of an elastic structure with an incompressible fluid*, in "Internat. J. Numer. Methods Engrg.", 2007, vol. 69, n^{o} 4, p. 794–821.

[8] C. FETITA, S. MANCINI, D. PERCHET, F. PRÊTEUX, M. THIRIET, L. VIAL. *Computational model of oscillatory flow in the proximal part of tracheobronchial trees*, in "Computer Methods in Biomechanics and Biomedical Engineering", 2005, vol. 8, p. 279-293.

[9] C. GRANDMONT. *Existence of weak solutions for the unsteady interaction of a viscous fluid with an elastic plate*, in "SIAM J. Math. Anal.", 2008, vol. 40, n^{o} 2, p. 716–737.

[10] A. MOUSSA, T. GOUDON, L. HE, P. ZHANG. *The Navier-Stokes-Vlasov-Fokker-Planck system near equilibrium*, in "SIAM Journal on Mathematical Analysis", September 2010, http://hal.inria.fr/hal-00652341/en.

[11] M. THIRIET. *Biology and Mechanics of Blood Flows, part I: Biology of Blood Flows (652 p.), part II: Mechanics and Medical Aspects of Blood Flows (464 p.)*, CRM Series in Mathematical Physics, Springer, 2008.

[12] I. VIGNON-CLEMENTEL, C. A. FIGUEROA, K. E. JANSEN, C. A. TAYLOR. *Outflow Boundary Conditions for Three-dimensional Finite Element Modeling of Blood Flow and Pressure in Arteries*, in "Computer Methods in Applied Mechanics and Engineering", 2006, vol. 195, p. 3776-3796.

Publications of the year

Doctoral Dissertations and Habilitation Theses

[13] C. BERTOGLIO. *Problèmes Directs et Inverses en Interaction Fluide-Structure. Application à l'hémodynamique*, Université Pierre et Marie Curie - Paris VI, November 2012, http://hal.inria.fr/tel-00768188.

[14] P. CAZEAUX. *Quelques modèles mathématiques homogénéisés appliqués à la modélisation du parenchyme pulmonaire*, Université Pierre et Marie Curie - Paris VI, December 2012, http://hal.inria.fr/tel-00765331.

[15] A.-C. EGLOFFE. *Etude de quelques problèmes inverses pour le système de Stokes. Application aux poumons.*, Université Pierre et Marie Curie - Paris VI, November 2012, http://hal.inria.fr/tel-00756334.

[16] S. HENDILI. *Structures élastiques comportant une fine couche d'hétérogénéités : étude asymptotique et numérique.*, Université Montpellier II - Sciences et Techniques du Languedoc, July 2012, Thèse financée par le projet ANR Epsilon et réalisée dans le cadre d'une collaboration entre l'université Montpellier 2 et l'Inria Rocquencourt., http://tel.archives-ouvertes.fr/tel-00765018.

[17] S. MARTIN. *Modélisation et analyse mathématique de problèmes issus de la mécanique des fluides : applications à la tribologie et aux sciences du vivant*, Université Paris Sud - Paris XI, December 2012, HDR, http://tel.archives-ouvertes.fr/tel-00765580.

Articles in International Peer-Reviewed Journals

[18] M. ASTORINO, J. HAMERS, S. SHADDEN, J.-F. GERBEAU. *A robust and efficient valve model based on resistive immersed surfaces*, in "International Journal for Numerical Methods in Biomedical Engineering", 2012, vol. 28, n^{o} 9, p. 937-959 [*DOI :* 10.1002/CNM.2474], http://hal.inria.fr/hal-00717213.

[19] A. BARETTA, C. CORSINI, A. MARSDEN, I. VIGNON-CLEMENTEL, T.-Y. HSIA, G. DUBINI, F. MIGLIAVACCA, G. PENNATI, F. THE MODELING OF CONGENITAL HEARTS ALLIANCE (MOCHA) INVESTIGATORS. *Respiratory effects on hemodynamics in patient-specific CFD models of the Fontan circula-*

tion under exercise conditions, in "European Journal of Mechanics B-Fluids", 2012, vol. 35, p. 61-69 [*DOI :* 10.1016/J.EUROMECHFLU.2012.01.012], http://hal.inria.fr/hal-00765808.

[20] C. BERTOGLIO, P. MOIREAU, J.-F. GERBEAU. *Sequential parameter estimation for fluid-structure problems. Application to hemodynamics*, in "International Journal for Numerical Methods in Biomedical Engineering", April 2012, vol. 28, n^{o} 4, p. 434-455 [*DOI :* 10.1002/CNM.1476], http://hal.inria.fr/inria-00603399.

[21] L. BOUDIN, B. GREC, M. PAVIC, F. SALVARANI. *Diffusion asymptotics of a kinetic model for gaseous mixtures*, in "Kinetic and related models", March 2013, vol. 6, n^{o} 1, p. 137-157 [*DOI :* 10.3934/KRM.2013.6.137], http://hal.inria.fr/hal-00704952.

[22] L. BOUDIN, B. GREC, F. SALVARANI. *A mathematical and numerical analysis of the Maxwell-Stefan diffusion equations*, in "Discrete and Continuous Dynamical Systems - Series B", 2012, vol. 17, n^{o} 5, p. 1427-1440 [*DOI :* 10.3934/DCDSB.2012.17.1427], http://hal.inria.fr/hal-00490511.

[23] L. BOUDIN, J. MATHIAUD. *A numerical scheme for the one-dimensional pressureless gases system*, in "Numerical Methods for Partial Differential Equations", September 2012, vol. 28, n^{o} 6, p. 1729-1746 [*DOI :* 10.1002/NUM.20700], http://hal.inria.fr/hal-00537145.

[24] L. BOUDIN, A. MERCIER, F. SALVARANI. *Conciliatory and contradictory dynamics in opinion formation*, in "Physica A: Statistical Mechanics and its Applications", 2012, vol. 391, p. 5672-5684 [*DOI :* 10.1016/J.PHYSA.2012.05.070], http://hal.inria.fr/hal-00613119.

[25] M. BOULAKIA, E. SCHENONE, J.-F. GERBEAU. *Reduced-order modeling for cardiac electrophysiology. Application to parameter identification*, in "International Journal for Numerical Methods in Biomedical Engineering", 2012, vol. 28, p. 727-744 [*DOI :* 10.1002/CNM.2465], http://hal.inria.fr/hal-00644396.

[26] M. BOULAKIA, E. SCHWINDT, T. TAKAHASHI. *Existence of strong solutions for the motion of an elastic structure in an incompressible viscous fluid*, in "Interfaces and Free Boundaries", 2012, vol. 14, n^{o} 3, p. 273-306 [*DOI :* 10.4171/IFB/282], http://hal.inria.fr/hal-00765176.

[27] J.-J. CHRISTOPHE, T. ISHIKAWA, Y. IMAI, K. TAKASE, M. THIRIET, T. YAMAGUCHI. *Hemodynamics in the pulmonary artery of a patient with pneumothorax*, in "Medical Engineering and Physics", 2012, vol. 34, n^{o} 6, p. 725-732 [*DOI :* 10.1016/J.MEDENGPHY.2011.09.016], http://hal.inria.fr/hal-00715123.

[28] C. CORRADO. *On the Stability of the Immersed finite element Method with High Order structural Elements*, in "Computers & Structures", October 2012, vol. 112-113, p. 422-432 [*DOI :* 10.1016/J.COMPSTRUC.2012.09.008], http://hal.inria.fr/hal-00764564.

[29] M. ESMAILY MOGHADAM, F. MIGLIAVACCA, I. VIGNON-CLEMENTEL, T.-Y. HSIA, A. MARSDEN, THE MODELING OF CONGENITAL HEARTS ALLIANCE (MOCHA) INVESTIGATORS, FOR. *Optimization of shunt placement for the Norwood surgery using multi-domain modeling.*, in "Journal of Biomechanical Engineering", May 2012, vol. 134, n^{o} 5, 051002 [*DOI :* 10.1115/1.4006814], http://hal.inria.fr/hal-00765729.

[30] M. ESMAILY MOGHADAM, I. VIGNON-CLEMENTEL, R. FIGLIOLA, A. MARSDEN, F. THE MODELING OF CONGENITAL HEARTS ALLIANCE (MOCHA) INVESTIGATORS. *A modular numerical method for implicit 0D/3D coupling in cardiovascular finite element simulations*, in "Journal of Computational Physics", 2012 [*DOI :* 10.1016/J.JCP.2012.07.035], http://hal.inria.fr/hal-00765816.

[31] C. FARHAT, J.-F. GERBEAU, A. RALLU. *FIVER: A Finite Volume Method Based on Exact Two-Phase Riemann Problems and Sparse Grids for Multi-Material Flows with Large Density Jumps*, in "Journal of Computational Physics", 2012, vol. 231, p. 6360-6379 [*DOI :* 10.1016/J.JCP.2012.05.026], http://hal.inria.fr/hal-00703493.

[32] M. A. FERNÁNDEZ VARELA. *Incremental displacement-correction schemes for incompressible fluid-structure interaction: stability and convergence analysis*, in "Numerische Mathematik", 2012 [*DOI :* 10.1007/S00211-012-0481-9], http://hal.inria.fr/inria-00605890.

[33] A. GLORIA, P. LE TALLEC, M. VIDRASCU. *Foundation, analysis, and numerical investigation of a variational network-based model for rubber*, in "Continuum Mechanics and Thermodynamics", 2013, p. 1–31 [*DOI :* 10.1007/S00161-012-0281-6], http://hal.inria.fr/hal-00673406.

[34] E. KUNG, A. BARETTA, C. BAKER, G. ARBIA, G. BIGLINO, C. CORSINI, S. SCHIEVANO, I. VIGNON-CLEMENTEL, G. DUBINI, G. PENNATI, A. TAYLOR, A. DORFMAN, A. M. HLAVACEK, A. MARSDEN, T.-Y. HSIA, F. MIGLIAVACCA, THE MODELING OF CONGENITAL HEARTS ALLIANCE (MOCHA) INVESTIGATORS, FOR. *Predictive modeling of the virtual Hemi-Fontan operation for second stage single ventricle palliation: Two patient-specific cases.*, in "Journal of Biomechanics", November 2012 [*DOI :* 10.1016/J.JBIOMECH.2012.10.023], http://hal.inria.fr/hal-00765797.

[35] V. MARTIN, A. DROCHON, O. FOKAPU, J.-F. GERBEAU. *MagnetoHemoDynamics in Aorta and Electrocardiograms*, in "Physics in Medicine and Biology", 2012, vol. 57, n^{o} 10, p. 3177-3195, Preprint of Vincent Martin et al 2012 Phys. Med. Biol. 57 3177 doi:10.1088/0031-9155/57/10/3177 [*DOI :* 10.1088/0031-9155/57/10/3177], http://hal.inria.fr/inria-00628032.

[36] A. MAXIM, W. TONY, L. WIN-LI, I. KUO, M. THIRIET. *Simulation study on acoustic streaming and convective cooling in blood vessels during a high-intensity focused ultrasound thermal ablation*, in "International Journal of Heat and Mass Transfer", 2012, vol. 55, n^{o} 4, p. 1261 - 1270, 4 4 [*DOI :* 10.1016/J.IJHEATMASSTRANSFER.2011.09.023], http://hal.inria.fr/hal-00715205.

[37] P. MOIREAU, C. BERTOGLIO, N. XIAO, C. A. FIGUEROA, C. A. TAYLOR, D. CHAPELLE, J.-F. GERBEAU. *Sequential identification of boundary support parameters in a fluid-structure vascular model using patient image data*, in "Biomechanics and Modeling in Mechanobiology", July 2012 [*DOI :* 10.1007/S10237-012-0418-3], http://hal.inria.fr/hal-00760703.

[38] P. MOIREAU, N. XIAO, M. ASTORINO, C. A. FIGUEROA, D. CHAPELLE, C. A. TAYLOR, J.-F. GERBEAU. *External tissue support and fluid-structure simulation in blood flows*, in "Biomechanics and Modeling in Mechanobiology", 2012, vol. 11, n^{o} 1-2, p. 1-18 [*DOI :* 10.1007/S10237-011-0289-Z], http://hal.inria.fr/hal-00701801.

[39] M. TANG, N. VAUCHELET, I. CHEDDADI, I. VIGNON-CLEMENTEL, D. DRASDO, B. PERTHAME. *Composite waves for a cell population system modelling tumor growth and invasion*, in "Chinese Annals of Mathematics - Series B", 2013, vol. 34B, n^{o} 2, p. 295-318 [*DOI :* 10.1007/S11401-007-0001-X], http://hal.inria.fr/hal-00685063.

[40] D. TRIMARCHI, M. VIDRASCU, D. TAUNTON, S. TURNOCK, D. CHAPELLE. *Wrinkle development analysis in thin sail-like structures using MITC shell finite elements*, in "Finite Elements in Analysis and Design", 2013, vol. 64, p. 48-64 [*DOI :* 10.1016/J.FINEL.2012.09.005], http://hal.inria.fr/hal-00733994.

[41] W. YANG, J. FEINSTEIN, S. SHADDEN, I. VIGNON-CLEMENTEL, A. MARSDEN. *Optimization of a Y-graft design for improved hepatic flow distribution in the Fontan circulation.*, in "Journal of Biomechanical Engineering", 2012 [*DOI :* 10.1115/1.4023089], http://hal.inria.fr/hal-00765804.

[42] W. YANG, I. VIGNON-CLEMENTEL, G. TROIANOWSKI, V. M. REDDY, J. FEINSTEIN, A. MARSDEN. *Hepatic blood flow distribution and performance in conventional and novel Y-graft Fontan geometries: A case series computational fluid dynamics study.*, in "Journal of Thoracic and Cardiovascular Surgery", May 2012, vol. 143, n^{o} 5, p. 1086-1097, Official Publication of The American Association for Thoracic Surgery and The Western Thoracic Surgical Association [*DOI :* 10.1016/J.JTCVS.2011.06.042], http://hal.inria.fr/hal-00649953.

International Conferences with Proceedings

[43] J. OAKES, A. MARSDEN, C. GRANDMONT, C. DARQUENNE, I. VIGNON-CLEMENTEL. *Multiscale Model of Airflow in Healthy and Emphysema Rat Lungs*, in "ASME 2012 Summer Bioengineering Conference", Fajardo, Porto Rico, ASME, June 2012, p. SBC2012-80418, http://hal.inria.fr/hal-00768268.

[44] M. SOLOVCHUK, T. SHEU, M. THIRIET. *Effects of acoustic nonlinearity and blood flow cooling during HIFU treatment*, in "ISTU 2012 - 12th International Symposium on Therapeutic Ultrasound", Heidelberg, Allemagne, S. MEAIRS (editor), American Institute of Physics, December 2012, p. 83-88 [*DOI :* 10.1063/1.4769922], http://hal.inria.fr/hal-00762555.

[45] I. VIGNON-CLEMENTEL, G. ARBIA, A. BARETTA, C. CORSINI, M. ESMAILY MOGHADAM, G. TROIANOWSKI, W. YANG, J. FEINSTEIN, T.-Y. HSIA, A. MARSDEN, F. MIGLIAVACCA, G. PENNATI, F. THE MODELING OF CONGENITAL HEARTS ALLIANCE (MOCHA) INVESTIGATORS. *From Patient-Specific Data to Multiscale Hemodynamics Simulations: the Challenge of Boundary Conditions*, in "10th International Symposium on Computer Methods in Biomechanics and Biomedical Engineering", Berlin, Allemagne, J. MIDDLETON (editor), ISBN: 978-0-9562121-5-3, Arup, 2012, p. 603-608, http://hal.inria.fr/hal-00765819.

Conferences without Proceedings

[46] M. A. FERNÁNDEZ VARELA, M. VIDRASCU. *Incremental displacement-correction schemes for the explicit coupling of an incompressible fluid with a non-linear shell*, in "10th world congress on computational mechanics", Sao-Paulo, Brésil, July 2012, http://hal.inria.fr/hal-00740415.

[47] M. VIDRASCU, G. GEYMONAT, S. HENDILI, F. KRASUCKI. *Matched asymptotic expansion and domain decomposition for an elastic structure*, in "21st International Conference on Domain Decomposition Methods", Rennes, France, June 2012, http://hal.inria.fr/hal-00740383.

[48] M. VIDRASCU, G. GEYMONAT, S. HENDILI, F. KRASUCKI. *Une méthode de résolution efficace pour un problème multi-échelle en élasticité*, in "XI ème Colloque Franco-Roumain de Mathématique Appliquées", Bucarest, Roumanie, August 2012, http://hal.inria.fr/hal-00740388.

Scientific Books (or Scientific Book chapters)

[49] M. THIRIET. *Intracellular Signaling Mediators in the Circulatory and Ventilatory Systems.*, Biomathematical and Biomechanical Modeling of the Circulatory and Ventilatory Systems, Springer New York, October 2012, vol. 4, 1064 [*DOI :* 10.1007/978-1-4614-4370-4], http://hal.inria.fr/hal-00762544.

[50] M. THIRIET. *Signaling at the Cell Surface in the Circulatory and Ventilatory Systems.*, Biomathematical and Biomechanical Modeling of the Circulatory and Ventilatory Systems, Springer, 2012, vol. 3, 996 [*DOI :* 10.1007/978-1-4614-1991-4], http://hal.inria.fr/hal-00715021.

Research Reports

[51] C. BERTOGLIO, A. CAIAZZO, M. A. FERNÁNDEZ VARELA. *Fractional-step schemes for the coupling of distributed and lumped models in hemodynamics*, Inria, April 2012, n^{o} RR-7937, http://hal.inria.fr/hal-00690493.

[52] C. BERTOGLIO, D. CHAPELLE, M. A. FERNÁNDEZ VARELA, J.-F. GERBEAU, P. MOIREAU. *State observers of a vascular fluid-structure interaction model through measurements in the solid*, Inria, December 2012, n^{o} RR-8177, 50 pages, http://hal.inria.fr/hal-00764332.

[53] P. CAZEAUX, J. S. HESTHAVEN. *Multiscale modelling of sound propagation through the lung parenchyma*, Inria, September 2012, http://hal.inria.fr/hal-00736483.

[54] A.-C. EGLOFFE, A. GLORIA, J.-C. MOURRAT, T. N. NGUYEN. *Random walk in random environment, corrector equation, and homogenized coefficients: from theory to numerics, back and forth*, Inria, November 2012, 44, http://hal.inria.fr/hal-00749667.

[55] M. A. FERNÁNDEZ VARELA, J. MULLAERT, M. VIDRASCU. *Explicit Robin-Neumann schemes for the coupling of an incompressible fluid with a general thin-structure*, Inria, December 2012, n^{o} RR-???.

[56] J.-F. GERBEAU, D. LOMBARDI. *Reduced-Order Modeling based on Approximated Lax Pairs*, Inria, November 2012, n^{o} RR-8137, 21, http://hal.inria.fr/hal-00752810.

[57] A. IOLLO, D. LOMBARDI. *Advection Modes by Optimal Mass Transfer*, Inria, February 2012, 33, http://hal.inria.fr/hal-00669693.

Other Publications

[58] L. BOUDIN, J. MATHIAUD. *Asymptotic behavior of a diffusive scheme solving the inviscid one-dimensional pressureless gases system*, 2012, submitted, http://hal.inria.fr/hal-00765620.

[59] M. BOULAKIA, A.-C. EGLOFFE, C. GRANDMONT. *Stability estimates for a Robin coefficient in the two-dimensional Stokes system*, 2012, http://hal.inria.fr/hal-00582559.

[60] M. BOULAKIA, A.-C. EGLOFFE, C. GRANDMONT. *Stability estimates for the unique continuation property of the Stokes system. Application to an inverse problem*, 2012, submitted, http://hal.inria.fr/hal-00760039.

[61] P. CAZEAUX, C. GRANDMONT, Y. MADAY. *Homogenization of a model for the propagation of sound in the lungs*, 2012, in preparation, http://hal.inria.fr/hal-00764982.

[62] D. CHAPELLE, A. COLLIN, J.-F. GERBEAU. *A surface-based electrophysiology model relying on asymptotic analysis and motivated by cardiac atria modeling*, 2012, http://hal.inria.fr/hal-00723691.

[63] G. GEYMONAT, S. HENDILI, F. KRASUCKI, M. VIDRASCU. *Matched asymptotic expansion method for an homogenized interface model.*, 2012, submitted, http://hal.inria.fr/hal-00757005.

[64] S. MARTIN, A. DECOENE, B. MAURY. *Microscopic modelling of active bacterial suspensions*, 2012, http://hal.archives-ouvertes.fr/hal-00601842.

[65] S. MARTIN, B. MAURY. *Numerical modeling of the oxygen transfer in the respiratory process*, 2012, submitted, http://hal.archives-ouvertes.fr/hal-00714239.

[66] A. MOUSSA, F. SUEUR. *A 2d spray model with gyroscopic effects*, 2013, Asymptotic Analysis, http://hal.inria.fr/hal-00713683.

References in notes

[67] A. AMSDEN, P. O'ROURKE, T. BUTLER. *A computer program for chemically reactive flows with sprays*, Los Alamos National Laboratory, 1989, n^{o} LA-11560-MS.

[68] M. A. BIOT. *Theory of propagation of elastic waves in a fluid-saturated porous solid. II higher frequency range*, in "J. Acoust. Soc. Am.", 1956, vol. 28, p. 179–191.

[69] D. CHAPELLE, J. SAINTE-MARIE, J.-F. GERBEAU, I. VIGNON-CLEMENTEL. *A poroelastic model valid in large strains with applications to perfusion in cardiac modeling*, in "Computational Mechanics", 2010, vol. 46, n^{o} 1, p. 91-101 [*DOI :* 10.1007/s00466-009-0452-x], http://hal.inria.fr/inria-00542672/en.

[70] J. DUPAYS, Y. FABIGNON, P. VILLEDIEU, G. LAVERGNE, G. ESTIVALEZES. *Some aspects of two phase flows in solid propellant rocket motors, in Solid propellant chemistry, combustion and interior ballistics*, in "Progress in Astronautics and Aeronautics", V. YANG, T. BRILL, W. PEN (editors), Academic Press, 2000, vol. 185.

[71] G. LINES, P. GROTTUM, A. TVEITO. *Modeling the electrical activity of the heart. A bidomain model of the ventricles embedded in a torso.*, in "Comput. Visual. Sci.", 2003, vol. 5, p. 195-213.

[72] R. MOTTE. *A numerical method for solving particle-fluid equations*, in "Trends in numerical and physical modeling for industrial multiphase flows", Cargèse, France, 2000.

[73] A. QUARTERONI, S. RAGNI, A. VENEZIANI. *Coupling between lumped and distributed models for blood flow problems*, in "Comput. Visual Sci.", 2001, vol. 4, p. 111–124.

[74] F. SACHSE. *Computational Cardiology: Modeling of Anatomy, Electrophysiology, and Mechanics*, Springer-Verlag, 2004.

[75] J. SUNDNES, G. LINES, X. CAI, B. NIELSEN, K.-A. MARDAL, A. TVEITO. *Computing the electrical activity in the heart*, Springer-Verlag, 2006.

[76] K. TERZAGHI. *Theoretical Soil Mechanics*, John Wiley and Sons, New-York, 1943.

[77] F. WILLIAMS. *Combustion theory*, 2nd, Benjamin Cummings, 1985.