Activity Report 2015

Team MEMPHIS

Modeling Enablers for Multi-PHysics and InteractionS

Inria teams are typically groups of researchers working on the definition of a common project, and objectives, with the goal to arrive at the creation of a project-team. Such project-teams may include other partners (universities or research institutions).

RESEARCH CENTER
Bordeaux - Sud-Ouest

THEME
Numerical schemes and simulations

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Team MEMPHIS

Creation of the Team: 2015 January 01

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2. Overall Objectives

2.1. Multi-physics numerical modeling

We aim at a step change in multi-physics numerical modeling by developing two fundamental enablers:

- **reduced-order models**;
- **hierarchical Cartesian schemes**.

Reduced-order models (ROMs) are simplified mathematical models derived from the full set of PDEs governing the physics of the phenomenon of interest. ROMs can be derived from first principles or be data-driven. With ROMs one trades accuracy for speed and scalability, and counteracts the curse of dimension by significantly reducing the computational complexity. ROMs represent an ideal building block of systems with real-time requirements, like interactive decision support systems that offer the possibility to rapidly explore various alternatives.

Hierarchical Cartesian schemes allow the multi-scale solution of PDEs on non body-fitted meshes with a drastic reduction of the computational setup overhead. These methods are easily parallelizable and they can efficiently be mapped to high-performance computer architectures. They avoid dealing with grid generation, a prohibitive task when the boundaries are moving and the topology is complex and unsteady.

3. Research Program

3.1. Hierarchical Cartesian schemes

We intend to conceive schemes that will simplify the numerical approximation of problems involving complex unsteady objects together with multi-scale physical phenomena. Rather than using extremely optimized but non-scalable algorithms, we adopt robust alternatives that bypass the difficulties linked to grid generation. Even if the mesh problem can be tackled today thanks to powerful mesh generators, it still represents a severe difficulty, in particular when highly complex unsteady geometries need to be dealt with. Industrial experience and common practice shows that mesh generation accounts for about 20% of overall analysis time, whereas creation of a simulation-specific geometry requires about 60%, and only 20% of overall time is actually devoted to analysis. The methods that we develop bypass the generation of tedious geometrical models by automatic implicit geometry representation and hierarchical Cartesian schemes.

The approach that we plan to develop combines accurate enforcement of unfitted boundary conditions with adaptive octree and overset grids. The core idea is to use an octree/overset mesh for the approximation of the solution fields, while the geometry is captured by level set functions and boundary conditions are imposed using appropriate interpolation methods. This eliminates the need for boundary conforming meshes that require time-consuming and error-prone mesh generation procedures, and opens the door for simulation of very complex geometries. In particular, it will be possible to easily import the industrial geometry and to build the associated level set function used for simulation.

Hierarchical octree grids offer several considerable advantages over classical adaptive mesh refinement for body-fitted meshes, in terms of data management, memory footprint and parallel HPC performance. Typically, when refining unstructured grids, like for example tetrahedral grids, it is necessary to store the whole data tree corresponding to successive subdivisions of the elements and eventually recompute the full connectivity graph. In the linear octree case that we develop, only the tree leaves are stored in a linear array, with a considerable memory advantage. The mapping between the tree leaves and the linear array as well as the connectivity graph is efficiently computed thanks to an appropriate space-filling curve. Concerning parallelization, linear octrees guarantee a natural load balancing thanks to the linear data structure, whereas classical non-structured meshes require sophisticated (and moreover time consuming) tools to achieve proper load distribution (SCOTCH, METIS etc.). Of course, using unfitted hierarchical meshes requires further development and analysis of methods to handle the refinement at level jumps in a consistent and conservative way, accuracy analysis for new finite-volume or finite-difference schemes, efficient reconstructions at the boundaries to recover appropriate accuracy and robustness. These subjects, that are presently virtually absent at Inria, are among the main scientific challenges of our team.

3.2. Reduced-order models

Massive parallelization and rethinking of numerical schemes will allow the solution of new problem in physics and the prediction of new phenomena thanks to simulation. However, in industrial applications fast on line responses are needed for design and control. For instance, in the design process of an aircraft, the flight conditions and manoeuvres, which provide the largest aircraft loads, are not known a priori. Therefore the aerodynamic and inertial forces are calculated at a large number of conditions to give an estimate of the maximum loads, and hence stresses, that the structure of the detailed aircraft design will experience in service. A simplistic estimate of the number of analyses required would multiply the numbers of conditions to give 10^7. Even with simplistic models of the aircraft behavior this is an unfeasible number of separate simulations. However, engineering experience is used to identify the most likely critical loads conditions, meaning that approximately 10^5 simulations are required for conventional aircraft configurations. Furthermore these analyses have to be repeated every time that there is an update in the aircraft structure...

Compared to existing approaches for ROMs, our interest will be focused on two axis. On the one hand, we start from the consideration that small, highly non-linear scales are typically concentrated in limited spatial regions of the full simulation domain. So for example, in the flow past a wing, the highly non-linear phenomena take place close to the walls at the scale of a millimeter for computational domains that are of the order of hundreds of meters. In this context our approach is characterized by a multi-scale model where the large scales are described by far field models based on ROMs and the small scales are simulated by high-fidelity models. The whole point for this approach is to optimally decouple the far field from the near field.

A second characterizing feature of our ROM approach is non-linear interpolation. We start from the consideration that dynamical models derived from the projection of the PDE model in the reduced space are neither stable to numerical integration nor robust to parameter variation when hard non-linear multi-scale phenomena are considered.

However, thanks to Proper Orthogonal Decomposition (POD) we can accurately approximate large solution databases using a small base. Recent techniques to investigate the temporal evolution of the POD modes (Koopman modes, Dynamic Mode Decomposition) allow a dynamic discrimination of the role played by each of them. This in turn can be exploited to interpolate between the modes in parameter space, thanks to ideas relying on optimal transportation that we have started developing in the FP7 project FFAST. In the following we precise these ideas on a specific example.

4. Application Domains

4.1. Energy conversion

We consider applications in the domain of wind engineering and sea-wave converters. As an example of application of our methods, we show a recent realisation where we model a sea-wave energy converter, see figure 1. In this unsteady example, the full interaction between the rigid floater, air and water is described by a monolithic model, the Newton's law, where physical parameters such as densities, viscosities and rigidity vary across the domain. The appropriate boundary conditions are imposed at interfaces that arbitrarily cross the grid using adapted schemes built thanks to geometrical information computed via level set functions. The background method for fluid structure interface is the volume penalization method where the level set functions is used to improve the degree of accuracy of the method and also to follow the object. The simulations are unsteady, three dimensional, with $O(10^8)$ grid points on 512 CPUs.

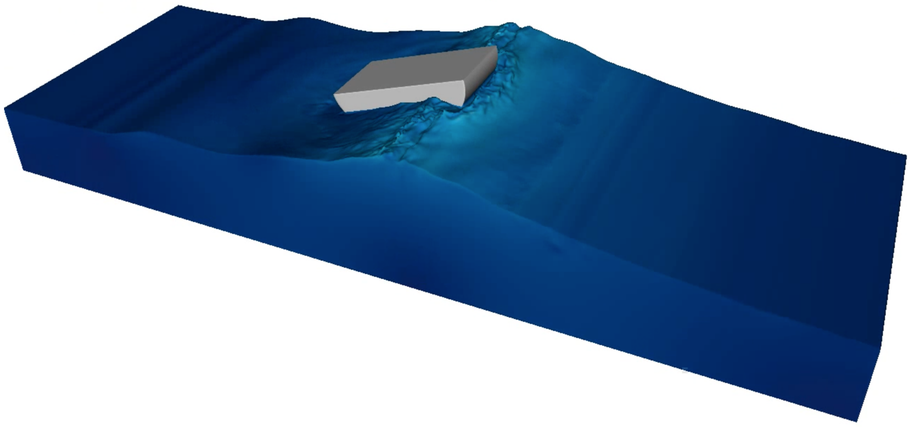

Figure 1. Numerical modeling of a sea-wave converter by a monolithic model and Cartesian meshes.

4.2. Impacts

We study hyper-velocity phenomena where several materials are involved. An example of this approach is the impact of a projectile immersed in air over a shield, see figure 2. Using the same set of equations across the entire domain, we model the compressible fluid, the hyperelastic material and the interaction at the interface that models possible rebounds. Only the constitutive laws characterize the different materials.

The simulation is performed over a 4000^2 fixed Cartesian grid so that the resulting numerical scheme allows an efficient parallelization (512 processors in this case) with an isomorphism between grid partitioning and processor topology. The challenge for our team is to increase the accuracy of the simulation thanks to grid refinement in the vicinity of the moving interfaces, still guaranteeing scalability and a simple computational set up.

4.3. New materials

Thanks to the multiscale schemes that we develop, we can charcterize new materials from constituents. As an example, consider the material presented in figure 3 left. It is a picture of a dry foam that is used as dielectric material. This micrography is taken at the scale of the dry bubbles, where on the surface of the bubble one can observe the carbon nanotubes as white filaments. The presence of nanotubes in the dry emulsion makes the electrical capacitance of this material significantly affected by its strain state by creating aligned dipoles at a larger scale compared to the size of the dielectric molecules. It is a typical multi-scale phenomenon in presence of widely varying physical properties. This material is used to generate micro currents when it undergoes vibrations. The schemes that we device allow to model this multi-scale irregular material by a

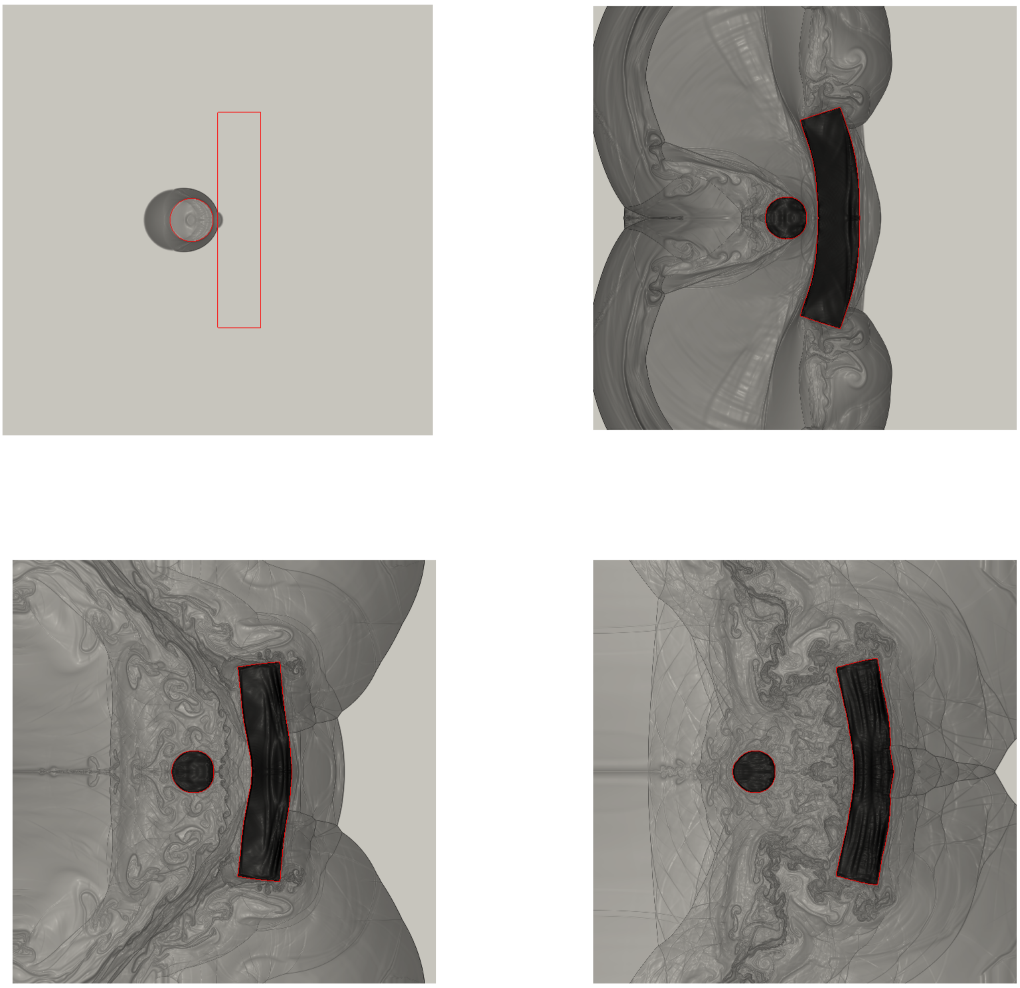

Figure 2. Impact and rebound of a copper projectile on a copper plate. Interface and schlieren at $50\mu s$, $199\mu s$, $398\mu s$ and $710\mu s$. From left to right, top to bottom.

monolithic model (same equation in the whole domain), in this case a variable coefficient diffusion equation. In order to recover adequate accuracy, the numerical scheme is adapted near the interfaces between the different subdomains. The computational hierarchical mesh is directly derived by the micrography of the material (figure 3 right).

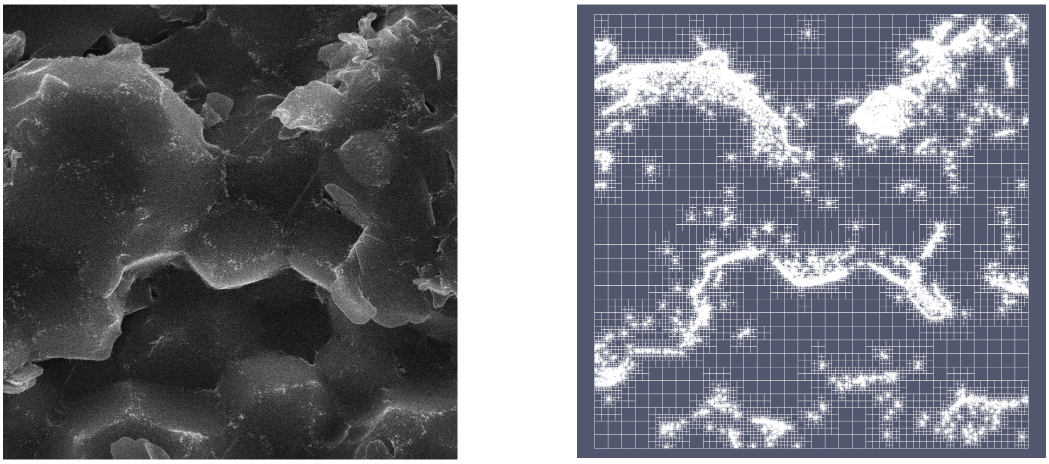

Figure 3. A micrography of an electrostrictive material is shown on the left: the bright regions visualize the carbon nanotubes. The hierarchical grid adapted to the nanotubes is shown on the right. The ratio between the largest and the smallest cell side is 2^7. Project developed in collaboration with the CRPP physics and chemistry lab of the CNRS in Bordeaux (Annie Colin, Philippe Poulin).

4.4. Bio-inspired robotic swimming

In bioinspired robotic swimming the aim is of simulating a three-dimensional swimmer starting from pictures. The first step is to build the three-dimensional fish profile based on two-dimensional data retrieved from the picture of an undeformed fish at rest. This is done by a skeleton technique and a three-dimensional level set function describing the body surface. Then the skeleton is deformed using an appropriate swimming law to obtain a sequence of level set functions corresponding to snapshots of the body surface uniformly taken at different instants.

Thanks to skeleton deformation we typically reconstruct 20% of the snapshots necessary to simulate a swimming stroke, since the time scale of the simulation is significantly smaller than the time step between two subsequent reconstructed snapshots. Also, the surface deformation velocity is required to set the boundary conditions of the flow problem. For this reason it is necessary to build intermediate level set functions and to compute the deformation velocity field between subsequent fish snapshots. Optimal transportation is well suited to achieve this goal providing an objective model to compute intermediate geometries and deformation velocities.

Numerical simulations have been performed in 3D, see figure 4. However, it has been observed that these algorithms do not preserve the physics/features of the represented objects. Indeed, the fish tends to compress during the deformation.

For this reason, we will consider incompressible or rigid transports.

5. Highlights of the Year

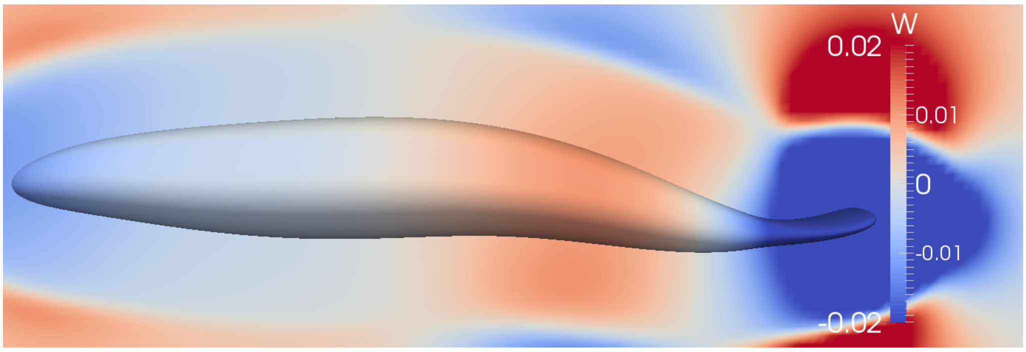

Figure 4. Comparison of the exact deformation velocity (presented inside the swimmer) and the approximated velocity identified using optimal transport (represented outside the fish). The error of the identification scheme is negligible for this component of the velocity, as it can be inferred by comparing the two velocities on the boundary of the swimmer.

5.1. Highlights of the Year

Capsule reentry in high atmosphere

The atmosphere reentry of a capsule is simulated in high atmosphere via a fully parallel code running on massive multi-thread platforms. In these flow conditions, rarefied flow models have to be used. We present here a simulation of a capsule reentry: the focus of this example is on dynamic octree-grid refinement as the geometry and the flow change. Adaptation is based on the distance to the geometry and on the temperature gradient. The dynamics of the capsule is taken into account: according to the force exerted by the fluid on the capsule, the geometry rotates around its center of mass up to the stationary position. The simulation is six-dimensional: three space dimensions and three velocity directions. Without parallelism and grid adaptation the simulation would be out of reach.

6. New Software and Platforms

6.1. New Software

6.1.1. NaSCar

This code is devoted to solve 3D-flows past moving and deformable bodies. The incompressible Navier-Stokes equations are solved on fixed grids, and the bodies are taken into account thanks to penalization and/or immersed boundary methods. The interface between the fluid and the bodies is tracked with a level set function or in a Lagrangian way. The numerical code is fully second order (time and space). The numerical method is based on projection schemes of Chorin-Temam type. The code is written in C language and use Petsc (http://www.mcs.anl.gov/petsc/petsc-as/) library for the resolution of large linear systems in parallel. NaSCar can be used to simulate both hydrodynamic bio-locomotion as fish like swimming and aerodynamic flows such wake generated by a wind turbine.

- Main developper: M. Bergmann.
- Version: 1
- Keywords: numerical analysis, fluid mechanics, language C, PETSc
- Software benefit: flow around deformable obstacles, moving into a fluid.

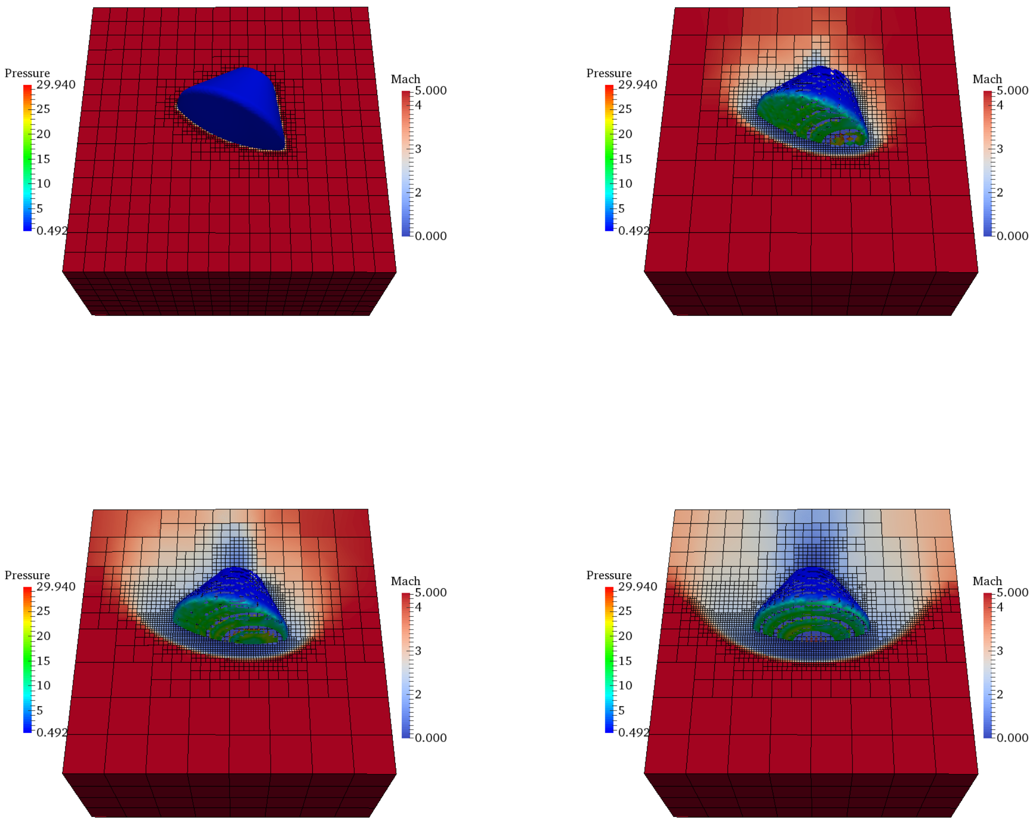

Figure 5. Capsule reentry dynamics in 3D. Rarefied flow and parallel adaptive grid refinement via Octrees.

- APP: in progress
- OS/Middelware: unix, linux, mac os
- Required library or software: PETSc item Programming language: C
- Documentation: in progress

6.1.2. NSMulti

The code is devoted to solve incompressible flows modeled by Navier-Stokes equations in two or three-dimensions. The equation of temperature can be added as well as Oldroyd-B model for viscous-elastic fluids. The two-dimensional version allows many sets of boundary conditions based on Dirichlet boundary condition, open boundary condition and periodic boundary condition. Bodies immersed in the fluid are taken into account by means of the volume penalization method as the code uses only uniform Cartesian meshes. The approximation is performed efficiently by a second order scheme for the linear terms and an upwind third order scheme for the convection terms. An efficient multigrid algorithm is used to accelerate the convergence. The whole code is written in FORTRAN 95 with MPI parallelization. When it is possible an hybrid MPI/OPEN MP parallelization is applied. The code yields the approximate solution at chosen times as well as the mean flow. In addition the time evolution of the main quantities at given points and global physical quantities such as the energy, the enstrophy, the lift, the drag are provided.

- Main developper: C.-H. Bruneau
- Version: 3
- Keywords: Incompressible flows, language FORTRAN95, MPI, OPEN MP.
- Software benefit : flow around solid or porous obstacles.
- APP: in progress
- OS/Middelware: unix, linux, mac os
- Required library or software: none
- Documentation: integrated

6.1.3. CoCoFlo

This is a research code to solve compressible multi-material flows modeled by conservation laws and hyperelatic constitutive models in three-dimensions. The whole code is written in FORTRAN 95 with MPI parallelization.

- Main developper: experimental code with contributions from past PhD students, mainly A. de Brauer and Y. Gorsse under the supervision of A. Iollo.
- Version: 0
- Keywords: Compressible material, language FORTRAN95, MPI, OPEN MP.
- Software benefit : impacts.
- APP: not foreseen
- OS/Middelware: unix, linux, mac os
- Required library or software: none
- Documentation: integrated

6.1.4. KOPPA

This code solves a polyatomic extension of the BGK or the ES-BGK models on octree meshes in parallel (Kinetic Octree Parallel Poly Atomic: KOPPA). It is a finite-volume code second-order accurate scheme in space and time with immersed boundaries. In collaboration with STORM team of Inria, Optimad and CINECA a porting on multi-integrated cores (XEON Phi for the moment) of this code is in progress.

- Main developper: F. Bernard
- Version: 0
- Keywords: Rarefied flows language C++, MPI, OPEN MP.
- Software benefit: simulation of non-equilibrium reentry flows, satellite nozzle plumes.
- APP: not foreseen at the moment
- OS/Middelware: unix, linux, mac os
- Required library or software: PABLO for octree.
- Documentation: integrated

7. New Results

7.1. Plastic impact of iron on aluminium

A new model for plasticity has been developed this year. An iron projectile is impacting an aluminium plate immersed in air. The initial horizontal velocity of the iron is $1000 m.s^{-1}$. The computation is performed on a 2000×1600 mesh with 144 processors. Homogeneous Neumann conditions are imposed on the left and right borders and embedded on the top and bottom.

The results are presented in Fig 6 with a schlieren image (bottom) and the von Mises criteria (top) at different time steps. A log scale is used and the minimum value is fixed to 10^9. We can see that the plate is strongly deformed and form at the end a filament. The projectile is flattened but not as much as in the literature because the yield plastic limit is higher. We see a longitudinal wave propagating in the plate followed by a shear wave that causes the plasticity of the material.

7.2. Air-helium shock-bubble interaction

A three-dimensional hyperelastic model has been developed. It can deal with multi-fluid and solids. Here we show the propagation in air of a Mach 1.22 shock through an helium bubble. The computation is performed on a $1000 \times 400 \times 400$ mesh and lasts for 50h on 300 processors. The zero iso-value of the level set function and schlieren on the horizontal plane through the center of the bubble are presented at different times on Fig. 7.

7.3. Particles flowing in a fluid

A new type of algorithm is designed to enable contacts efficiently between particles immersed in a fluid by adding a short range repulsive force. The algorithm is derived from the multi geometric deformable model introduced for image segmentation. It can handle multiple deforming bodies and avoid collision using a short range repulsive force depending on the distance to the closest interface. The main advantages of this method is it requires only five fields (three label maps and two distance functions) and one level set function to capture an arbitrary number of cells and it can, at the same time, deal with collisions.

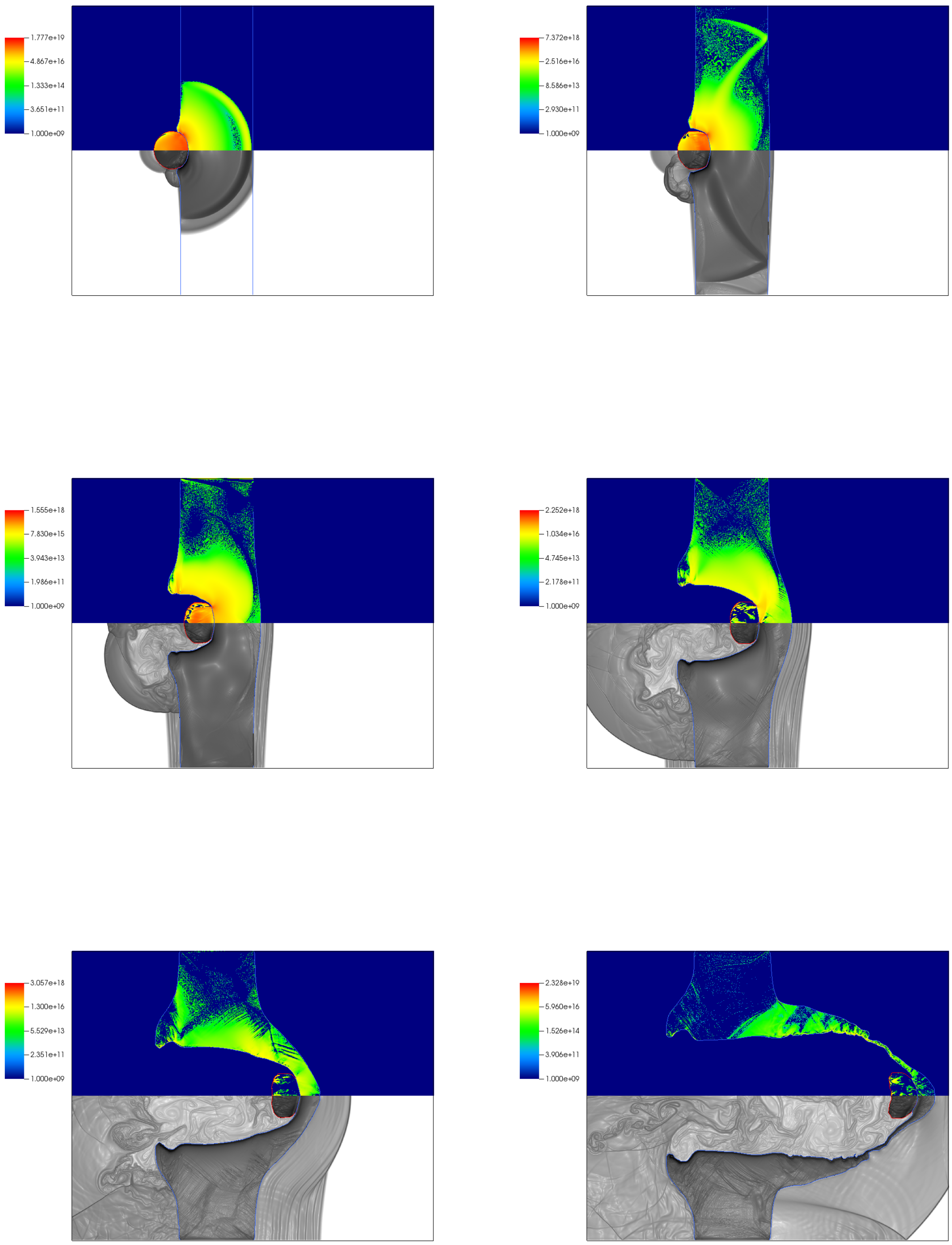

Figure 6. Impact of Iron on Aluminium TC2. Schlieren image and von Mises criteria at $t = 0.03$*ms,* 0.06*ms,* 0.13*ms,* 0.26*ms,* 0.53*ms and* $t = 1.04$*ms from left to right, top to bottom*

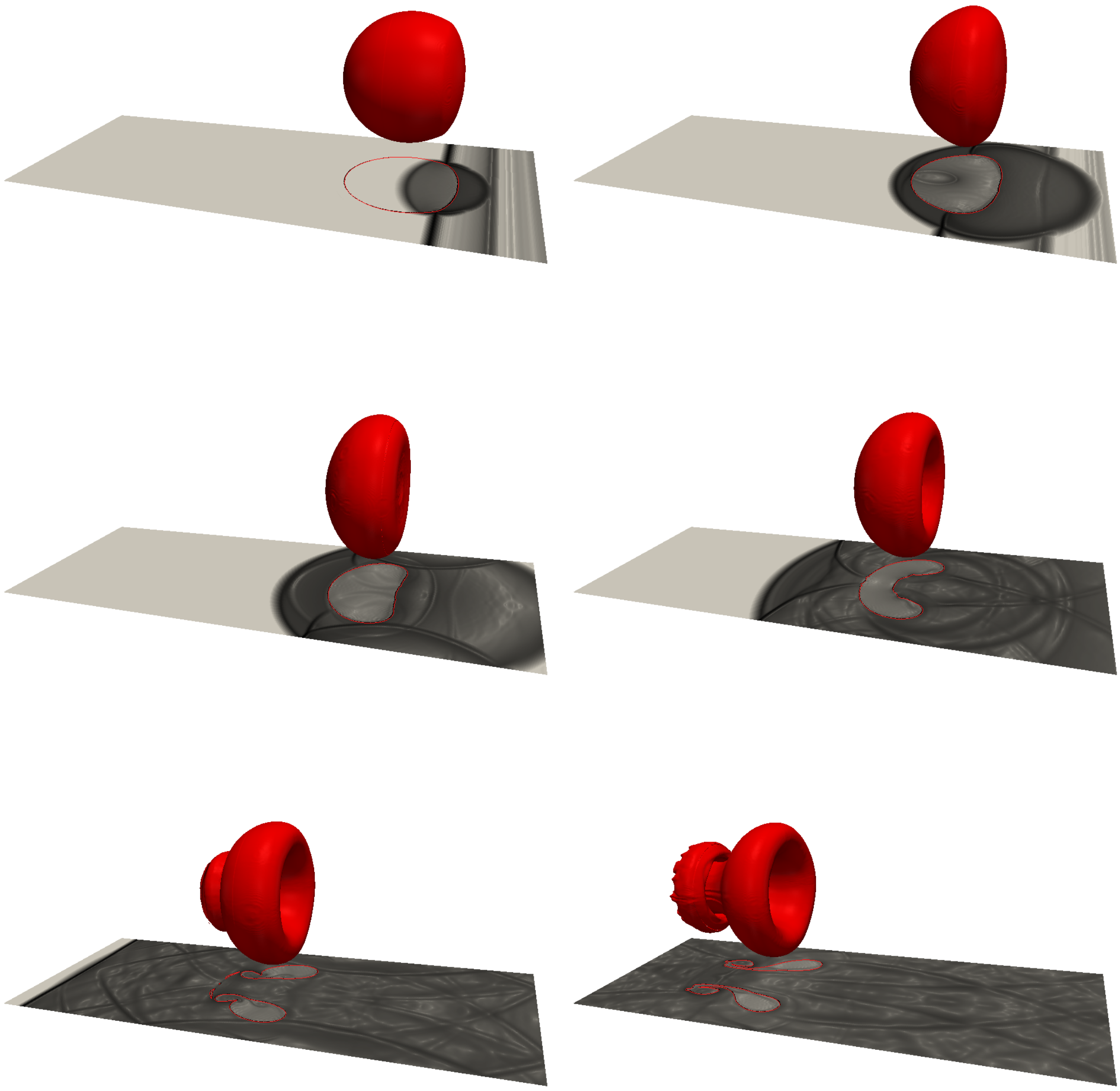

Figure 7. Interaction of a Mach 1.22 shock propagating in air through an helium bubble (TC1). Pictures at $t = 62\mu s$, $110\mu s$, $163\mu s$, $264\mu s$, $471\mu s$, $735\mu s$. From left to right, top to bottom.

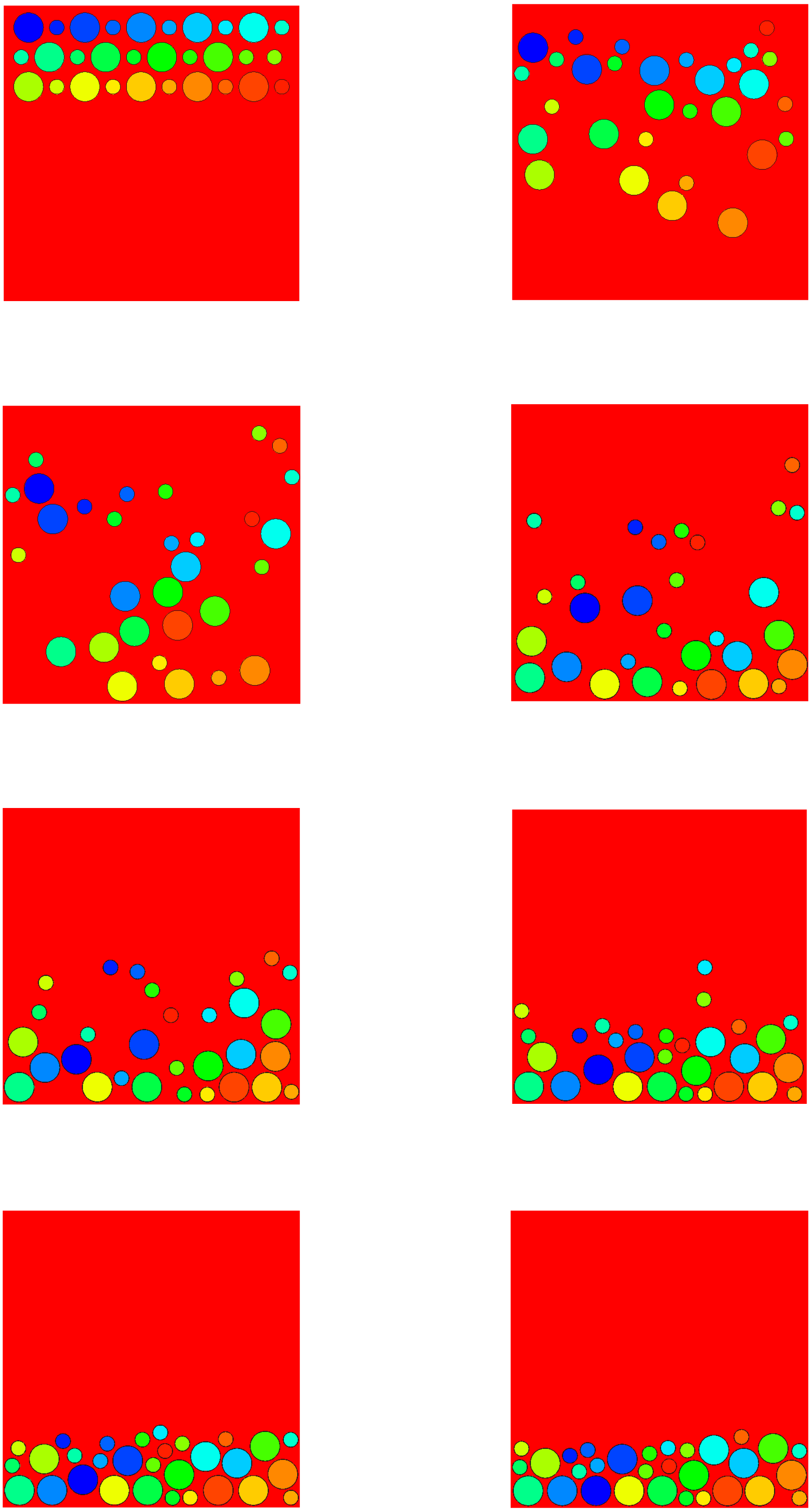

Figure 8. Simulation of 30 rigid bodies of different radii (R = 0.05 or R = 0.025) falling under gravity. The colors indicate the values of the first label map from dark blue for the first body to dark orange for the 30th body and red for the fluid that is the 31st object.

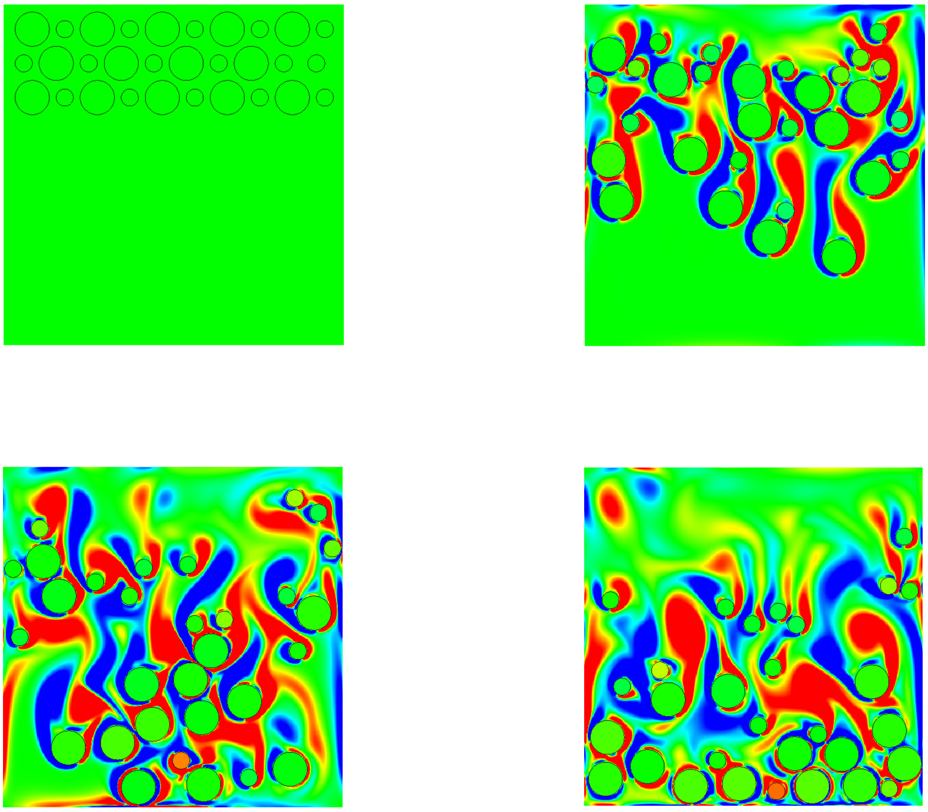

Figure 9. Simulation of 30 rigid bodies of different radii (R = 0.05 or R = 0.025) falling under gravity. The colors indicate the vorticity levels from dark blue for -200 and dark red for 200.

7.4. Inertial Sea Wave Energy Converter (ISWEC)

The ISWEC is a floater and was design by Wave For Energy (http://www.waveforenergy.com) to extract the energy of typical waves in the Mediterranean Sea. The energy is extracted using a mechanical system based on a gyroscope activated by the motion of the floater generated by sea waves. This is a complex system coupling Fluid/Fluid/structure interfaces, computation of the rigid motion of the floater and computation of the power extraction. The problem is solved using in-house numerical solver (NaSCar) developed in MEMPHIS team. The interfaces are tracked using level se functions. The bi fluid interface is computed using Continuous Surface Force method (CSF), the motion of the floater imposed by penalization is computed using the forces and the torques exerted by the flow, and finally this motion activates the gyroscope for power extraction. The gyroscope model was developed by the Politecnico di Torino. Figure 1 shows a numerical simulation of the iswec (see http://www.math.u-bordeaux1.fr/ mbergman/ for a movie)

7.5. Flow with many particles

A version of the code NaSCar has been developed to simulated the flow around particules with high volume fraction (see figure 10). The standard central lubrification forces are used to computed the interaction between spherical particules. Ongoing project will deal with non spherical particules (Lisl Weynans and PhD Baptiste Lambert).

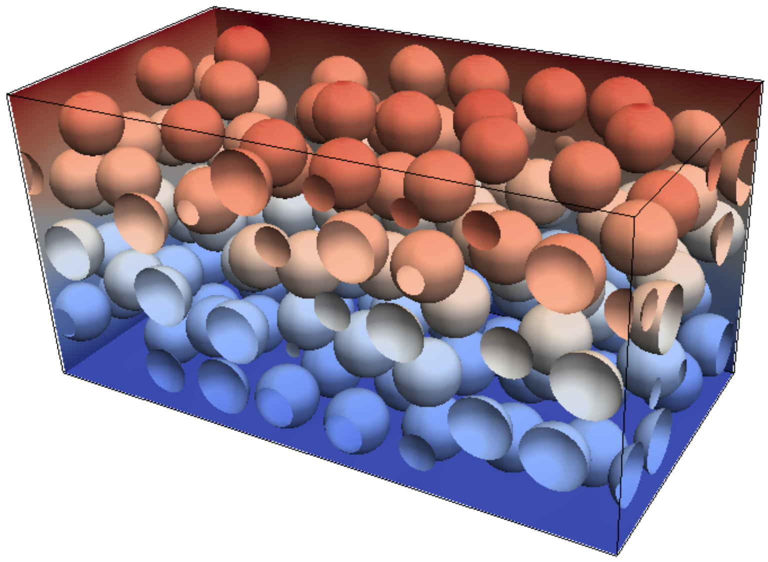

Figure 10. Rheology of a Couette flow with solid particles.

7.6. Overset method

With Valeol (Cifre PhD Claire Morel) we are developing an Overapping grids approach coupling a background cartesian grid with a body fitted grid around wind turbine blades. This method allows us to push away the limit of the numerical simulation on octree grids when small boundary layers play an important role. The generation of overset grids is based on level set functions (post doc AMIES by Franck Luddens). This method has been implemented for two dimensional test cases using the Schwartz method to deal with the domain decomposition. In the same time, we are also building the global operators onto the whole domain, i.e. without Schwartz iterations (PhD Federico Tesser).

7.7. Electrostrictive materials: modelling and simulation

In this work, a result of the collaboration between physicists, chemists (Annie Colin and Philippe Poulin, CRPP Bordeaux) and applied mathematicians, we deal with mathematical modelling and simulation of electrostrictive materials. These kinds of materials are composed by a polymeric matrix with carbon nanotubes embedded in and this structure gives them interesting electrical properties. Their dielectric constant varies as a function of the mechanical deformation. Housed in a capacitor, they show variable capacity when subjected to vibration and they can generate potential differences from mechanical deformations. Because of their composition, their structure involves different physical scales, from the small nanotube dimension, through the scale of nanotube clusters, to the large dimension of the sample. Our purpose is to provide physicists and chemists with a tool to test in silico several material configurations and to have a deeper insight into the features of these materials, developing numerical models which can predict their steady and unsteady behaviour. We propose to model the physical problem by reducing the nanotubes to dipoles and solving a Gauss equation for the electrical potential equation informed of the presence of nanotubes with zero electrical field conditions on the centres of the nanotubes. We started considering the steady problem, which is interesting for the purpose of understanding the basic electrical properties of different nanotube configurations and of designing of the material. In order to discretize and simulate the mathematical problem, we chose parallel linear octree-based adaptive meshes and we developed an original hybrid Finite Volume/Finite Difference second-order scheme for 2D and 3D elliptic problems on this kind of mesh. A convergence analysis of the numerical scheme has been developed and validating test cases have been performed. Good qualitative agreement between numerical and real experiments has been observed for the steady model. In the future we aim to quantitatively compare the numerical results and the real material behaviour, to model the unsteady problem and to deal with electrical consequences of mechanical deformations.

7.8. Development of a sharp cartesian method for the simulation of flows with high density ratios

We have developed a sharp cartesian method for the simulation of incompressible flows with high density and viscosity ratios, like air-water interfaces. This method is inspired from a second-order cartesian method for elliptic problems with immersed interfaces (Cisternino-Weynans 2012). A classical predictor-corrector algorithm is used to solve the fluid equations, in a non-incremental version, which means that the guess value for the pressure is zero. This choice avoids instability issues due to the discontinuous pressure values when the interface moves. We take into account the viscous forces by regularizing the density and viscosity values. This approach allows for a more straightforward and robust treatment, and has been proven to provide satisfactory accuracies for high Reynolds numbers. To compute the pressure, it is necessary to solve an elliptic problem. This elliptic problem with discontinuous values across an interface is solved with the second order method cited above. The originality of this method lies in the use of unknowns located at the interface. These interface unknowns are used to discretize the flux jump conditions and the elliptic operator accurately enough to get a second order convergence in maximum norm.

8. Bilateral Contracts and Grants with Industry

8.1. Bilateral Contracts with Industry

We intend to pursue our partnership with Valeol, a wind turbine contractor in Aquitaine. Valeol poses simulation problems that cannot be addressed with standard tools. We have developed for them simplified

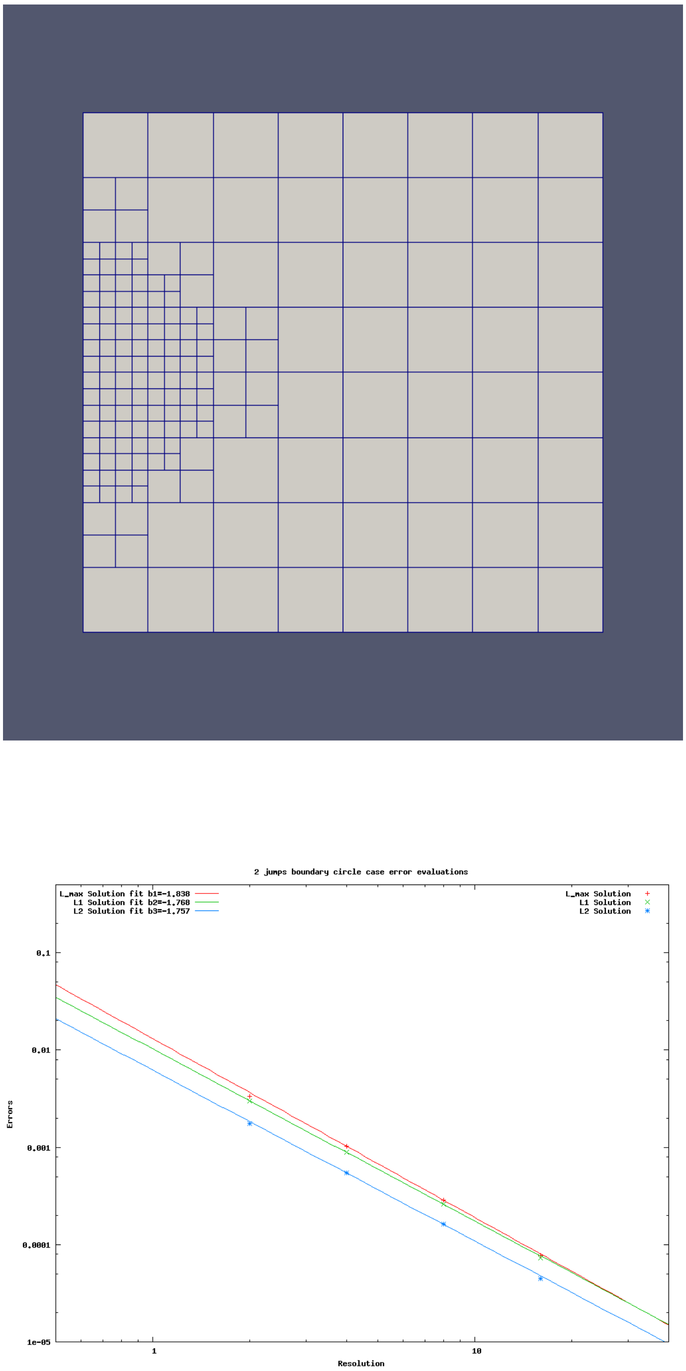

Figure 11. Electrostrictive materials: Mesh and convergence results for the solver.

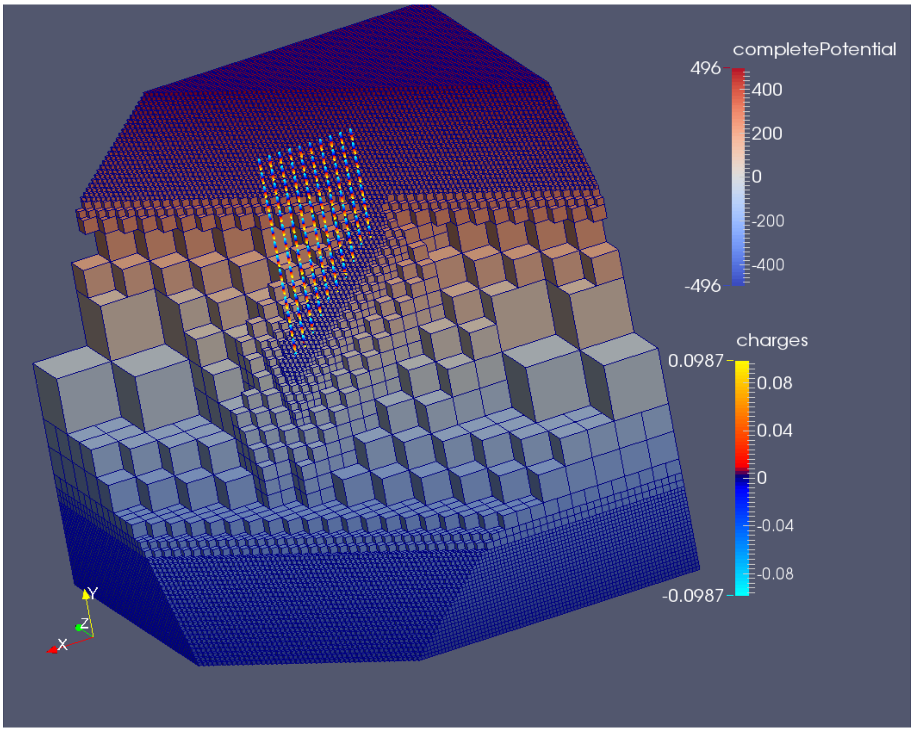

Figure 12. Electrostrictive materials: 3D configuration with nanotubes

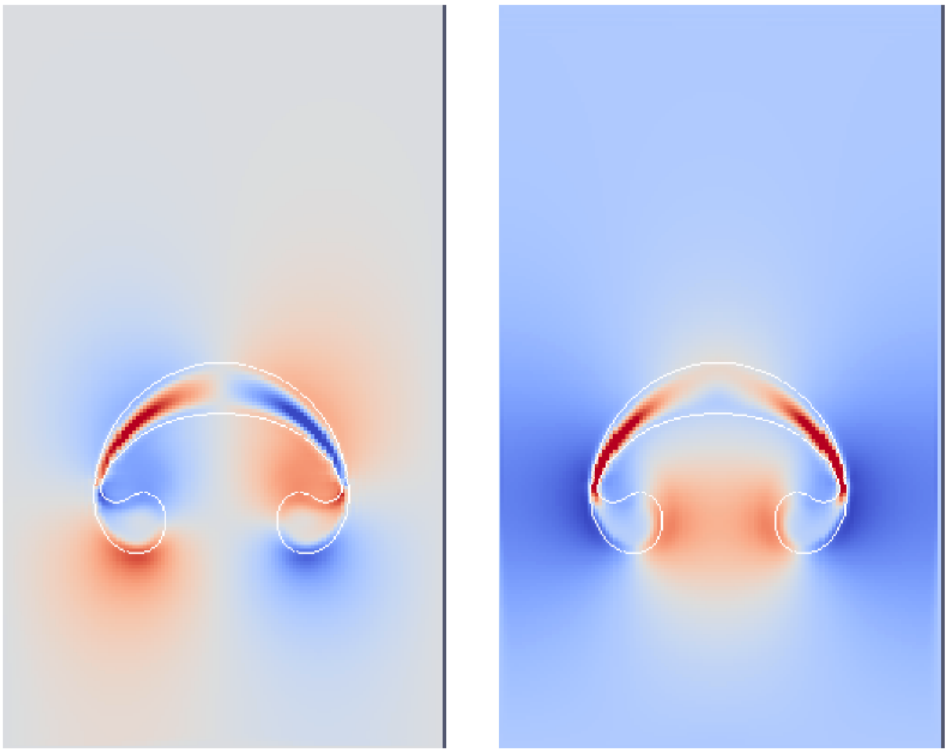

Figure 13. Horizontal et vertical velocity profile of an air bubble rising into water.

PDE models for design in the frame of a industry funded PhD (CIFRE). We are currently adapting octree and Chimera approaches to the design of aerodynamic appendices to improve performance of existing installations. This is done in the frame of yet another CIFRE PhD thesis and the corresponding research contract. Moreover, thanks to this technology readiness, Valeol could join for the first time an H2020 research project, AEROGUST, that we are promoting with several academic and industrial institutions across Europe.

We continue to deploy our effort in flow control and drag reduction for ground vehicles. After a fruitful collaboration with Renault, we are in the phase of negotiating a new collaboration. A new collaboration is starting with Valeo to optimize car cooling devices. DNS simulations are performed and compared to the industrial results obtained with URANS and LES methods and an EU network about this subject is going to be proposed.

9. Partnerships and Cooperations

9.1. Regional Initiatives

The project members are activelly participating to the CPU cluster of excellence of Idex Bordeaux (http://cpu.labex.u-bordeaux.fr/).

9.2. National Initiatives

We belong to the GDR AMORE on ROMs.

9.2.1. Starting grants

A PEPS project ("Programme Exploratoire Premier Soutien"), initiated by Afaf Bouharguane, about Optimal Transport Theory. Angelo Iollo and Lisl Weynans are also involved in this project.

9.3. European Initiatives

9.3.1. FP7 & H2020 Projects

EU research projects were and will be a privileged instrument of diffusion and transfer of our results. The AEROGUST H2020 project involves aeronautical industry (Airbus, Dassault, Piaggio..) and research labs (University of Bristol, DLR, NLR, University of Cape Town) and is dedicated to modeling of aerodynamic gust response for applications. We take part in this project by developing simulation models for unsteady aeroelastic problems and data-driven reduced-order models. We played a similar role for the past in the FP7 project FFAST with the same partners.

9.3.1.1. AEROGUST

Title: Aeroelastic Gust Modelling

Programm: H2020

Duration: May 2015 - May 2018

Coordinator: University of Bristol

Partners:

- Airbus Defence and Space (Germany)
- Dassault Aviation (France)
- Deutsches Zentrum fur Luft - und Raumfahrt Ev (Germany)
- Stichting Nationaal Lucht- en Ruimtevaartlaboratorium (Netherlands)
- Numerical Mechanics Applications International (Belgium)
- Optimad Engineering S.R.L. (Italy)

Piaggio Aero Industries Spa (Italy)

The University of Liverpool (United Kingdom)

University of Cape Town (South Africa)

University of Bristol (United Kingdom)

Valeols (France)

Inria contact: Angelo IOLLO

Encounters with atmospheric turbulence are a vitally important in the design and certification of many manmade structures such as aircraft and wind turbines. Gusts cause rapid changes in the flow about the structures which leads to rigid and flexible unsteady responses. Knowledge of aircraft/gust interactions is therefore vital for loads estimation during aircraft design as it impacts on control systems and often defines the maximum loads that these structures will experience in service. At present industry typically uses the linear doublet lattice method with static loads corrections from expensive wind tunnel data. The wind tunnel data is created using the final aerodynamic surface in the predicted cruise shape. This means that gust loads come relatively late when the design options have been narrowed. Increased competition and environmental concerns are likely to lead to the adoption of more flexible materials and the consideration of novel configurations, in which case the linear assumptions of the current gust loads process will become unacceptable. To introduce non-linearity into the gust loads process without significantly increasing the cost and time, this project has three main objectives: to carry out investigations using CFD so that the non-linearities in gust interactions are understood; to create a gust loads process that does not require wind tunnel data and hence reduces the need for wind tunnel testing; to develop updated reduced order models for gust prediction that account for non-linearity at an acceptable cost. These investigations will reduce the need for expensive wind tunnel testing and hence lead to time and cost savings at the design stage therefore ensuring that the European aerospace and defence industry remain competitive in the future. The wind turbine industry has similar concerns, with gusts and wind shear restricting the locations available for wind farms. The project will also address these issues using common methodology.

9.3.2. Collaborations with Major European Organizations

Partner 1: Chalmers University (Sweden)

This activity is complemented by several international interactions, in particular with Chalmers University in order to converge towards the real implementation of new control technologies on cars, buses and trucks.

Partner 2: Optimad Engineering , Torino (Italy)

We have a crucial partnership with Optimad Engineering, a spin-off of the Politecnico di Torino. This society has implemented in industrial codes several schemes that we have developed for the past. In exchange, we have access to these codes. One example is Pablo, an octree managing parallel library (http://www.optimad.it/products/pablo/). Three former PhD students at Inria are presently employed in Optimad and several others have spent or will spend a research period in this company in order to get acquainted with code architecture and massive parallelism. This company represents for us an ideal partner for the actual industrial feedback on our methods. As mentioned, we plan to create a local start-up in close collaboration with Optimad. This start-up will respond to actual industrial needs by specific software packages built starting from open source tools that are made available to the applied research community via a consortium. Florian Bernard has been recruited in Memphis for two years with the objective of bringing to a higher maturity level a set of modules developed within the team. He plans to fully invest himself in the creation of the start-up. As for the consortium, we are discussing with several partners including Cineca (Italy HPC center) and Optimad about how to structure such a mutual effort. The Storm Inria team is included in the discussions as a possible partner.

Partner 3: W4E (Wave for Energy) (Italy)

One project is the design of an ISWEC (Inertial See Wave Energy Converter) in collaboration with W4E (Wave for Energy), Optimad and others. The ISWEC is a floater prototype that can extract energy form the sea waves. The mechanism is based on a gyroscope that is rotating due to the passive motion of the floater. This prototype is actually tested in the Mediterranean sea in Italy. We will develop the numerical simulation as well as the shape optimization of the ISWEC.

Partner 4: MRGM (Maladies Rares : Génétique et Métabolisme), Bordeaux University (France)

We develop a collaboration the MRGM lab. They are interesting in the swimming of a zebrafish larvae under genetic modifications. One aim is to quantify the power spent by such fishes to swim after a stimuli reaction. The numerical simulation we develop can help computing integral quantities such the power. This simulation is challenging coupling several methods like image treatment (from movies given by MRGM), optimal transport and numerical simulations.

Partner 5: CRPP (Centre de recherche Paul Pascal), LOF (Laboratoire du Futur) and LOMA (Laboratoire Ondes et Matière d'Aquitaine) labs, Bordeaux University, France.

We established collaborations with physics and chemistry labs in Bordeaux, namely the CRPP, the LOF and the LOMA. They are concerned with the behavior of many passive (CRPP and LOF) and active (LOMA) particles in an incompressible flow. With these partners we intend to use a combined experimental and computational approach to calibrate models in the case of dilute and concentrated suspensions. The numerical simulations of such particles can help to understand some underlying phenomena at the particles scale and thus to develop mesoscopic models for the whole system (PhD of Baptiste Lambert, oct. 2015).

9.4. International Initiatives

9.4.1. Inria International Partners

9.4.1.1. Informal International Partners

With Rajat Mittal, of Johns Hopkins University, we collaborate on the simulation of complex biological flows that involve fluid- structure interactions with large deformations like fonation, heart beating, freely moving elastic capsules in blood vessels, fish-like swimming or flapping wings. A common journal paper in Bionspiration & Biomimetics has been issued so far. This collaboration will continue in the future.

9.5. International Research Visitors

9.5.1. Visits of International Scientists

Frédéric Gibou, from UC Santa Barbara, visited us in 2015. With the team of Frédéric Gibou we collaborate to develop general enough numerical models that allow a simplified geometrical and computational set up by the systematic use of hierarchical Cartesian meshes and monolithic models: multi-resolution schemes based on octree grid structures, refined grid patches, numerical zooms, overset.

Giovanni Russo, of the University of Catania, shares many of our scientific objectives: one of his past PhD students, Armando Cocco, has spent one year in Bordeaux dedicated to the parallelization of a multigrid cartesian solver. G. Russo has spent several weeks in Bordeaux as a visiting scientist at the Memphis team in 2015. This visit was dedicated to the study of new all-Mach schemes for conservative equations, guaranteeing accuracy and efficiency of the schemes used to solve problems where the time scales are those of the material velocities as opposed to acoustic wave time scales.

Gabriella Puppo, initially at the Politecnico di Torino and now at the university of Insubria, also visited us in 2015. We have an established collaboration with her to extend our approaches to rarefied gas dynamics, i.e., problems governed by the BGK equation. We have co-directed the PhD of Florian Bernard and we have now another co-direction, that of Emanuela Abbate, who will be studying relaxation equations for stiff problems of compressible non-linear elasticity.

Conglin Liu (univ. Harbin China), visited Charles-Henri Bruneau during the whole academic year 2014-2015. She had a grant from the Chinese Government.

9.5.1.1. Internships

Nadia Loy is an international internship from the university of Florence.

9.5.2. Visits to International Teams

With the team of Frédéric Gibou we collaborate to develop general enough numerical models that allow a simplified geometrical and computational set up by the systematic use of hierarchical Cartesian meshes and monolithic models: multi-resolution schemes based on octree grid structures, refined grid patches, numerical zooms, overset.

In this framework we have recently organized a commun workshop in Santa Barbara funded by the Idex initiative in Bordeaux.

10. Dissemination

10.1. Promoting Scientific Activities

10.1.1. Scientific events organisation

10.1.1.1. Member of the organizing committees

Organization of the Scientific Day of the team "Modelling and Scientific Computing" of the Mathematics Institute of Bordeaux.

With Frédéric Gibou we have organized an international workshop in Santa Barbara funded by the Idex initiative in Bordeaux. The topics of the workshop were about our common research subjects: hierarchical Cartesian meshes and monolithic models: multi-resolution schemes based on octree grid structures, refined grid patches, numerical zooms, overset.

Charles-Henri Bruneau is in the organizing commettee of ICCFD conference, a major conference in CFD.

10.1.2. Journal

10.1.2.1. Member of the editorial boards

Angelo Iollo is in the advisory board of Acta Mechanica.

10.1.2.2. Reviewer - Reviewing activities

- projects CSCS Swiss National Supercomputing Centre
- reviews of applications for PhD and Postdoc grants at Inria (commission jeunes chercheurs)
- journals: Journal of Computational Physics, International Journal of CFD, Journal of Non-linear Analysis B, ASME Journal of Computational and Nonlinear Dynamics, Journal of Fluid Mechanics, Acta Mechanica, AIAA Journal, International Journal Numerical Methods in Fluids, Computers & Fluids, Journal of Engineering Mathematics, European Journal of Mechanics / B Fluids, Journal Européen de Systèmes Automatisés, Applied Mathematics and Computation. Nuclear Science and Engineering, Computer Methods in Applied Mechanics and Engineering, Journal of Theoretical Biology, Computational Optimization and Applications. Applied science, Meccanica.

10.1.3. Invited talks

Invited seminars at Institut Montpelliérain Alexander Grothendieck, Ecole Centrale Nantes, Laboratoire de Mathématiques et Applications de Poitiers, Laboratoire de Mathématiques d'Orsay, Florence University .

10.1.4. Leadership within the scientific community

Angelo Iollo is responsible of the scientific policy of the scientific computing departement of the LabEx CPU. This departement gathers 60 researhers of the math lab IMB, of the computer science lab LaBRI, of the mecanichs lab I2M and of the CEA.

10.1.5. Scientific expertise

Angelo Iollo has been reviewer of the PhD defense « Modélisation numérique du vol inspiré à la biologie » of Thomas Engels, TU Berlin et Université Aix-Marseille, 12/12/2015. Also he is scientific reviewer for ANR (1 project) and the Romanian Research Agency (8 projects).

Michel Bergmann has a reviewing activity for the CSCS Swiss National Supercomputing Center. He is also member of the Inria Young Researchers Commission, which allocates PhD and Postdoc grants.

10.2. Teaching - Supervision - Juries

10.2.1. Teaching

Four members of the team are Professors or Assistant Professors at Bordeaux University and have a teaching duty, which consists in courses and practical exercises in numerical analysis and scientific computing.

E-learning

Online course on the Moodle webpage of Bordeaux University, 13 weeks, licence 2, Differential equations, Lisl Weynans, 5 students registered.

10.2.2. Supervision

In case of co-supervision, the name of the concerned student/postdoc is mentionned twice.

Michel Bergmann:

- PhD students:
  - Alice Raeli (cpu)
  - Federico Tesser (inria)
  - Claire Morel (valeol)
  - Baptiste Lambert (univ. Bordeaux)
- Postdoc:
  - Andrea Ferrero (Aerogust)

Afaf Bouharguane

- Research Engineer: Andrea Valenti (cpu)

Charles-Henri Bruneau

- PhD student: Meriem Jedouaa (co-tutelle Grenoble Emmanuel Maitre)

Angelo Iollo:

- PhD students:
  - Alice Raeli (cpu)
  - Federico Tesser (inria)
  - Claire Morel (valeol)
  - Emanuela Abbate (univ. Insubria)
  - Mathias Braun (univ. Insubria)
- Postdoc:
  - Andrea Ferrero (Aerogust)
- Research Engineers:
  - Marco Cisternino (cpu)
  - Florian Bernard (Inria)
  - Andrea Valenti (CPU)
- Master: Nadia Loy (univ/ Florence)

Lisl Weynans

- PhD student:Baptiste Lambert (univ. Bordeaux)
- Research Engineers:Marco Cisternino (CPU)

  2012-2015. Dr. Alexia de Brauer. Compressible Materials Simulations. Codirectors A. Iollo and T. Milcent. DGA Grant. University of Bordeaux.

  2012-2015. Dr. Gwladys Ravon. Inverse Problems in Cardiac Electrophysiology. Codirectors A. Iollo, Y. Coudiere. Idex and IHU Grant. University of Bordeaux.

  2012-2015. Dr. Florian Bernard. Efficient Asymptotic Preserving Schemes for BGK and ES-BGK models on Cartesian grids. Codirectors A. Iollo and G. Puppo. University of Bordeaux and Politecnico di Torino. Grant from the Politecnico di Torino.

10.2.3. Juries

Participation to hiring comittees ("comités de sélection"): Ecole Centrale de Nantes, I2M laboratory at Bordeaux University.

Participation to PhD defence juries: C.-H. Bruneau for Eysteinn Helgason (Chalmers, Sweden), L. Weynans for Pierre Bigay (Ecole Centrale Nantes)

10.3. Popularization

One member of the team (Lisl Weynans) is in charge of the communication with secondary degree for the Mathematics Institute.

Participation popularization operations, such as: "Fête de la Science", "Des enseignants dans les labos", "Le printemps de la mixité", and several talks in high schools to popularize scientific computing.

Pedagogic project with an high in rural area about statistics: the PARADOX project, awarded by a grant from the fundation "Sciences à l'école".

11. Bibliography

Publications of the year

Articles in International Peer-Reviewed Journals

[1] F. BERNARD, A. IOLLO, G. PUPPO. *Accurate Asymptotic Preserving Boundary Conditions for Kinetic Equations on Cartesian Grids*, in "Journal of Scientific Computing", 2015, 34 p. [*DOI :* 10.1007/s10915-015-9984-8], https://hal.inria.fr/hal-01148397

[2] A. BOUHARGUANE, A. IOLLO, L. WEYNANS. *Numerical solution of the Monge–Kantorovich problem by density lift-up continuation*, in "ESAIM: Mathematical Modelling and Numerical Analysis", November 2015, vol. 49, n^o 6, pp. 1577-1592 [*DOI :* 10.1051/M2AN/2015024], https://hal.archives-ouvertes.fr/hal-01250636

[3] M. LEGUÈBE, C. POIGNARD, L. WEYNANS. *A second-order Cartesian method for the simulation of electropermeabilization cell models*, in "Journal of Computational Physics", July 2015, vol. 292, 26 p. [*DOI :* 10.1016/J.JCP.2015.03.028], https://hal.inria.fr/hal-01158377

[4] F. LUDDENS, M. BERGMANN, L. WEYNANS. *Enablers for high-order level set methods in fluid mechanics*, in "International Journal for Numerical Methods in Fluids", December 2015, vol. 79, pp. 654-675 [*DOI :* 10.1002/FLD.4070], https://hal.archives-ouvertes.fr/hal-01250641

[5] J. PINILLA, C.-H. BRUNEAU, S. TANCOGNE. *Front-tracking by the level-set and the volume penalization methods in a two-phase microfluidic network*, in "International Journal for Numerical Methods in Fluids", January 2016, vol. 80, n^o 1, https://hal.inria.fr/hal-01251457

Invited Conferences

[6] L. WEYNANS, M. BERGMANN, F. LUDDENS. *A Sharp Cartesian Method For The Simulation Of Flows With High Density Ratios*, in "BIS Workshop Inria-UC Santa Barbara", Santa Barbara, United States, June 2015, https://hal.archives-ouvertes.fr/hal-01251182

International Conferences with Proceedings

[7] G. RAVON, Y. COUDIÈRE, A. IOLLO, O. BERNUS, R. D. WALTON. *Issues in Modeling Cardiac Optical Mapping Measurements*, in "Functional Imaging and Modeling of the Heart", Maastricht, Netherlands, Functional Imaging and Modeling of the Heart, June 2015 [*DOI :* 10.1007/978-3-319-20309-6_52], https://hal.archives-ouvertes.fr/hal-01214073

Scientific Books (or Scientific Book chapters)

[8] *A two-way coupling CFD method to simulate the dynamics of a wave energy converter*, 2015 [*DOI :* 10.1109/OCEANS-GENOVA.2015.7271481], https://hal.inria.fr/hal-01251419

Research Reports

[9] L. WEYNANS. *A proof in the finite-difference spirit of the superconvergence of the gradient for the Shortley-Weller method*, Inria Bordeaux ; Inria, July 2015, n^o RR-8757, 14 p. , https://hal.inria.fr/hal-01176994

Other Publications

[10] C.-H. BRUNEAU, K. KHADRA. *High Parallel Computing of a Multigrid Solver for 3D Navier-Stokes equations*, December 2015, working paper or preprint, https://hal.inria.fr/hal-01247678

[11] M. JEDOUAA, C.-H. BRUNEAU, E. MAITRE. *An efficient interface capturing method for a large collection of interacting cells immersed in a fluid*, December 2015, working paper or preprint, https://hal.archives-ouvertes.fr/hal-01236468

[12] A. RAELI, M. AZAÏEZ, M. BERGMANN, A. IOLLO. *Numerical Modelling for Phase Changing Materials (PCM)*, October 2015, EDP Normandie 2015, https://hal.inria.fr/hal-01251126