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Team pumas

*Plasma, tUrbulence, Modeling,
Approximation and Simulation*

Sophia Antipolis - Méditerranée

Theme : Computational models and simulation

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R *eport*

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1. Team

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2. Overall Objectives

2.1. Overall Objectives

Turbulence often called “the last unsolved problem in classical statistical mechanics” from a citation by Richard Feynman is a fundamental feature of fluid flows. Its correct description impacts such diverse fields as weather prediction and ocean dynamics, aircraft and ship design or transport and instabilities in plasmas to cite but a few.

The challenge of understanding and modeling turbulence has been with us for more than 100 years with very modest results. Since the 1941 Kolmogorov theory [41], no universally valid successful theory has emerged in this field. This is certainly due to the fact that a universal theory of turbulence does not exist and that instead one has to face very different mechanisms with very different properties.

However, with emerging multi-teraflop and soon petaflop computers, some direct numerical simulation of fluid turbulence is becoming possible. This is specially true in application domains like transport in Tokamaks where some internal mechanism forbids the size of the turbulent eddies to go below certain limits (here, the Larmor radius). In other application areas such as classical aerodynamics, although direct numerical simulations are still out of reach, attention is becoming focused on unsteady processes and instabilities requiring the use of models beyond the RANS ones (“Reynolds averaged”).

The main objective of the PUMAS team is to contribute to the development of innovative numerical tools to improve the computer simulations of complex turbulent or unstable flows. Although not strictly restricted to these areas, we plan to develop these researches for three main application domains that are Plasma Physics, Large Eddy Simulation and hybrid models in Fluid turbulence and environmental flows.

3. Scientific Foundations

3.1. Plasma Physics

Participants: Hervé Guillard, Boniface Nkonga, Afeintou Sangam, Richard Pasquetti, Audrey Bonnemet, Marie Martin, Cédric Lachat, Laure Combe.

In order to fulfil the increasing demand, alternative energy sources have to be developed. Indeed, the current rate of fossil fuel usage and its serious adverse environmental impacts (pollution, greenhouse gas emissions, ...) lead to an energy crisis accompanied by potentially disastrous global climate changes.

Controlled fusion power is one of the most promising alternatives to the use of fossil resources, potentially with a unlimited source of fuel. France with the ITER (<http://www.iter.org/default.aspx>) and Laser Megajoule (<http://www-lmj.cea.fr/>) facilities is strongly involved in the development of these two parallel approaches to master fusion that are magnetic and inertial confinement. Although the principles of fusion reaction are well understood from nearly sixty years, (the design of tokamak dates back from studies done in the '50 by Igor Tamm and Andreï Sakharov in the former Soviet Union), the route to an industrial reactor is still long and the application of controlled fusion for energy production is beyond our present knowledge of related physical processes. In magnetic confinement, beside technological constraints involving for instance the design of plasma-facing component, one of the main difficulties in the building of a controlled fusion reactor is the poor confinement time reached so far. This confinement time is actually governed by turbulent transport that therefore determines the performance of fusion plasmas. The prediction of the level of turbulent transport in large machines such as ITER is therefore of paramount importance for the success of the researches on controlled magnetic fusion.

The other route for fusion plasma is inertial confinement. In this latter case, large scale hydrodynamical instabilities prevent a sufficient large energy deposit and lower the return of the target. Therefore, for both magnetic and inertial confinement technologies, the success of the projects is deeply linked to the theoretical understanding of plasma turbulence and flow instabilities as well as to mathematical and numerical improvements enabling the development of predictive simulation tools.

3.2. Turbulence Modelling

Participants: Alain Dervieux, Boniface Nkonga, Richard Pasquetti.

Fluid turbulence has a paradoxical situation in science. The Navier-Stokes equations are an almost perfect model that can be applied to any flow. However, they cannot be solved for any flow of direct practical interest. Turbulent flows involve instability and strong dependence to parameters, chaotic succession of more or less organised phenomena, small and large scales interacting in a complex manner. It is generally necessary to find a compromise between neglecting a huge number of small events and predicting more or less accurately some larger events and trends.

In this direction, PUMAS wishes to contribute to the progress of methods for the prediction of fluid turbulence. Taking benefit of its experience in numerical methods for complex applications, PUMAS works out models for predicting flows around complex obstacles, that can be moved or deformed by the flow, and involving large turbulent structures. Taking into account our ambition to provide also short term methods for industrial problems, we consider methods applying to high Reynolds flows, and in particular, methods hybridizing Large Eddy Simulation (LES) with Reynolds Averaging.

Turbulence is the indirect cause of many other phenomena. Fluid-structure interaction is one of them, and can manifest itself for example in Vortex Induced Motion or Vibration. These phenomena can couple also with liquid-gas interfaces and bring new problems. Of particular interest is also the study of turbulence generated noise. In this field, though acoustic phenomena can also in principle be described by the Navier-Stokes equations, they are not generally numerically solved by flow solvers but rather by specialized linear and nonlinear acoustic solvers. An important question is the investigation of the best way to combine a LES simulation with the acoustic propagation of the waves it produces.

3.3. Astrophysical and Environmental flows

Participants: Hervé Guillard, Boniface Nkonga.

Although it seems inappropriate to address the modeling of experimental devices of the size of a tokamak and for instance, astrophysical systems with the same mathematical and numerical tools, it has long been recognized that the behaviour of these systems have a profound unity. This has for consequence for instance that any large conference on plasma physics includes sessions on astrophysical plasmas as well as sessions on laboratory plasmas. PUMAS does not intend to consider fluid models coming from Astrophysics or Environmental flows for themselves. However, the team is interested in the numerical approximation of some problems in this area as they provide interesting reduced models for more complex phenomena. To be more precise, Let us give some concrete examples : The development of Rossby waves ¹ a common problem in weather prediction has a counterpart in the development of magnetic shear induced instabilities in tokamaks and the understanding of this latter type of instabilities has been largely improved by the Rossby wave model. A second example is the water bag model of plasma physics that has a lot in common with multi-layer shallow water system.

To give a last example, we can stress that the development of the so-called well-balanced finite volume schemes used nowadays in many domains of mathematical physics or engineering was largely motivated by the desire to suppress some problems appearing in the approximation of the shallow water system.

Our goal is therefore to use astrophysical or geophysical models to investigate some numerical questions in contexts that, in contrast with plasma physics or fluid turbulence, do not require huge three dimensional computations but are still of interest for themselves and not only as toy models.

4. Software

4.1. FluidBox

Participants: Boniface Nkonga [contact], Hervé Guillard.

FluidBox is a software dedicated to the simulation of inert or reactive flows. It is also able to simulate multiphase, multi-material and MDH flows. There exist 2D and 3D dimensional versions. The 2D version is used to test new ideas that are later implemented in 3D. Two classes of schemes are available : A classical finite volume scheme and the more recent residual distribution schemes. Several low Mach number preconditioning are also implemented. The code has been parallelized with and without domain overlapping. The linear solver PaStiX is integrated in FluidBox. A partitioning tool exists in the package and uses Scotch. At present the software is only a private project but some parts of FluidBox are expected to be in the public domain by the end of the year.

4.2. PlaTo

Participants: Hervé Guillard [contact], Laure Combe.

The development of PlaTo (A platform for Tokamak simulation) (<http://www-sop.inria.fr/pumas/plato.php>) is being supported by an ADT action of the D2T. PlaTo is a suite of data and softwares dedicated to the geometry and physics of Tokamaks and its main objective is to provide the Inria large scale initiative "FUSION" teams working in plasma fluid models with a common development tool. The construction of this platform will integrate the following developments.

1. A (small) database corresponding to axi-symmetrical solutions of the equilibrium plasma equations for realistic geometrical and magnetic configurations (ToreSupra, JET and ITER). The construction of meshes always takes considerable time. Plato will provide meshes and solutions corresponding to equilibrium solutions that will be used as initial data for more complex computations.
2. A set of tool for the handling, manipulation and transformation of meshes and solutions using different discretisations (P1, Q1, P3, etc)

¹Rossby waves are giant meanders in high altitude wind that have major influence on weather. Oceanic Rossby waves are also know to exist and to affect the world ocean circulation

3. Numerical templates allowing the use of 3D discretization schemes using finite element schemes in the poloidal plane and spectral Fourier or structured finite volume representations in the toroidal plane.
4. Several applications (Ideal MHD and drift approximation) used in the framework of the Inria large scale initiative “FUSION”.

This year, after a definition of the PlaTo architecture, the points 1. and 2. have been developped.

4.3. PaMPA

Participants: Cécile Dobrzynski [Bacchus], Hervé Guillard, Laurent Hascoët [Tropics], Cédric Lachat, François Pellegrini [Bacchus].

PaMPA (“Parallel Mesh Partitioning and Adaptation”) is a middleware library dedicated to the management of distributed meshes. Its purpose is to relieve solver writers from the tedious and error prone task of writing again and again service routines for mesh handling, data communication and exchange, remeshing, and data redistribution. An API of the future platform has been devised, and the coding of the mesh handling and redistribution routines is in progress. PaMPA will be used as a base module for the PLATO solvers, to balance dynamically, refine and coarsen its distributed mesh.

5. New Results

5.1. Numerical methods

5.1.1. Finite volume methods in curvilinear coordinates

Participants: Audrey Bonnement, Hervé Guillard, Boniface Nkonga, Marie Martin, Afeintou Sangam.

Finite volume methods are specialized numerical techniques for the solving of divergence equations in strong conservation forms of the form

$$\frac{\partial S}{\partial t} + \text{div}T = 0 \quad (1)$$

where S is a scalar or a vector while T is a vector or a second-order tensor. Using textbook formulas for the expression of the divergence operator in curvilinear coordinates, the use of these coordinate systems instead of the cartesian one can lead to a loss of the strong conservation form of the equations and introduce a source term in (1). Actually, this is unnecessary and one can show that whatever the system of curvilinear coordinate used, there exists a strong conservation law form of the system. However, when vector equations have to be considered (that is if S is a vector and T a tensor), it is necessary to extract from (1) scalar equations for the components of the vector S and this may destroy the strong conservation form of the equation. We have studied in this work a method where instead of projecting the equations on a curvilinear coordinate system and then discretizing the resulting scalar equations, we first discretize the vector system and then project the resulting discretized system on the curvilinear basis. This method is general (it does not depend on the specific curvilinear system used) and it gives a natural way to discretize the spurious source terms coming from the use of curvilinear coordinates.

5.1.2. Entropy viscosity for conservation laws

Participants: Jean-Luc Guermond [Texas A & M University], Richard Pasquetti.

Together with J.L. Guermond, Texas A & M University, we are developing a technique to compute solutions of non-linear hyperbolic problems [43]. The main idea is here to introduce a non-linear viscous term which is set up from the residual of the entropy equation associated to the considered PDE. This entropy viscosity method has been applied using various types of approximations, from finite element to Fourier via spectral elements. We checked that the approach preserves the approximation properties of the underlying numerical method. Tests have been carried out for challenging 2D scalar conservation laws as well as for the (compressible) Euler equations with very satisfactory results. Just like the SVV (see section 5.3.1) technique, this entropy viscosity method may be of interest for the LES of turbulent flows.

5.1.3. Entropy preserving schemes for conservation laws

Participants: Christophe Berthon [University of Nantes], Bruno Dubroca [CEA/DAM/CESTA and University of Bordeaux 1], Afeintou Sangam.

In collaboration with C. Berthon and B. Dubroca, we have established a new technique that proves discrete entropy inequalities of finite volume methods to approximate conservation laws. This technique is free of additional numerical models such as kinetic and relaxation schemes. Moreover, our results leads to a full class of entropy preserving schemes for general Euler equations. This proposed technique is currently extended to 10-moment equations and Saint-Venant model.

5.1.4. Spectral element approximations

Participants: Richard Pasquetti, Francesca Rapetti [University of Nice - Sophia Antipolis].

We are working on the development of spectral element methods (SEM) on unstructured meshes that make use of simplicial elements. In this frame, comparisons have been recently provided between different sets of interpolation points. Solvers have been developed for elliptic problems and very recently for the incompressible Navier-Stokes equations, as part of the PhD research of Laura Lazar. This Navier-Stokes solver makes use of a projection technique to take care of the divergence free constraint. For the sake of consistency of the approximation, curved boundaries are approximated with isoparametric elements. The polynomial approximation degree within each element, say N , is an input of the solver. Different standard test cases have been successfully addressed.

The final algebraic systems being ill-conditioned, we have especially focused on the resolution techniques. They may be based on a Schur complement method, in order to solve only for the unknowns located on the "skeleton" of the mesh, or on a p-multigrid approach, thus providing at the lowest level a finite element coarse solver. The Navier-Stokes solver recently developped is thus based on a Schur complement method, so that the dimension of the algebraic system increases like N whereas the number of grid-points scales like N^2 .

5.1.5. Mesh adaptation Methods

Participants: Anca Belme [EPI Tropics], Alain Dervieux, Frédéric Alauzet [EPI Gamma, INRIA-Rocquencourt], Adrien Loseille [George washington University], Damien Guégan [Lemma].

Resulting from a cooperation between Gamma, Tropics, Pumas, and Lemma, the new transient fixed point mesh adaptive algorithm has been published in [15]. It relies on a $L^\infty - L^P$ error control. The new adjoint based mesh adaptation criterion developed in 2009 for steady models has been improved and published [16], [27], [26]. It has been extended to unsteady models. These results have been presented at several international conferences. [21], [22].

5.1.6. Flows with interfaces

Participants: Alain Dervieux, Hervé Guillard, Frédéric Alauzet [Projet Gamma, INRIA-Rocquencourt], Olivier Allain [Lemma], Damien Guégan [Lemma], Thomas Boucherès [Lemma], Cécile Lesage [Barcelona Computing Center].

We extend the level set method to new applications. Two fields of applications are considered, the interaction of sea surface with obstacles, and the motion of fuel in tanks in a micro-gravity field. A first topic particularly addressed in 2008-2009 is the improvement of mass conservation in the Level Set method. In a previous publication [42], we describe a new conservative formulation of Level Set, the Dual Level Set scheme. The main idea is to measure in a variational integral the defect of a predictor with respect to the advection of the discontinuous phase colour function. This is made possible by the continuous test functions used in the level set approximation scheme. A second important topic is the combination of a Level Set based Navier-Stokes numerical model with the fixed point dynamic mesh adaptive algorithm. As a result of the collaboration between LEMMA, GAMMA, and PUMAS, a paper presenting a method for this combination has been submitted.

5.1.7. Fluid-Structure interaction

Participants: Alain Dervieux, Charbel Farhat [Stanford University], Bruno Koobus [University of Montpellier 2], Mariano Vázquez [Barcelona Supercomputing center].

The Geometric Conservation Law (GCL) expresses the exactness of an Arbitrary Lagrangian-Eulerian discretisation for uniform flows. We have demonstrated that this is a necessary condition for total energy conservation. This also extends the GCL to boundaries in a canonical manner. Total energy conservation is a key property for numerical models of any mechanical system in which the internal energy of a compressible fluid is converted into mechanical energy transmitted to a structure. A new finite-volume scheme satisfying this condition has been built from our previous scheme, developed and tested. The stabilisation effect of this improvement has been exhibited for a standard flutter test case. The gain in accuracy has been evaluated for the motion of a piston in a closed vessel. A paper written in cooperation with Charbel Farhat (Stanford) and Mariano Vázquez (Barcelona Supercomputing Center) has been published in [14].

5.1.8. Parallel solvers for CFD algorithms

Participants: Hubert Alcin [Tropics], Olivier Allain [Lemma], Anca Belme [Tropics], Marianna Braza [IMF-Toulouse], Alexandre Carabias [Tropics], Alain Dervieux, Bruno Koobus [Université Montpellier 2], Carine Moussaed [Université Montpellier 2], Hilde Ouvrard [IMF-Toulouse], Stephen Wornom [Lemma].

Pumas is associated to the ANR ECINADS project started in end of 2009, devoted to the design of new solution algorithms for unsteady compressible flows, adapted to scalable parallelism and to reverse (adjoint) Automatic Differentiation. See in the activity report of Tropics.

5.2. Plasma physics

5.2.1. Analysis of the drift approximation

Participants: Hervé Guillard, Afeintou Sangam, Philippe Ghendrih [IRFM, CEA Cadarache], Yanick Sarazin [IRFM, CEA Cadarache], Patrick Tamain [IRFM, CEA Cadarache].

Drift approximation consider the slow evolution of the fields in the vicinity of a tokamak equilibrium. These models are typically used to study the micro-instabilities that are believed to be responsible of turbulent transport in tokamaks. Since the drift asymptotic uses a “slow” scaling of the velocity field, the resulting models are significantly different from the full MDH models. This is particularly true with respect to the computation of the electric field that is given by an Ohm’s law in MDH models whereas it is computed by a vorticity-like evolution equation in drift approximations. Drift asymptotic models are extremely interesting from a computational point of view since they save substantial CPU time and computer memory. However, the mathematical and numerical properties of these models are essentially unknown. We have begun a detailed study of the derivation of these models from two-fluid Braginskii-type models in order to establish the range of applicability of these asymptotic models, understand their mathematical properties and relations with the reduced MDH models and design appropriate numerical methods for their approximations.

5.2.2. Bohm boundary conditions in plasma physics

Participants: Hervé Guillard, Nishan Mann [Erasmus Mundus Intership], Muhammad Kamboh [Erasmus Mundus Intership].

During a six month internship followed by a one month project at CEMRACS² the Bohm's boundary conditions used in plasma physics have been studied. These conditions state that in case of plasma-wall interaction, the fluid enters the wall at Mach number equal to one. Different ways to numerically implement these conditions have been tested in the framework of finite volume methods. Several 1D and 2D tests in planar and cylindrical geometry have shown that the ghost cell technique that involves solving a Riemann problem between plasma and vacuum is a simple and efficient way to impose these boundary conditions.

5.2.3. Anisotropic heat diffusion equation

Participants: Audrey Bonnement, Hervé Guillard, Richard Pasquetti.

Magnetized plasmas are characterized by extremely anisotropic properties relative to the direction of the magnetic field. Perpendicular motions of charged particles are constrained by the Lorentz force, while relatively unrestrained parallel motions lead to rapid transport along magnetic field lines. Heat transport models (e.g [40]) are therefore characterized by an extreme anisotropy of the transport coefficient that differ by several order of magnitude in the parallel and perpendicular directions. The use of field aligned coordinates that essentially reduce the problem to one-dimension is one way to overcome this difficulty. However, for complex or unsteady magnetic configurations or for problems requiring a high degree of geometrical realism, this approach leads to serious numerical difficulties. An alternative is to use a numerical representation that has a high rate of spatial convergence like high order finite element methods or spectral elements. We have carried out a numerical study to compare the two approaches, revealing that aligned coordinates are effectively required with low order approximations whereas satisfactory results can still be obtained when high order approximations, typically based on Q_4 elements, are involved. Using a Fourier- Q_4 spectral element method approximation, we have been able to compute a 3D strongly anisotropic diffusion problem with diffusion lines aligned along a torus-spiral.

5.2.4. Stabilized C1-Finite Element Method for MHD

Participants: Boniface Nkonga, Marie Martin.

Although kinetic approach is the most complete modeling for plasma, computational resources needed to solve it numerically are too large to make it usable for our target applications. In the context of the PhD work of Marie Martin, we consider fluid models that are derived by considering first moments of the distribution function. This year's work has been devoted to the analysis of the mathematical structure of the MHD models in order to derive stabilized numerical approximation. One dimensional developments have been performed and some numerical strategies improved. The next step is to extend these analysis to the toroidal configuration of tokamaks and perform computations using Jorek tools developed at CEA Cadarache.

5.2.5. Anisotropic Navier-Stokes governing equations

Participants: Audrey Bonnement, Hervé Guillard, Richard Pasquetti.

Towards the development of a two-fluid model this work extends the one described in 5.2.3. We address here the Navier-Stokes equations with anisotropic viscosity in a Tore Supra like geometry, including the presence of a limiter where the so-called Bohms boundary conditions apply, i.e. the fluid enters the limiter at Mach number equal to one. Again two different numerical approximations are used, based on a Godunov finite volume / finite element approach and on a stabilized Fourier - Q_N spectral element approximation. The two codes are now operational and the numerical results will be soon compared.

5.3. Fluid Turbulence

5.3.1. SVV-LES of turbulent flows

Participant: Richard Pasquetti.

²http://smai.emath.fr/cemracs/cemracs10/en_index.html

The SVV-LES approach for the Large-Eddy Simulation (LES) of turbulent flows is based on the Spectral Vanishing Viscosity technique, which was initially developed for conservation laws and extended to LES in the 2000's. Our SVV-LES spectral code, specially developed to compute turbulent wakes using a multi-domain Fourier-Chebyshev approximation, has recently been used to compute the far wake of a sphere in a thermally stratified fluid. The main idea was first to compute the spatial development of the wake and then to use this result to start a temporal development study. Results in close agreement with the experiments of G.R. Spedding, obtained in the late 90's, have been recovered, as described in [19]. This approach is now used by the LEMMA company, under the expertises of A. Dervieux and R. Pasquetti, in the frame of a contract with CTSN.

5.3.2. Hybrid RANS-LES models

Participants: Anca Belme [Tropics], Alain Dervieux, Bruno Koobus [University of Montpellier 2], Carine Moussaed [University of Montpellier 2], Hilde Ouvrard [IMF-Toulouse], Maria-Vittoria Salvetti [University of Pisa], Stephen Wornom [Lemma].

The purpose of our work in hybrid RANS/LES is to develop new approaches for industrial applications of LES-based analyses. In the foreseen applications (aeronautics, hydraulics), the Reynolds number can be as high as several tens of millions, a far too large number for pure LES models. However, certain regions in the flow can be much better predicted with LES than with usual statistical RANS (Reynolds averaged Navier-Stokes) models. These are mainly vortical separated regions as assumed in one of the most popular hybrid model, the hybrid Detached Eddy Simulation model. Here, "hybrid" means that a blending is applied between LES and RANS. The french-italian team has designed a novel type of hybrid model. The Continuous Correction Hybrid Model (CCHM) combines a Variational Multiscale LES component and a low-Reynolds K-epsilon model. In contrast to many existing hybrid models, the CCHM hybrid model involves a hybridisation method able to combine a very large class of LES and RANS submodel since each component is directly weighted independantly of a common structure of turbulent viscosity. A sophisticated version relying on the computation of two flow fields has been developed by Anca Belme.

These results have been published in [23], [38], [18], [39].

5.3.3. Reduced order modeling

Participants: Alain Dervieux, Marianna Braza [Institut de Mécanique des Fluides de Toulouse], Rémi Bourguet [MIT].

Also in relation with unsteady turbulence models, a cooperation with IMFT (Marianna Braza and Rémi Bourguet) has continued on reduced order models. A novel parametrisation of a wing shape relying on the Hadamard formula has been introduced successfully in the Proper Orthogonal Decomposition compressible model. An article is being published, [13]

5.3.4. A Stabilized Finite Element Method for Compressible Turbulent Flows

Participants: Christelle Wervaecke [Bacchus], Heloise Beaugendre [EM2C], Boniface Nkonga.

The main weakness of the classical finite element method (Galerkin) is its lack of stability for advection dominated flows. We consider in this work a compressible Navier-Stokes equations combined with the one equation Spalart-Allmaras turbulence model. These equations are solved in a coupled way. The numerical stability is achieved thanks to the Streamline Upwind Petrov-Galerkin (SUPG) formulation. Within the framework of SUPG method, artificial viscosity is anisotropic and the principal component is aligned with streamlines. The aim is to put sufficient viscosity to get rid of instability and unphysical oscillations without damaging the accuracy of the method. The amount of artificial viscosity is controlled by a stabilization tensor. Since an optimal way to choose this tensor is still unknown, several ways have been investigated. Beside SUPG method is also used in combination with a shock-parameter term which supplied additional stability near shock fronts. Numerical results show that the method is able to reproduce good turbulent profiles with less numerical diffusion than a finite volume method. Even in the case of almost incompressible flow, the numerical strategy is robust and gives good results, [29],[31],[36].

5.3.5. Acoustics

Participants: Anca Belme [Tropics], Ilya Abalakin [IMM-Moscou], Alain Dervieux, Alexandre Carabias.

A method for the simulation of aeroacoustic problems has been designed and developed by a cooperation between the Computational Aeroacoustics Laboratory (CAL) of Intitute for Mathematical Modeling at Moscow and INRIA. Further applications have been developed by the Russian team from the two common numerical scheme, the Mixed-Element-Volume at sixth-order, and the quadratic reconstruction scheme. This year the cooperation is concentrated on the study of a new quadratic reconstruction scheme, which extends the one developed by Hilde Ouvrard and Ilya Abalakin. The novelty is that now we hope to get fourth-order accuracy with a less costly quadratic reconstruction.

5.4. Environmental flows

5.4.1. Mobile bed and sediment transport

Participants: Hervé Guillard, Boniface Nkonga, Marco Bilanceri [University di Pisa, Italy], Maria-Vittoria Salvetti [University of Pisa, Italy], Imad Elmahi [University of Oudja, Morocco].

In the framework of a collaborative 3+3 Euro-Méditerranée action, we have studied the numerical approximation of a model coupling the shallow-water equations with a sediment transport equation for the morphodynamics. In shallow-water problems, time advancing can be carried out by explicit schemes. However, if the interaction with the mobile bed is weak, the characteristic time scales of the flow and of the sediment transport can be very different introducing time stiffness in the global problem. For this case, it is of great interest to use implicit schemes. The aim of the present work is to investigate the behaviour of implicit linearised schemes in this context. These results have been presented in [24] and [32].

6. Other Grants and Activities

6.1. National Actions

The ANR ESPOIR (Edge Simulation of the Physics Of Iter Relevant turbulent transport) associates the PUMAS team with the M2P2, LPIIM and LATP laboratories in Marseille and IRFM in Cadarache to investigate edge plasma turbulence. The numerical simulation of the plasma wall interactions requires efficient codes and thus the development of advanced numerical methods and solvers. The aim of this ANR is to study different numerical strategies for edge plasma models in the real geometrical and magnetical configurations corresponding to the future Iter machine.

6.2. International Grants

6.2.1. 3+3 Euro méditerranée project Mhycof

This project associates the University Ibn Zohr, Agadir, the Mohamedia Engineering school, the university of Oujda in Morocco, the University of Pisa (Italy) the Universidad de Zaragoza (spain), the Polytechnic school of Tunisia, the university of Paris 13 and Inria Sophia-Antipolis to develop numerical modelling of coastal flows.

6.2.2. Bilateral Scientific Relations

6.2.2.1. Institute of Mathematical Modeling, Moscow : Acoustics

Participants: Alain Dervieux, Tatiana Kozubskaya [IMM-Moscow], ILYa Abalakin [IMM-Moscou].

The long-term scientific collaboration with IMM on acoustics focussed this year on new reconstruction schemes for noise propagation with linear and non-linear hyperbolic models.

6.2.2.2. *Ingegneria Aerospaziale, university of Pisa : Turbulence Modeling*

Participants: Hervé Guillard, Alain Dervieux, Bruno Koobus [Montpellier 2], Simone Camarri [University of Pisa], Maria-Vittoria Salvetti [University of Pisa].

The long-term scientific collaboration with the Department of Ingegneria Aerospaziale at university of Pisa has concerned during last years complex fluid flows with cavitation. It continues with the development of hybrid models for turbulent flows and a common work on the transport of sediment in shallow water flows.

6.2.2.3. *Texas A & M : High order methods*

Participants: Jean-Luc Guermond [Texas A & M University], Richard Pasquetti.

This collaboration involves the development of techniques to compute solutions of non-linear hyperbolic problems by the use of artificial viscosity. The main idea is here to introduce a non-linear viscous term whose strength is derived from the residual of the entropy equation associated to the considered PDE.

7. Dissemination

7.1. Animation of the scientific community

7.1.1. *Conference Program Committees*

- H. Guillard is member of the Committee "Computational Fluid Dynamics" of ECCOMAS : European Community of Computational Methods in Applied Sciences
- H. Guillard is member of the scientific committee of the FVCA6 conference to be held in June 2011 in Prague - Czech republic.

7.1.2. *Ph.D. thesis and HDR Committees*

Alain Dervieux was in the PhD jury of the following PhD and HDR thesis defences:

- Julien Montagnier, PhD Thesis, "Étude de schémas numériques d'ordre élevé pour la simulation de dispersion de polluant dans des géométries complexes. ", University of Lyon,
- Ludovic Martin, PhD Thesis, "Conception Aérodynamique robuste", University of Toulouse,
- Guillaume Barbut, PhD Thesis, "Analyse Physique par Simulation Numérique d'Écoulements Turbulents Instationnaires autour de Surfaces Portantes Fixes ou en Mouvement, à Nombres de Reynolds et de Mach Élevés", University of Toulouse.

Hervé Guillard was in the PhD jury of :

- Livia Isoardi, PhD Thesis, " Modélisation du transport dans le plasma de bord d'un tokamak", University of Provence, December 14 2010

and acted as "rapporteur" for the HDR defence of :

- Stéphane Dellacherie, HDR, "Etude et discrétisation de modèles cinétiques et de modèles fluides à bas nombre de Mach", University Pierre and Marie Curie, 2011.

Boniface Nkonga was in the PhD jury of :

- Laetitia Carballal Perdiz, PhD Thesis(04/12/2010), " ", University of Toulouse,

. and acted as "rapporteur" for the PhD Thesis defences of :

- Christelle Wervaecke, PhD Thesis(09/12/2010), "Simulation d'écoulements turbulents compressibles par une méthode d'éléments finis stabilisée ", University of Bordeaux 1, December 9, 2010.

R. Pasquetti was in the PhD jury as "rapporteur" of the following thesis defences:

- Pierre Guillaume Gourio-Jewell, PhD Thesis, "Application à la propagation d'ondes de chocs en milieu fluide et frontière mobile", University of Toulon, March 30, 2010

7.2. Teaching

7.2.1. Doctoral formation

- H. Guillard is member of the "école doctorale" ED 353 council : Sciences pour l'Ingénieur : Mécanique, Physique, Micro et Nanoélectronique of the university of Provence.

7.2.2. Summer schools and tutorials

- B. Nkonga, Models & Approximation : Applications to fluid mechanics, CARI'2010, October 18-21, 2010, Yamoussoukro, Ivory coast
- B. Nkonga, Les outils numériques, Ecole d'Aquitaine Ondes et Matière, October 4-8, 2010, Carcans-Maubuisson, France.

7.2.3. Internships

- Nishan Mann & Muhammad Kamboh, Erasmus Mundus MathMods Master 1, University of Nice : Bohm Boundary conditions in plasma physics, Advisor: H. Guillard.
- Sandrine Berte, Manon Casella, Alexandre Reignier, Paul-Louis Vincenti, Polytech'Nice, University of Nice : Boundary conditions for plasma wall interactions in plasma physics, Advisor: H. Guillard.
- Delyan Zhelyazov & Soheil Hajian, Erasmus Mundus MathMods Master 1, University of Nice : MagnetoHydroDynamics Simulation in the Presence of Magneto Monopoles, Advisor: B. Nkonga.
- Mehdi Arfa, Polytech'Nice, University of Nice, Numerical model for pedestrian traffic, Advisor: B. Nkonga.
- Yue Jia & Adeleke Bankole, Erasmus Mundus MathMods Master 1, University of Nice : Fast-marching method and application to pedestrian traffic. Advisor: B. Nkonga.
- Thomas Milotti, Polytech'Nice, University of Nice : Pedestrians Flow, Advisors: M. Rascles, A. Sangam.

7.3. Conferences and workshops

7.3.1. Conference organization

- **Eccomas CFD2010** In the framework of the Eccomas CFD2010 conference held in Lisbon (June 14-17), Hervé Guillard has organized a symposium session on "Shallow Water Models for Environmental Flows".
- **Large scale Initiative Fusion : Organisation of CEMRACS'2010** In the framework of the Large scale Initiative Fusion, the Calvi EPI and the Pumas team have organized the CEMRACS 2010 on Numerical Modelling of Fusion. The CEMRACS is a scientific event of the SMAI (the french Society of Applied and Industrial Mathematics) and of SMF (Société Mathématique de France). The Cemracs 2010 has consisted in two types of events:
 1. a one week summer school that took place from July 19th to 23th
 2. and a five week research session (July 26th - August 27th) where young scientists assisted by one or more senior researchers have worked together on a dedicated research project. 19 differents projects involving a total of more than 40 students have been developed during Cemracs2010.

- **MHyCoF:** From September 20 to 24, a workshop and summer school on Numerical Methods for interactions between sediments and water have been organized in Paris 13 University, by LAGA Laboratory, as part of the Euro-Mediterranean Inria Cooperative Project MHyCoF. This event has gathered more than 40 participants, mainly young researchers and students.

7.3.2. Seminars and Invited Conferences

- Richard Pasquetti has presented a talk on viscosity methods for the Navier-Stokes equations and conservation laws at the “Séminaire d’Analyse Numérique” of the university of Nice-Sophia Antipolis. January 7, 2010.
- Alain Dervieux presented new results of Tropics and Pumas researchs at Workshop ECINADS (Sophia-Antipolis, october 26-27, 2010).
- Boniface Nkonga has been invited speaker at the CARI’2010 Ivory coast, Yamoussoukro, October 18 – 21, 2010 where he has presented a lecture on the numerical simulation of plasma for fusion applications.
- Boniface Nkonga has presented a talk on "Numerical Challenges for controlled fusion design : MHD models" in the workshops of GdR CHANT and GdR MOMAS, November 5, 2010 , IHP Paris.
- Boniface Nkonga has presented a talk on "Numerical modeling of low Mach multifluid flows with surface tension." at the seminar of Laboratoire Jacques-Louis Lions (Univ. Paris Pierre et Marie Curie), january 29, 2010, Paris.
- Boniface Nkonga has presented a talk on "Some numerical strategies to be improved in the context of the controlled fusion" at the first workshop of the GDR Calcul, novembre 9-10 , 2009, IHP Paris.
- Hervé Guillard has presented a talk on the Bohm boundary conditions in a seminar at University Pierre and Marie Curie, 18 november 2010.

8. Bibliography

Major publications by the team in recent years

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- [14] A. DERVIEUX, C. FARHAT, B. KOOBUS, M. VÁZQUEZ. *Total energy conservation in ALE schemes for compressible flows*, in "European Journal of Computational Mechanics", 2010, vol. 19:4, p. 337-363.
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