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Activity Report 2013

Project-Team REO

Numerical simulation of biological flows

IN COLLABORATION WITH: Laboratoire Jacques-Louis Lions

RESEARCH CENTER
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THEME
Modeling and Control for Life Sciences

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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

- Cristóbal Bertoglio was awarded
  - the best thesis Gamni prize by SMAI.
  - the "Best Thesis in Mathematics and their interactions" prize by the EADS/Airbus Foundation

  for his PhD thesis entitled "Direct and inverse problems in fluid-structure interaction. Application to hemodynamics", under the supervision of Jean-Frédéric Gerbeau and Miguel Àngel Fernández Varela.
- Justine Fouchet-Incaux, supervised by Céline Grandmont and Bertrand Maury, was awarded the best poster prize by the Société de Physiologie at the 8th congress of "Physiologie, Pharmacologie et Thérapeutique", Anger 2013.

3. Research Program

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 [83] in the frame of combustion. It was later used to develop the Kiva code [70] at the Los Alamos National Laboratory, or the Hesione code [77], for example. It has a wide range of applications, besides the nuclear setting: diesel engines, rocket engines [73], 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 [79]. 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 [82], and Biot [71] 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 [72]), 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.* [76], [81], [80] 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 and Platforms

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

Participant: Jean-Frédéric Gerbeau [correspondant].

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: Muriel Boulakia, Miguel Ángel Fernández Varela, Jean-Frédéric Gerbeau, Céline Grandmont, Mikel Landajuela Larma, Jimmy Mullaert, Marina Vidrascu.

- In [17] we analyze the performances of two types of Luenberger observers – namely, the so-called Direct Velocity Feedback and Schur Displacement Feedback procedures, originally devised for elasto-dynamics – 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. We first assess the observers using hemodynamics-inspired test problems with the complete model, including the Navier-Stokes equations in Arbitrary Lagrangian-Eulerian formulation, in particular. Then, in order to obtain more detailed insight we consider several well-chosen simplified models, each of which allowing a thorough analysis – emphasizing spectral considerations – while illustrating a major phenomenon of interest for the observer performance, namely, the added mass effect for the structure, the coupling with a lumped-parameter boundary condition model for the fluid flow, and the fluid dynamics effect per se. Whereas improvements can be sought for when additional measurements are available in the fluid domain, the present framework this establishes Luenberger observer methods as very attractive strategies – compared, e.g., to classical variational techniques – to perform state estimation, and more generally for uncertainty estimation since other observer procedures can be conveniently combined to estimate uncertain parameters.
- In [27] we introduce a class of incremental displacement-correction schemes for the explicit coupling of a thin-structure with an incompressible fluid. We provide a general stability and convergence analysis that covers both the incremental and the non-incremental variants. Their stability properties are independent of the added-mass effect. The superior accuracy of the incremental schemes (with respect to the original non-incremental variant) is highlighted by the error estimates, and then confirmed in a benchmark by numerical experiments.

- In [28], [61] we introduce a class of fully decoupled time-marching schemes (velocity-pressure-displacement splitting) for the coupling of an incompressible fluid with a thin-walled viscoelastic structure. A priori energy estimates guaranteeing unconditional stability are established for the variants without extrapolation and with first-order extrapolation. The accuracy and performance of the methods proposed are discussed in several numerical examples.
- In [29] we introduce a class of explicit coupling schemes for the numerical solution of fluid-structure interaction problems involving a viscous incompressible fluid and a general thin-walled structure (e.g., including damping and non-linear behavior). The fundamental ingredient in these methods is the (parameter free) explicit Robin interface condition for the fluid, which enables the fluid-solid splitting through appropriate extrapolations of the solid velocity and fluid stress on the interface. The resulting solution procedures are genuinely partitioned. Stability and error estimates are provided for all the variants (depending on the extrapolations), using energy arguments within a representative linear setting. In particular, we show that one of them yields added-mass free unconditional stability and optimal (firs-order) time accuracy. A comprehensive numerical study, involving different examples from the literature, supports the theory.
- In [62] we introduce a new class of explicit coupling schemes for the numerical solution of fluid-structure interaction problems involving a viscous incompressible fluid and an elastic structure. These methods generalize the arguments reported in [27], [29] to the case of the coupling with thick-walled structures. The basic idea lies in the derivation of an intrinsic interface Robin consistency at the space semi-discrete level, using a lumped-mass approximation in the structure. The fluid-solid splitting is then performed through appropriate extrapolations of the solid velocity and stress on the interface. Based on these methods, a new, parameter-free, Robin-Neumann iterative procedure is also proposed for the partitioned solution of implicit coupling. A priori energy estimates, guaranteeing the (added-mass free) stability of the schemes and the convergence of the iterative procedure, are established. The accuracy and robustness of the methods are illustrated in several numerical examples.
- In [22] we discuss explicit coupling schemes for fluid-structure interaction problems where the added mass effect is important. We show the close relation between coupling schemes using Nitsche's method and a Robin-Robin type coupling. In the latter case the method may be implemented either using boundary integrals of the stresses or the more conventional discrete lifting operators. We also make the observation that these scheme are stable under a hyperbolic type CFL condition, but that optimal accuracy imposes a parabolic type CFL conditions due to the splitting error. Two strategies to enhance the accuracy of the coupling scheme under the hyperbolic CFL-condition are suggested, one using extrapolation and defect-correction and one using a penalty-free non-symmetric Nitsche method. Finally we illustrate the performance of the proposed schemes on some numerical examples in two and three space dimensions.
- In [59] we consider the extension of the Nitsche method to the case of fluid-structure interaction problems on unfitted meshes. We give a stability analysis for the space semi-discretized problem and show how this estimate may be used to derive optimal error estimates for smooth solutions, irrespective of the mesh/interface intersection. Some numerical examples illustrate the theoretical discussion.
- In [21] we are interested by the three-dimensional coupling between an incompressible fluid and a rigid body. The fluid is modeled by the Navier-Stokes equations, while the solid satisfies the Newton's laws. In the main result of the paper we prove that, with the help of a distributed control, we can drive the fluid and structure velocities to zero and the solid to a reference position provided that the initial velocities are small enough and the initial position of the structure is close to the reference position. This is done without any condition on the geometry of the rigid body.
- In the book chapter [56] we deal with some specific existence and numerical results applied to a 2D/1D fluid-structure coupled model, for an incompressible fluid and a thin elastic structure. We underline some of the mathematical and numerical difficulties that one may face when studying

this kind of problems such as the geometrical nonlinearities or the added mass effect. In particular we underline the link between the strategies of proof of weak or strong solutions and the possible algorithms to discretize these types of coupled problems.

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

Participants: Grégory Arbia, Benoit Fabrèges, Jean-Frédéric Gerbeau, Sanjay Pant, Saverio Smaldone, Marc Thiriet, Irène Vignon-Clementel.

- In [60] we propose a new approach to the loosely coupled time-marching of a fluid-fluid interaction problems involving the incompressible Navier-Stokes equations. The methods combine a specific explicit Robin-Robin treatment of the interface coupling with a weakly consistent interface pressure stabilization in time. A priori energy estimates guaranteeing stability of the splitting are obtained for a total pressure formulation of the coupled problem. The performance of the proposed schemes is illustrated on several numerical experiments related to simulation of aortic blood flow.
- In [48] we present our strategy to meet the MICCAI Challenge 2013: the goal was to recover a measured (but unrevealed) pressure drop across a coarctation of the aorta through 3D simulation. A filtering-based strategy is devised to perform parameter estimation and subsequent multiscale CFD simulations of arterial blood flow. The method is applied to the patient-specific case in the two physiological states of rest and stress. In both cases, the method is shown to be effective in closely matching the available clinically measured data. Pressure drop across the coarctation is predicted for both states. At the time of [46], these measurements were available: the computed pressure drop across the coarctation for the stress case appears to be very close to the measured one, while the one for the rest case is not as good. One should note that no participant of the challenge managed to recover the measured pressure drop for the rest case.
- In [34], we aim to reduce the complexity of patient-specific simulations by combining image analysis, computational fluid dynamics and model order reduction techniques. The proposed method makes use of a reference geometry estimated as an average of the population, within an efficient statistical framework based on the currents representation of shapes. Snapshots of blood flow simulations performed in the reference geometry are used to build a POD (Proper Orthogonal Decomposition) basis, which can then be mapped on new patients to perform reduced order blood flow simulations with patient specific boundary conditions. This approach is applied to a data-set of 17 tetralogy of Fallot patients to simulate blood flow through the pulmonary artery under normal (healthy or synthetic valves with almost no backflow) and pathological (leaky or absent valve with backflow) conditions to better understand the impact of regurgitated blood on pressure and velocity at the outflow tracts. The model reduction approach is further tested by performing patient simulations under exercise and varying degrees of pathophysiological conditions based on reduction of reference solutions (rest and medium backflow conditions respectively).
- In [16], we analyze two 3D-0D coupling approaches in which a fractional-step projection scheme is used in the fluid. Our analysis shows that explicit approaches might yield numerical instabilities, particularly in the case of realistic geometries with multiple outlets. We introduce and analyze an implicitly 3D-0D coupled formulation with enhanced stability properties and which requires a negligible additional computational cost. Furthermore, we also address the extension of these methods to fluid-structure interaction problems. The theoretical stability results are confirmed by meaningful numerical experiments in patient specific geometries coming from medical imaging.
- In [35], 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.

- 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 [42] 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.
- 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 [26], 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 [74]).
- In [25] we propose the first patient-specific predictive modeling of stage 2 palliation for congenital heart disease by using virtual surgery and closed-loop multi-scale modeling. We present a workflow to perform post-operative simulations from pre-operative clinical data. Two surgical options (bi-directional Glenn and hemi-Fontan operations) are virtually performed and coupled to the pre-operative LPM, with the hemodynamics of both options reported. Results are validated against postoperative clinical data.
- In [14] we study the influence of solvers and test case setup on the result of numerical simulations. The need for detailed construction of the numerical model depends on the precision needed to answer the biomedical question at hand and should be assessed for each problem on a combination of clinically relevant patient-specific geometry and physiological conditions. Methods and results between a commercial code and an in-house research code are illustrated on three congenital heart disease examples of increasing complexity. This publication is designed as a tool to better communicate with clinical researchers interested in simulations.

6.3. Numerical methods for cardiac electrophysiology

Participants: Muriel Boulakia, Jean-Frédéric Gerbeau, Annabelle Collin, Elisa Schenone.

- In [24], Computational electrophysiology is a very active field with tremendous potential in medical applications, albeit leads to highly intensive simulations. We here 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. Moreover, 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. Our proposed 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.
- In [44] we assess a previously-proposed surface-based electrophysiology model with detailed atrial simulations. This model - derived and substantiated by mathematical arguments - is specifically designed to address thin structures such as atria, and to take into account strong anisotropy effects related to fiber directions with possibly rapid variations across the wall thickness. The simulation

results are in excellent adequacy with previous studies, and confirm the importance of anisotropy effects and variations thereof. Furthermore, this surface-based model provides dramatic computational benefits over 3D models with preserved accuracy.

6.4. Lung and respiration modeling

Participants: Grégory Arbia, Laurent Boudin, Muriel Boulakia, Benoit Fabrèges, Miguel Ángel Fernández Varela, Jean-Frédéric Gerbeau, Céline Grandmont, Stéphane Liwarek, Jessica Oakes, Ayman Moussa, Irène Vignon-Clementel.

- In [65] we are interested in the mathematical modeling of the deformation of the human lung tissue, called the lung parenchyma, during the respiration process. The parenchyma is a foam-like elastic material containing millions of air-filled alveoli connected by a tree- shaped network of airways. In this study, the parenchyma is governed by the linearized elasticity equations and the air movement in the tree by the Poiseuille law in each airway. The geometric arrangement of the alveoli is assumed to be periodic with a small period. We use the two-scale convergence theory to study the asymptotic behavior as the period goes to zero. The effect of the network of airways is described by a nonlocal operator and we propose a simple geometrical setting for which we show that this operator converges. We identify in the limit the equations modeling the homogenized behavior under an abstract convergence condition on this nonlocal operator. We derive some mechanical properties of the limit material by studying the homogenized equations: the limit model is nonlocal both in space and time if the parenchyma material is considered compressible, but only in space if it is incompressible. Finally, we propose a numerical method to solve the homogenized equations and we study numerically a few properties of the homogenized parenchyma model.
- In [30] we present a calculation of the functioning of an acinus at exercise. We show that, given the geometry and the breathing dynamics of real acini, respiration can be correlated to a single equivalent parameter that we call the integrative permeability. We find that both V_{O2max} and PAO2 depend on this permeability in a non-linear manner.
- In [19], In this paper, we consider the Stokes equations and we are concerned with the inverse problem of identifying a Robin coefficient on some non accessible part of the boundary from available data on the other part of the boundary. We first study the identifiability of the Robin coefficient and then we establish a stability estimate of logarithm type thanks to a Carleman inequality due to A. L. Bukhgeim and 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 [18],In this work, 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 [38], In this paper we introduce a PDE system which aims at describing the dynamics of a dispersed phase of particles moving into an incompressible perfect fluid, in two space dimensions. The system couples a Vlasov-type equation and an Euler-type equation: the fluid acts on the dispersed phase through a gyroscopic force whereas the latter contributes to the vorticity of the former. First we give a Dobrushin type derivation of the system as a mean-field limit of a PDE system which describes the dynamics of a finite number of massive pointwise particles moving into an incompressible perfect fluid. This last system is itself inferred from a joint work of the second author with O. Glass and C. Lacave, where the system for one massive pointwise particle was derived as the limit of the motion of a solid body when the body shrinks to a point with fixed mass and

circulation. Then we deal with the well-posedness issues including the existence of weak solutions. Next we exhibit the Hamiltonian structure of the system and finally, we study the behavior of the system in the limit where the mass of the particles vanishes.

- In [39] we solved for the airflow and aerosol particle distribution in healthy and emphysematous rat lungs. Following our preliminary work in [78], we first estimated the respiratory resistance and compliance parameters from pressure measurements taken during ventilation experiments performed in healthy and emphysematous rats. Next, the 3D Navier-Stokes equations were solved in a Magnetic Resonance derived airway geometry coupled to 0D models at the boundaries leading to the five rat lobes. The multiscale 3D-0D simulations enabled consistent pressure and airflow results, unlike what was found when a constant pressure was described at the boundaries. Aerosolized particles were tracked throughout inspiration and the effects of particle size and gravity were studied. Healthy, homogeneous and heterogeneous disease cases were assessed. Once available, these in-silico predictions may be compared to experimental deposition data.

6.5. Miscellaneous

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

- In [13] we analyse the solution of the linear advection equation on a uniform mesh by a non dissipative second order scheme for discontinuous initial condition. We focus on the case of advection of a step function by the leapfrog scheme. We derive closed form exact and approximate solutions for the scheme that accurately predict oscillations of the numerical scheme.
- In [40] The recent biomechanical theory of cancer growth considers solid tumors as liquid-like materials comprising elastic components. In this fluid mechanical view, the expansion ability of a solid tumor into a host tissue is mainly driven by either the cell diffusion constant or the cell division rate, the latter depending either on the local cell density (contact inhibition), on mechanical stress in the tumor, or both. For the two by two degenerate parabolic/elliptic reaction-diffusion system that results from this modeling, we prove there are always traveling waves above a minimal speed and we analyse their shapes. They appear to be complex with composite shapes and discontinuities. Several small parameters allow for analytical solutions; in particular the incompressible cells limit is very singular and related to the Hele-Shaw equation. These singular traveling waves are recovered numerically.
- In [67] This paper is devoted to the use of the entropy and duality methods for the existence theory of reaction-cross diffusion systems consisting of two equations, in any dimension of space. Those systems appear in population dynamics when the diffusion rates of individuals of two species depend on the concentration of individuals of the same species (self-diffusion), or of the other species (cross diffusion).
- In [64] We consider in this paper a spray constituted of an incompressible viscous gas and of small droplets which can breakup. This spray is modeled by the coupling (through a drag force term) of the incom- pressible Navier-Stokes equation and of the Vlasov-Boltzmann equation, together with a fragmentation kernel. We first show at the formal level that if the droplets are very small after the breakup, then the solutions of this system converge towards the solution of a simplified system in which the small droplets produced by the breakup are treated as part of the fluid. Then, existence of global weak solutions for this last system is shown to hold, thanks to the use of the DiPerna-Lions theory for singular transport equations.
- In [41],We propose a method of modelling sail type structures which captures the wrinkling behaviour 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 behaviour of various structures with spherical and cylindrical shapes, characteristic of downwind sails over a rather wide range of shape and 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, out of the scope of the present study.

- In [33],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 have 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 [47] We apply the domain decomposition method to linear elasticity problems for multi-materials where the heterogeneities are concentrated in a thin internal layer. In the first case the heterogeneities are small, identical and periodically distributed on an internal surface and in the second one all the thin, curved internal layer is made of an elastic material much more strong than the surrounding one. In the first case the domain decomposition is used to efficiently solve the non-standard transmission problems obtained by the asymptotic expansion method. In the second case a non-standard membrane transmission problem originates from a surface shell like energy.
- In [31] : Our aim is to numerically validate the effectiveness of a matched asymptotic expansion formal method introduced in a pioneering paper by Nguetseng and Sànchez Palencia and extended in [75], [32]. Using this method a simplified model for the influence of small identical heterogeneities periodically distributed on an internal surface to the overall response of a linearly elastic body is derived. In order to validate this formal method a careful numerical study compares the solution obtained by a standard method on a fine mesh to the one obtained by asymptotic expansion. We compute both the zero and the first order terms in the expansion. To efficiently compute the first order term we introduce a suitable domain decomposition method.
- In [38] we introduce a PDE system which aims at describing the dynamics of a dispersed phase of particles moving into an incompressible perfect fluid, in two space dimensions. The system couples a Vlasov-type equation and an Euler-type equation: the fluid acts on the dispersed phase through a gyroscopic force whereas the latter contributes to the vorticity of the former. First we give a Dobrushin type derivation of the system as a mean-field limit of a PDE system which describes the dynamics of a finite number of massive pointwise particles moving into an incompressible perfect fluid. This last system is itself inferred from a joint work of the second author with O. Glass and C. Lacave, where the system for one massive pointwise particle was derived as the limit of the motion of a solid body when the body shrinks to a point with fixed mass and circulation. Then we deal with the well-posedness issues including the existence of weak solutions. Next we exhibit the Hamiltonian structure of the system and finally, we study the behavior of the system in the limit where the mass of the particles vanishes.
- In [64] we consider a spray constituted of an incompressible viscous gas and of small droplets which can breakup. This spray is modeled by the coupling (through a drag force term) of the incom- pressible Navier-Stokes equation and of the Vlasov-Boltzmann equation, together with a fragmentation kernel. We first show at the formal level that if the droplets are very small after the breakup, then the solutions of this system converge towards the solution of a simplified system in which the small droplets produced by the breakup are treated as part of the fluid. Then, existence of global weak solutions for this last system is shown to hold, thanks to the use of the DiPerna-Lions theory for singular transport equations.

7. Partnerships and Cooperations

7.1. National Initiatives

7.1.1. ANR

7.1.1.1. ANR Project "M3RS"

Participants: Laurent Boudin, Muriel Boulakia, Céline Grandmont [Principal Investigator], 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.

7.1.1.2. ANR Project "Epsilon"

Participant: Marina Vidrascu [local coordinator].

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.

7.1.1.3. ANR Project "EXIFSI"

Participants: Benoit Fabrèges, Miguel Ángel Fernández Varela [Principal Investigator], Mikel Landajuela Larma, Marina Vidrascu.

Period: 2012-2016
The aim of this project, coordinated by Miguel Àngel Fernández Varela, is to study mathematically and numerically new numerical methods for incompressible fluid-sructure interaction.

7.1.1.4. ANR Project "CARDIOXCOMP"

Participants: Muriel Boulakia, Jean-Frédéric Gerbeau [Principal Investigator], Fabien Raphel.

Period: 2013-2013.
This project, coordinated by Jean-Frédéric Gerbeau, is carried out in the framework of a joint laboratory ("LabCom" call of ANR) with the software company NOTOCORD. The focus is the mathematical modeling of a device measuring the electrical activity of cardiomyocytes. The overall objective of CardioXcomp is to enrich NOTOCORD's software with modelling and simulation solutions and provide to pharmacology research a completely new set incorporating state of the art signal processing and numerical simulation.

7.1.1.5. ANR Project "iFLOW"

Participants: Chloé Audebert, Jean-Frédéric Gerbeau, Irène Vignon-Clementel [co-Principal Investigator].

Period: 2013-2017.
This ANR-tecsan, co-managed by Eric Vibert (Paul Brousse Hospital) and Irene Vignon-Clementel, aims at developing an Intraoperative Fluorescent Liver Optimization Workflow to better understand the relationship between architecture, perfusion and function in hepatectomy.

7.2. European Initiatives

7.2.1. FP7 Projects

7.2.1.1. REVAMMAD

Type: PEOPLE

Instrument: Marie Curie Initial Training Network

Duration: April 2013 - March 2017

Coordinator: Andrew Hunter, University of Lincoln (UK)

Partners: See the web site

Inria contact: J-F Gerbeau

Abstract: REVAMMAD is a European Union project aimed at combatting some of the EU's most prevalent chronic medical conditions using retinal imaging. The project aims to train a new generation of interdisciplinary scientists for the academic, clinical and industrial sectors, and to trigger a new wave of biomedical interventions. The role of REO team within this consortium is to propose a mathematical model and a simulation tool for the retina hemodynamics.

7.3. International Initiatives

7.3.1. Inria Associate Teams

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

Period: 2008-2013

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 University of California in San Diego and the and the Shadden group at University of California in Berkeley.. CA Figueroa is now at KCL, UK.

7.3.2. Trans-Atlantic Network of Excellence for Cardiovascular Research

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

Period: 2010-2015

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

7.3.3. German BMBF national project Lungsys II

Participant: Irène Vignon-Clementel.

Period: 2012-2015 "Systems Biology of Lung Cancer “Dynamic Properties of Early Spread and Therapeutic Options”. In collaboration with Dirk Drasdo EPI Bang, Inria & Paris 6 UPMC

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

7.4. International Research Visitors

7.4.1. Internships

- Stephanie Lindsey, PhD student at Cornell University, Aug 2013 - February 2014

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.
  - Member of the think-tank for first-year programs in Mathematics at UPMC.
  - Member of the IREM (Institutes for Research on Mathematics Teaching) Scientific Committee.
  - Co-organizer of the conference "Multiscale multiphysics modelling for the respiratory system", with C. Grandmont and B. Grec,
  - Co-organizer of first-year ending workshop of the Kindymo project, with J.-P. Nadal and A. Vignes.
- Muriel Boulakia
  - Organization of the workshop "Mathematical Aspects of Fluid-Structure Interactions", IHP (Paris), November 2013
- Miguel Ángel Fernández Varela
  - Member of the Postdocs Selection Committee, Inria Paris-Rocquencourt
  - Mini-symposium on *Advanced numerical methods for fluid mechanics*, ENUMATH 2013, August 26-30, Lausanne, Switzerland (organized with E. Burman and A. Ern).
  - Mini-symposium on *Fluid-structure interaction and fictitious domain methods*, SMAI 2013, 6ème biennale française des mathématiques appliquées et industrielles, May 27-31, 2013, Seignosse Le Penon, France (organized with S. Boyaval and L. Monasse).
  - Member of the "Ramón y Cajal" Program selection committee, mathematics section, Ministry of research, development and innovation (Spain).
  - Member of the committee CEA-EDF-Inria summer school on Numerical methods for interface problems in fluid and solids with discontinuities, June 23-July 4, 2014, Cadarache (with P. Massin and J. Segré).
- Jean-Frédéric Gerbeau
  - Editor-in-Chief of Mathematical Modelling and Numerical Analysis (M2AN)
  - Member of the editorial boards of International Journal for Numerical Methods in Biomedical Engineering (IJNMBE) and of 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 Inria Evaluation Committee; Member of the Inria International Chairs committee.

  - Service activity in other French institutions: 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 scientific committee of Labex NUMEV, Montpellier.
  - Service activity abroad: member of the Reference Committee of the PhD program Mathematical Models and Methods in Engineering (Politecnico di Milano, Italy);
  - Organizing Committee of the SIAM APDE 2013 conference. Orlando, USA.
  - Scientific Committee of the ENUMATH 2013 conference. Lausanne, Switzerland.
  - Advisory Committee of the 3rd International conference on Computational & Mathematical Biomedical Engineering (CMBE 2013). Hong-Kong
- Céline Grandmont
  - Member of the CNU 26 (2011–2015).
  - Co-organizer of the international conference "Multiscale multiphysics modelling for the respiratory system" June 26-27, 2013, Paris, around 50 participants. https://www.ljll.math.upmc.fr/m3rs2013/
  - Co-organizer of the second Math-parity Day (on gender issues in the mathematics community), 24 juin 2013, IHP, Paris. http://postes.smai.emath.fr/apres/parite/journee2013/
- Jessica Oakes
  - International Society of Aerosol Medicine Student Forum Leader. September 2013 - Present.
  - 4th International Conference on Engineering Frontiers in Pediatric and Congenitial Heart Disease. Sub-Organizer. November 2013 - Present.
- Elisa Schenone
  - Co-organizer of the monthly Junior Seminar of Inria Paris-Rocquencourt
- Marc Thiriet
  - Member of the Scientific committee of the collaborative platform DiscInNet.
  - 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)
  - Member of several Evaluation Groups of the Canadian Granting Agency NSERC (mainly Mechanical Engineering, but also Mathematics)
- Marina Vidrascu
  - Member of the Postdocs Selection Committee, Inria Paris-Rocquencourt
- Irène Vignon-Clementel
  - Review Editor of Frontiers in Pediatric Cardiology
  - 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 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

  - Contributed talk, Congrès SMAI , Seignosse, France, May 2013.
  - Contributed talk, Modelling of physiological flows , Chia, Italy, June 2013.
  - Inria Junior Seminar, January 2013 Inria Junior Seminar, January 2013
- Laurent Boudin
  - Seminar, Numerical analysis, Irmar, Univ. Rennes 1, January 2013
  - Seminair, MIP, Univ. Toulouse 3, February 2013.
- Muriel Boulakia
  - Seminar, Univ. Darmstadt (Germany), february 2013
  - Seminar, Maths-Club, Univ. Paris-Diderot, march 2013
  - Contributed talk, Workshop Control of fluid-structure systems, Paris, november 2013
- Miguel Ángel Fernández Varela
  - Talk at minisymposium, SMAI 2013, 6ème biennale française des mathématiques appliquées et industrielles, May 27-31, 2013, Seignosse Le Penon
  - Seminar, University of Montpellier, May
- Benoit Fabrèges
  - Contributed talk, M3RS ending conference, UPMC Paris 6, June 2013
  - Contributed talk, 3th International Conference on Computational & Mathematical Biomedical Engineering, 16-18 December 2013, Hong Kong, China
  - Seminar, Nantes, January 2013
  - Contributed talk, Journée Dynamo 2013, March 2013, Orléans
  - Seminar, Strasbourg, May 2013
- Justine Fouchet-Incaux
  - Seminar at "Groupe de Travail des Thésards", March 2013, Laboratoire Jacques-Louis Lions, Paris 6
  - Poster, VIIIème congrès de Physiologie, de Pharmacologie et de The´rapeutique (P2T'13), April 2013, Angers
  - Seminar at "Groupe de Travail Numérique", May 2013, Laboratoire de Mathématiques d'Orsay
  - Talk at minisymposium "Calcul scientifique et pathologies pulmonaires", Congrès SMAI 2013, May 27-31, Seignosse,
  - Seminar of "Analyse Numérique et Equations aux Dérivées Partielles" team, June 2013, Laboratoire de Mathématiques d'Orsay
  - Contributed talk, workshop "Multiscale multiphysics modelling for the respiratory system", ANR M3RS ending conference, June 2013, Laboratoire Jacques-Louis Lions, Paris 6
  - Poster, colloque EDP-Normandie, October 2013, Caen
  - Invited speaker, workshop "BioPhysMath", December 2013, Nice
- Jean-Frédéric Gerbeau
  - Invited conference, Workshop “EDP Normandie”, Caen, 2013
  - Seminar Simon Fraser University, Vancouver, Canada, November, 2013
  - Seminar Université de Rouen, February 2013.
  - Talk at minisymposium, SIAM Conference on Analysis of Partial Differential Equation, Orlando, USA, 2013
  - Talk at minisymposium, USNCCM, Raleigh, USA, 2013

  - Talk at minisymposium, ECCOMAS, Lausanne, Switzerland, 2013
- Céline Grandmont
  - Invited speaker, Opening day of GDR Metice, May 2013, Paris
  - Contributed talk, Minisymposium, Equadiff 13, sept. 2013, Prague, Czech Republic
  - Invited speaker, PDEs and Dynamical system in Biology, Oct. 2013, Tel Aviv, Israel
  - EDP Seminar, Univ Paris-Sud, oct. 2013
- Matthieu Hillairet
  - Invited talk at Mathematical Aspects of Fluid-Structure Interactions, November 4-8, Paris,
  - Invited talk at Asymptotic behaviour of systems of PDE arising in physics and biology: theoretical and numerical points of view, November 6-8, Lille
  - Seminar, University of Paris 13, November
  - Seminar, University of Avignon, November
  - Seminar, University of Toulouse, December
  - Seminar, University of Lyon, December
- Mikel Landajuela
  - Contributed talk, 12th U.S National Congress on Computational Mechanics (USNCCM12), Raleigh, USA, July 22-25, 2013
- Damiano Lombardi
  - Contributed talk "Tom Hughes 70", San Diego USA, February 2013.
- Ayman Moussa
  - Workshop Kinetic Days (Toulouse, April 2013)
  - M3RS Ending Conference (LJLL, June 2013)
  - Workshop Math Bio (Versailles, March 2013)
  - Numerical Analysis/PDE Seminar (ENS Ker Lann, October 2013)
  - MFO "Classical and Quantum Mechanical Models of Many-Particle Systems" (Oberwolfach, December 2013)
  - Numerical Analysis/PDE Seminar (ENS Cachan, December 2013)
- Jessica Oakes
  - Talk and poster, 19th International Congress of the International Society for Aerosols in Medicine, Chapel Hill, USA, April 2013.
  - Poster, University of California, San Diego Research Exposition. April 2013.
  - Poster, Whitaker Grantee Orientation, July 2013.
  - Inria Junior Seminar, October 2013.
- Sanjay Pant
  - Contributed talk and poster, 4th International Workshop on Statistical Atlases and Computational Models of the Heart held in conjunction with the 16th International conference on Medical Image Computing and Computer Assisted Intervention, Sep 22–26, 2013, Nagoya, Japan.
- Elisa Schenone
  - Contributed talk at V International Symposium on Modelling Of Physiological Flows - MPF2013, June 11-14, 2013
  - Contributed talk at Mini Symposium on Cardiovascular Biomechanics at APCOM&ISCM2013, Singapore, December 11-14, 2013.
  - 2nd Feel++ Users Days, January 23-25, 2013

  - Matinée "Contrôle" avec Alfio Quarteroni, LJLL, 21 mars 2013
- Saverio Smaldone
  - 5th International Symposium on Modelling of Physiological Flows (MPF 2013), Chia Laguna, Sardinia, Italy, 11-14 June 2013;
- Marc Thiriet
  - Keynote speaker 11th International Symposium on Computer Methods in Biomechanics and Biomedical Engineering, April 3-7, 2013, Salt Lake City, Utah
  - Keynote speaker at Annual Meeting of the Canadian Applied and Industrial Mathematics Society, CAIMS 2013, Quebec City, June 16 - 20 (joint work with Deleuze, TWH. Sheu)
  - 4th CREST-SBM International Symposium, 13-14 March 2013, Tokyo, Japan.
  - International Conference on Life Science & Biological Engineering (LS&BE'13), 15-17 March, 2013, Tokyo (joint work with Y. Deleuze, TWH. Sheu, M.)
  - 2013 International Conference on Life Science & Biological Engineering (LS&BE'13), 15-17 March, 2013, Tokyo (joint work with M. Solovchuk, TWH. Sheu)
  - 2014 IEEE International Symposium on Biomedical Imaging, Beijing, China, April 29 - May 2, 2014 Passat N.)
- Marina Vidrascu
  - Plenary talk 22st International Conference on Domain Decomposition Methods, September 16-20, 2013 - Università della Svizzera italiana - Lugano, Switzerland
  - Seminar Laboratoire Jacques Louis Lions, Paris 6 UPMC, October, 2013
- Irène Vignon-Clementel
  - Contributed talk in honor of TJR Hughes 70th birthday, FEF2013, Feb 24th-27th, San Diego, USA
  - Seminar, Department of Mechanical and Aerospace Engineering, University of California San Diego, Feb 28th, San Diego, USA
  - Plenary, CREST-SBM conference, March 13th-14th, Tokyo, Japan
  - Invited lecture (3h), University of Tokyo, March 15th, Tokyo Japan
  - Contributed talk, BIS' workshop, May 20th-21rst, Paris, France
  - Invited talk, GDR Metice, June 17th-19th, Paris, France
  - Contributed talk, MAFELAP, June 10th-13th, London, UK
  - Seminar, Department of Biomedical Engineering, King's College London, June 12th, London, UK
  - Invited talk, Multiscale multiphysics modelling for the respiratory system workshop, June 26th-27th, Paris, France
  - Contributed talk, USNCCM12, July 22nd-25th, Raleigh, USA
  - Seminar, Demi-heure de science, Inria, Sept 12th, Rocquencourt, France
  - Evaluation seminar, associated team CARDIO 2008-2013, Oct 9th, Online
  - Contributed talk, 3rd International Conference on Computational and Mathematical Biomedical Engineering, Dec 15th-18th, Honk-Hong, China

8.2. Teaching - Supervision - Juries

8.2.1. Teaching

DUT :

- Justine Fouchet-Incaux 1ère année: Mathématiques S'1, 45h, IUT d'Orsay, département Mesures Physiques, Université Paris-Sud,
- Justine Fouchet-Incaux 1ère année: Informatique et algorithmique S'1, 28h, IUT d'Orsay, département Mesures Physiques, Université Paris-Sud

Licence :

- Grégory Arbia
  - Algèbre 1 : calcul vectoriel, 36h, L1, UPMC
  - Calcul matriciel numérique, 24h, L3, UPMC.
- Chloé Audebert Calculus, 22h, L1 - undergraduate, Université Paris 6 UPMC
- Laurent Boudin
  - Series and integrals (10h), L2, UPMC.
  - Multivariable calculus and multiple integrals (111 h), L2, UPMC.
  - Shared studies supervision in mathematics licence for approximately 250 students (20h), L2, UPMC.
  - Co-supervisor (for mathematics) of the bidisciplinary computer science / applied mathematics licence program and of the joint program UPMC-Brown on computer science / applied mathematics (no hour dedicated), L2, UPMC.
- Muriel Boulakia
  - Scilab (30h), L2, UPMC
  - Hilbertian analysis (30h), level L3, Polytech'Paris,
- Miguel Àngel Fernàndez Varela Scientific computing, 30h, level L3, École des Ponts ParisTech,
- Céline Grandmont Numerical Analysis, 36 h, L3, UPMC
- Elisa Schenone
  - Calcul vectoriel, 72h, L1, UPMC
  - Calcul matriciel numérique, 24h, L3, UPMC
  - Scilab, 34h, L2, UPMC
- Irène Vignon-Clementel Mathematics for biology, 64h ETD, L1 - undergraduate, Université de Versailles Saint Quentin

Master :

Laurent Boudin

- Basics for numerical methods (48h), M1, UPMC.
- Studies supervision in mathematics master for 15 students (10h), M1, UPMC.

Muriel Boulakia

- Numerical Methods (48h), level M1, Polytech'Paris,
- Preparatory course for teaching admission examination Agrégation (80h), M2, UPMC,

Jean-Frédéric Gerbeau

- Numerical methods in hemodynamics (20h), level M2, UPMC / Univ Paris-Sud / Ecole Polytechnique.

Miguel Àngel Fernàndez Varela

- Numerical methods in bio-fluids, 6h, level M2, University of Vigo, Spain.
- Numerical methods for fluid-structure interaction, 6h, level M2, Université de Laval, Québec, Canada

Marc Thiriet

- “Biofluid flows”, 12 h, University Pierre & Marie Curie

Others

- Irène Vignon-Clementel Ecole d’ingénieur: Numerical simulations of blood flow, 1h30, as part of the undergraduate "continuum mechanics" class at AgroParisTech, France

8.2.2. Supervision

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 : Chloé Audebert, *Modeling of liver hemodynamics*, since October 2013. 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 : Mikel Landajuela, Coupling schemes and unfitted mesh methods for fluid-structure interaction, since October 2012, Supervisor: M.A. Fernández Varela.

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

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

8.2.3. Juries

- Laurent Boudin
  - Member of the PhD committee of Nicolas Lelong (Univ. Tours, Sept. 2013).
- Muriel Boulakia
  - Hiring committee: UPMC (MCF position)
- Miguel Àngel Fernàndez Varela
  - Member of the PhD committees (referee) of I. Dione (Université de Laval, Québec, Canada).
- Jean-Frédéric Gerbeau
  - Habilitation (HDR) committee: Jing-Rebecca Li (HDR), Université Paris-Sud.
  - PhD committees: Simon Labarthe, Université de Bordeaux (reviewer), Vincent Chabannes, Université de Grenoble (reviewer), Alexandre Impérial, Univ. Paris 6.
  - Hiring committee: Université Paris-Sud (assistant prof), Inria Bordeaux (junior researcher), Inria (senior researcher).
- Céline Grandmont
  - AERES Committee: LMPA, Calais Univ., Nov 2013
  - Hiring committee: Metz Univ. (Professor position).
- Marc Thiriet
  - Member of the PhD committee of Robin Chatelin,(University Toulouse)

- Marina Vidrascu
  - Member of the PhD committee (referee) of Vincent Visseq (University Montpellier)
- Irène Vignon-Clementel
  - Member of the PhD committee Jessica Oakes, University of California San Diego, USA, May 31rst
  - Member of the PhD committee Charlotte Debbaut (referee), Ghent University, Belgium, Sept 20th;
  - Member of the PhD committee (referee) Alessandro Melani, MOX, Politecnico di Milano, Italy, Sept 30th.

8.3. Popularization

- Ayman Moussa
  - Participation at “Fête de la science” at Paris 7

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, pp. 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, pp. 341-365 [*DOI :* 10.1016/J.MATPUR.2010.04.002], http://hal.inria.fr/hal-00648710/en/

[3] E. BURMAN, M. Á. FERNÁNDEZ. *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, pp. 409–439

[4] E. BURMAN, M. Á. FERNÁNDEZ. *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, pp. 485-498, http://hal.inria.fr/inria-00543090

[7] M. Á. FERNÁNDEZ, 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, pp. 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, pp. 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, pp. 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, pp. 3776-3796

Publications of the year

Articles in International Peer-Reviewed Journals

[13] G. ARBIA, D. BOUCHE. *Closed form solution and equivalent equation approximation of linear advection by a non dissipative second order scheme for step initial conditions*, in "Acta Applicandae Mathematicae", September 2013 [*DOI :* 10.1007/S10440-013-9844-1], http://hal.inria.fr/hal-00918645

[14] G. ARBIA, C. CORSINI, M. E. MOGHADAM, A. MARSDEN, F. MIGLIAVACCA, G. PENNATI, T.-Y. HSIA, I. VIGNON-CLEMENTEL. *Numerical blood flow simulation in surgical corrections: what do we need for an accurate analysis ?*, in "Journal of Surgical Research", January 2014, vol. 186, n^{o} 1, pp. 44-55 [*DOI :* 10.1016/J.JSS.2013.07.037], http://hal.inria.fr/hal-00911298

[15] C. BERTOGLIO, D. BARBER, N. GADDUM, I. VALVERDE, M. RUTTEN, P. BEERBAUM, P. MOIREAU, R. HOSE, J.-F. GERBEAU. *Identification of artery wall stiffness: in vitro validation and in vivo results of a data assimilation procedure applied to a 3D fluid-structure interaction model*, in "Journal of Biomechanics", 2014 [*DOI :* 10.1016/J.JBIOMECH.2013.12.029], http://hal.inria.fr/hal-00925902

[16] C. BERTOGLIO, A. CAIAZZO, M. Á. FERNÁNDEZ. *Fractional-step schemes for the coupling of distributed and lumped models in hemodynamics*, in "SIAM Journal on Scientific Computing", 2013, vol. 35, n^{o} 3, pp. 551-575 [*DOI :* 10.1137/120874412], http://hal.inria.fr/hal-00690493

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[18] 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, pp. 137-157 [*DOI :* 10.3934/KRM.2013.6.137], http://hal.inria.fr/hal-00704952

[19] M. BOULAKIA, A.-C. EGLOFFE, C. GRANDMONT. *Stability estimates for a Robin coefficient in the two-dimensional Stokes system*, in "Mathematical control and related field", March 2013, vol. 3, n^{o} 1, https://www.aimsciences.org/journals/pdfs.jsp?paperID=8296&mode=full, http://hal.inria.fr/hal-00582559

[20] M. BOULAKIA, A.-C. EGLOFFE, C. GRANDMONT. *Stability estimates for the unique continuation property of the Stokes system. Application to an inverse problem*, in "Inverse Problems", November 2013, http://hal.inria.fr/hal-00760039

[21] M. BOULAKIA, S. GUERRERO. *Local null controllability of a fluid-solid interaction problem in dimension 3*, in "Journal of the European Mathematical Society", 2013, vol. 15, n^o 3, pp. 825-856, http://hal.inria.fr/hal-00847963

[22] E. BURMAN, M. Á. FERNÁNDEZ. *Explicit strategies for incompressible fluid-structure interaction problems: Nitsche type mortaring versus Robin-Robin coupling*, in "International Journal for Numerical Methods in Engineering", 2014, vol. 97, n^o 10, pp. 739–758 [*DOI :* 10.1002/NME.4607], http://hal.inria.fr/hal-00819948

[23] P. CAZEAUX, J. S. HESTHAVEN. *Multiscale modelling of sound propagation through the lung parenchyma*, in "ESAIM: Mathematical Modelling and Numerical Analysis", 2013 [*DOI :* 10.1051/M2AN/2013093], http://journals.cambridge.org/action/displayAbstract?fromPage=online&aid=9073971, http://hal.inria.fr/hal-00736483

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[26] M. ESMAILY MOGHADAM, I. VIGNON-CLEMENTEL, R. FIGLIOLA, A. MARSDEN, THE MODELING OF CONGENITAL HEARTS ALLIANCE (MOCHA) INVESTIGATORS, FOR. *A modular numerical method for implicit 0D/3D coupling in cardiovascular finite element simulations*, in "Journal of Computational Physics", July 2013, vol. 244, pp. 63-79 [*DOI :* 10.1016/J.JCP.2012.07.035], http://hal.inria.fr/hal-00765816

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ogy and Neurobiology", February 2013, vol. 185, n^{o} 3, pp. 625-638 [*DOI :* 10.1016/J.RESP.2012.10.013], http://hal.inria.fr/hal-00918646

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[35] 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", 2013, vol. 46, n^{o} 2, pp. 423-429 [*DOI :* 10.1016/J.JBIOMECH.2012.10.023], http://hal.inria.fr/hal-00765797

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[42] 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", 2013, vol. 135, n° 1, 011002 p. [*DOI :* 10.1115/1.4023089], http://hal.inria.fr/hal-00765804

Invited Conferences

[43] M. VIDRASCU, M. Á. FERNÁNDEZ, J. MULLAERT. *Robin-Neumann semi explicit and explicit schemes in fluid-structure interaction problems*, in "DD22 International Conference on Domain Decomposition Methods", Lugano, Switzerland, 2013, http://hal.inria.fr/hal-00920127

International Conferences with Proceedings

[44] A. COLLIN, J.-F. GERBEAU, M. HOCINI, M. HAÏSSAGUERRE, D. CHAPELLE. *Surface-based electrophysiology modeling and assessment of physiological simulations in atria*, in "FIMH - 7th International Conference on Functional Imaging and Modeling of the Heart", Londres, United Kingdom, S. OURSELIN, D. RUECKERT, N. SMITH (editors), Springer Berlin Heidelberg, 2013, vol. 7945, pp. 352-359 [*DOI :* 10.1007/978-3-642-38899-6_42], http://hal.inria.fr/hal-00815974

[45] C. DUPONT, A.-V. SALSAC, D. BARTHES-BIESEL, M. VIDRASCU, P. LE TALLEC. *Coupling boundary integral and shell finite element methods to study the fluid structure interactions of a microcapsule in a simple shear flow*, in "International Conference on Boundary Element and Meshless Techniques (Beteq)", Palaiseau, France, 2013, http://hal.inria.fr/hal-00913201

[46] B. FABRÈGES, S. PANT, I. VIGNON-CLEMENTEL, J.-F. GERBEAU. *Parameter estimation for a 3D Navier-Stokes - 0D coupled system: application to patient-specific haemodynamics*, in "3rd International Conference on Computational & Mathematical Biomedical Engineering", Hong Kong, China, September 2013, http://hal.inria.fr/hal-00918373

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National Conferences with Proceedings

[49] C. DUPONT, A.-V. SALSAC, D. BARTHES-BIESEL, M. VIDRASCU, P. LE TALLEC. *Motion of a spherical capsule in simple shear flow: influence of the bending resistance*, in "CSMA 2013", Giens, France, 2013, http://hal.inria.fr/hal-00913002

[50] C. TOUZÉ, M. VIDRASCU, D. CHAPELLE. *Calcul direct de la raideur non linéaire géométrique pour la réduction de modèles de coques en éléments finis*, in "CSMA 2013", Giens, France, May 2013, http://hal.inria.fr/hal-00860823

Conferences without Proceedings

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[52] C. BERTOGLIO, P. MOIREAU, J.-F. GERBEAU, M. Á. FERNÁNDEZ, D. CHAPELLE, D. BARBER, N. GADDUM, I. VALVERDE, P. BEERBAUM, R. HOSE. *Inverse problems in fluid-structure interaction: Application to hemodynamics*, in "2nd ECCOMAS Young Investigators Conference (YIC 2013)", Bordeaux, France, September 2013, http://hal.inria.fr/hal-00855837

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Scientific Books (or Scientific Book chapters)

[55] M. BERGMANN, T. COLIN, A. IOLLO, D. LOMBARDI, O. SAUT, H. TELIB. *Reduced Order Models at work*, in "Modeling, Simulation and Applications", A. QUARTERONI (editor), Springer, 2013, vol. 9, http://hal.inria.fr/hal-00906908

[56] C. GRANDMONT, Š. NEČASOVÁ, M. LUKACOVA-MEDVID'OVA. *Mathematical and Numerical Analysis of some fluid-structure interaction problems*, in "Fluid-Structure interaction and biomedical applications", T. BODNÁR, G. P. GALDI, Š. NEČASOVÁ (editors), Advances in Mathematical Fluid Mechanics, Springer, 2014, http://hal.inria.fr/hal-00917363

[57] M. THIRIET. , *Tissue Functioning and Remodeling in the Circulatory and Ventilatory Systems*, Biomathematical and Biomechanical Modeling of the Circulatory and Ventilatory Systems, Springer, New York, 2013, vol. 5, 962 p. , http://hal.inria.fr/hal-00922904

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Research Reports

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[60] M. Á. FERNÁNDEZ, J.-F. GERBEAU, S. SMALDONE. , *Explicit coupling schemes for a fluid-fluid interaction problem arising in hemodynamics*, Inria, December 2013, n° RR-8415, http://hal.inria.fr/hal-00915213

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[62] M. Á. FERNÁNDEZ, J. MULLAERT, M. VIDRASCU. , *Generalized Robin-Neumann explicit coupling schemes for incompressible fluid-structure interaction: stability analysis and numerics*, Inria, October 2013, n° RR-8384, http://hal.inria.fr/hal-00875819

[63] J.-F. GERBEAU, D. LOMBARDI. , *Approximated Lax Pairs for the Reduced Order Integration of Nonlinear Evolution Equations*, Inria, January 2014, n° RR-8454, http://hal.inria.fr/hal-00933172

Other Publications

[64] S. BENJELLOUN, L. DESVILLETTES, A. MOUSSA. , *Existence theory for a kinetic-fluid coupling when small droplets are treated as part of the fluid*, 2013, Accepted for publication in JHDE, http://hal.inria.fr/hal-00805104

[65] P. CAZEAUX, C. GRANDMONT. , *Homogenization of a Multiscale Viscoelastic Model with Nonlocal Damping, Application to the Human Lungs*, October 2013, http://hal.inria.fr/hal-00873549

[66] M. DE BUHAN, A. GLORIA, P. LE TALLEC, M. VIDRASCU. , *Reconstruction of a constitutive law for rubber from in silico experiments using Ogden's laws*, January 2014, http://hal.inria.fr/hal-00933240

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