RESEARCH CENTRE

Sophia Antipolis - Méditerranée

IN PARTNERSHIP WITH:

CNRS, Université Côte d'Azur

2021

ACTIVITY REPORT

Project-Team

CASTOR

Control, Analysis and Simulations for TOkamak Research

IN COLLABORATION WITH: Laboratoire Jean-Alexandre Dieudonné (JAD)

DOMAIN

Digital Health, Biology and Earth

THEME

Earth, Environmental and Energy Sciences

Contents

Project-Team CASTOR

Creation of the Project-Team: 2014 July 01

Keywords

Computer sciences and digital sciences

A6. – Modeling, simulation and control

A6.1. – Methods in mathematical modeling

A6.1.1. – Continuous Modeling (PDE, ODE)

A6.1.4. – Multiscale modeling

A6.1.5. – Multiphysics modeling

A6.2. – Scientific computing, Numerical Analysis & Optimization

A6.2.1. – Numerical analysis of PDE and ODE

A6.2.6. – Optimization

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A6.2.8. – Computational geometry and meshes

A6.3. – Computation-data interaction

A6.3.1. – Inverse problems

A6.3.2. – Data assimilation

A6.3.4. – Model reduction

A6.4. – Automatic control

A6.4.1. – Deterministic control

A6.4.4. – Stability and Stabilization

A6.5. – Mathematical modeling for physical sciences

Other research topics and application domains

B4. – Energy

B4.2.2. – Fusion

1 Team members, visitors, external collaborators

Research Scientists

- Hervé Guillard [Team leader, Inria, Senior Researcher, HDR]
- Florence Marcotte [Inria, Researcher]

Faculty Members

- Didier Auroux [Univ Côte d'Azur, Professor, HDR]
- Jacques Blum [Univ Côte d'Azur, Emeritus, HDR]
- Cédric Boulbe [Univ Côte d'Azur, Associate Professor]
- Boniface Nkonga [Univ Côte d'Azur, Professor, HDR]
- Francesca Rapetti [Univ Côte d'Azur, Associate Professor, HDR]
- Afeintou Sangam [Univ Côte d'Azur, Associate Professor]

Post-Doctoral Fellow

- Paul Mannix [Inria]

PhD Students

- Ashish Bhole [Univ Côte d'Azur, until Nov 2021]
- Louis Lamerand [Univ Côte d'Azur]

Technical Staff

- Blaise Faugeras [CNRS, Engineer, HDR]

Interns and Apprentices

- Guillaume Gros [Inria, from May 2021 until Jul 2021]

Administrative Assistant

- Montserrat Argente [Inria]

2 Overall objectives

In order to fulfill 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 and Laser Megajoule 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 sufficiently 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.

CASTOR gathers the activities in numerical simulation of fusion plasmas with the activities in control and optimisation done in the laboratory Jean-Alexandre Dieudonné of Université Côte d'Azur. The main objective of the CASTOR team is to contribute to the development of innovative numerical tools to improve the computer simulations of complex turbulent or unstable flows in plasma physics and to develop methods allowing the real-time control of these flows or the optimisation of scenarios of plasma discharges in tokamaks. CASTOR is a common project between Inria, Université Côte d'Azur and CNRS through the laboratory Jean-Alexandre Dieudonné, UMR UNS-CNRS 7351, LJAD.

3 Research program

3.1 Plasma Physics

The main reseach topics are:

1. Modelling and analysis
   - Fluid closure in plasma
   - Turbulence
   - Plasma anisotropy type instabilities
   - Free boundary equilibrium (FBE)
   - Coupling FBE – Transport
   - MHD instabilities
2. Numerical methods and simulations
   - High order methods
   - Curvilinear coordinate systems
   - Equilibrium simulation
   - Pressure correction scheme
   - Anisotropy
   - Solving methods and parallelism
3. Identification and control
   - Inverse problem: Equilibrium reconstruction
   - Open loop control

4 Application domains

4.1 MHD and plasma stability in tokamaks

Participants: Hervé Guillard, Boniface Nkonga, Afeintou Sangam, Ali Elarif, Ashish Bhole.

The magnetic equilibrium in tokamaks results from a balance between the Lorentz force and the pressure gradient. Using Ampère law, a convenient description of this equilibrium is provided by the Grad-Shafranov equation. Of course, the magnetic equilibrium solution of the Grad-Shafranov equation is required to be stable. Actually any loss of MHD stability can lead to the end of the existence of the plasma, the so-called disruptions that can affect negatively the integrity of the machine. The primary goal of MHD (Magneto-Hydro-Dynamics) studies is therefore to determine the stability domain that constraints the operational range of the machine.
A secondary goal of MHD studies is to evaluate the consequences of possible disruptions in term of heat loads and stresses on the plasma facing components. In modern machines in the so-called H-mode some mild instabilities leading to a near oscillatory behavior are also known to exist. In particular, the so-called ELMs (Edge Localized Modes) are of particular importance since they can have large effects on the plasma facing components. The control and understanding of these instabilities is therefore of crucial importance for the design of future machines as ITER. Unfortunately, ELM occur in the edge plasma and their modeling requires to take in account not only the intricate magnetic topology of this region where co-exist both open and closed field lines but also the existence of molecular and atomic processes involving neutrals.

At present, the linear theory of MHD stability is relatively well understood. However, the description of the non-linear behavior is far from being complete. As a consequence and due to the intrinsic difficulty of the subject, only a few numerical codes worldwide have been developed and validated for non linear MHD in tokamaks. One of these codes is the JOREK code developped since 2006 from a collaborative work between CEA-Cadarache (main developer), LABRI Bordeaux, LJAD-UCA and Inria. A comprehensive description of JOREK is given in [21]

4.2 Long term plasma evolution and optimization of scenarii

Participants: Didier Auroux, Jacques Blum, Cédric Boulbe, Blaise Faugeras, Hervé Guillard.

The magnetic equilibrium evolves in time due to diffusion processes on the slow resistive diffusive time scale and moreover it has to be monitored with active and passive control based on external coils, current drive, heating system, particle or pellets injections. This set of control mechanism has to be modeled and this is the goal of real time codes or global evolution codes.
In the same order of ideas, the steering and control of the plasma from the beginning to the end of the discharge require the research of optimal trajectories through the space of operational parameters. This is usually performed in an empirical way in present Tokamaks, but the complexity of the problem requires today the use of optimization techniques for processes governed by MHD and diffusion-type equations.

4.3 Turbulence and models for the edge region of tokamaks

Participants: Didier Auroux, Louis Lamerand, Francesca Rapetti.

The edge region of the plasma is characterized by low temperature and density leading to an increase of the collision frequency that makes the edge plasma nearly collisional. This combined with the intricate magnetic topology of this region makes the development of kinetic codes adapted to the edge regions a real long term adventure. Consequently the fluid approach remains a standard one to study edge plasma turbulence. The use of optimal control theory to derive simplified models matching data either experimental or derived from direct numerical simulations is part of the objectives of the team.

4.4 Understanding magnetogenesis in stellar systems

Participants: Didier Auroux, Paul Mannix, Florence Marcotte.

The considerable diversity of long-lived magnetic fields observed in the Universe raises fundamental questions regarding their origin. Although it is now widely accepted that such fields are sustained by a dynamo instability in the electrically conducting fluid layers of astrophysical bodies, in most cases the very nature of the flow motions powering the dynamo is essentially unknown, and the conditions required for amplifying large-scale magnetic fields in non-convective stellar systems are poorly understood. We claim that optimal control represents a powerful tool to investigate the nonlinear stability of fully 3D, unsteady magnetohydrodynamic flows with respect to the dynamo instability. Nonlinear optimisation can be also used as a physical diagnostic to gain novel understanding of the mechanisms that are most favorable to dynamo action in a natural system.

5 New results

5.1 First equilibrium reconstruction for ITER with the code NICE

Participants: Blaise Faugeras, Jacques Blum, Cédric Boulbe.

In the short paper [18], we present the first application of the IMAS compatible code NICE to equilibrium reconstruction for ITER geometry. The inverse problem is formulated as a least square problem and the numerical methods implemented in NICE in order to solve it are presented. The results of a numerical experiment are shown: a reference equilibrium is computed from which a set of synthetic magnetic measurements are extracted. Then these measurements are used successfully to reconstruct the equilibrium of the plasma.

5.2 Equilibrium reconstruction of discharges from EUROfusion tokamaks using the WPCD scientific workflows

Participants: A. Merle, R. Coelho, F. Carpanese, S. Dixon, M. Dunne, B. Faugeras, L. FLeury, J. Hollocombe, F. Imbeaux, L. Kogan.

Equilibrium reconstruction codes are the corner stone of many workflows for analysis of tokamak discharges. Code benchmarking can be facilitated when the codes share the same data ontology, which also allows for easier porting to new devices. Such an approach has been adopted by the Work Package for Code Development (WPCD) using the ITER Integrated Modelling and Analysis Suite (IMAS), building upon the work of the European Integrated Modelling framework. Following up on some initial work, we report here on a benchmarking exercise using the EQRECONSTRUCT workflow, developed within WPCD and sporting the EQUAL and NICE equilibrium reconstruction codes, using data from the TCV, AUG and JET EUROfusion tokamaks. Most reconstructions presented here will use magnetics data only but the workflow is already equipped to also handle data from interferometry, polarimetry or MSE diagnostics. The plasma pressure in the outer radius can also be constrained by input profiles. Results from the EQUAL and NICE codes will be compared to the local codes used for reconstruction on each machine

5.3 Plasma initiation and preliminary magnetic control in the HL-2M tokamak

Participants: X. Song, B. Li, J. Zhou, E. Nardon, H. Heumann, B. Faugeras, J.X. Li, Sh. Wang, SH.Y. Liang.

The first plasmas have been achieved in the HL-2M tokamak by fulfilling the usual criteria for plasma breakdown, i.e. optimal working gas pressure, field null configuration of poloidal magnetic field, reasonable toroidal electrical field and clean wall conditions. The characterization of plasma initiation, such as identification of initiation time and position, is performed by diagnostic data analysis and numerical simulation. A model-based method, which enables dedicated pick-up sensors to estimate plasma radial position in real time, is applied for the limiter plasma shape in the first plasma commissioning phase. For a circular cross-section plasma, feedback control on plasma current and radial position allowed us to extend discharge durations to ~ 250 ms associated with a 120 kA plasma current in flat-top. Preliminary plasma equilibrium reconstruction by the NICE code from pick-up sensors and flux loops, as well as interferometry measurements, gives plasma boundaries, plasma profiles of toroidal current density and safety factor, as well as electron density, in an offline way.

5.4 Development of the RAPTOR suite of codes towards real-time reconstruction of JET discharges

Participants: C. Piron, F. Felici, B. Faugeras, N. Ferron, G. Manduchi, N. Marconato, C. Meekes, L. Piron, Z. Stancar, D. Valcarcel, D. Voltolina, M. Weiland, JET contributors.

The brand-new RAPTOR suite of codes is here presented. The suite has been developed for JET to combine real-time model-based predictions of the plasma state with the available diagnostic measurements. The suite embeds: the upgraded equilibrium reconstruction EQUINOX code, the FLUXMAP algorithm, which maps the diagnostic measurements from geometric to normalized magnetic flux coordinates; the RABBIT code for the NBI reconstruction and eventually RAPTOR state observer, which combines the output from all these codes with the predictions of 1D control-oriented transport code. The suite is both implemented in MATLAB/Simulink and it is being integrated in the C++ real-time MARTe2 framework. Thanks to its user-friendly interfaces, which are based on the MDSplus I/O and visualization tools, the RAPTOR suite can be used both offline, for a fast reconstruction of the plasma state, and in integrated control algorithms once it will be deployed in the JET real-time data network. This work is detailed in the paper [11].

5.5 High-order finite elements in tokamak free-boundary plasma equilibrium computations

Participants: F. Rapetti, B. Faugeras, C. Boulbe.

We wish to compute numerically the equilibrium for a hot plasma in a tokamak. For such a problem in an axisymmetric configuration, we present a non-overlapping mortar element approach, that couples piece-wise linear finite elements in a region that does not contain the plasma and reduced Hsieh-Clough-Tocher finite elements elsewhere, to approximate the magnetic flux field on a triangular mesh of the poloidal tokamak section. This approach has the flexibility to achieve easily and at low cost higher order regularity for the approximation of the flux function in the domain covered by the plasma, while preserving accurate meshing of the geometric details in the rest of the computational domain and simplifying the inclusion of ferromagnetic parts. Details can be found in [19].

5.6 Introduction of C1 Clought-Tocher finite elements in NICE

Participants: A. Elarif, B. Faugeras, F. Rapetti.

The numerical simulation of the equilibrium of the plasma in a tokamak as well as its self-consistent coupling with resistive diffusion should benefit from higher regularity of the approximation of the magnetic flux map. In this work [4], we propose a finite element approach on a triangular mesh of the poloidal section, that couples piece-wise linear finite elements in a region that does not contain the plasma and reduced Hsieh-Clough-Tocher finite elements elsewhere. This approach gives the flexibility to achieve easily and at low cost higher order regularity for the approximation of the flux function in the domain covered by the plasma, while preserving accurate meshing of the geometric details in the rest of the computational domain. The continuity of the numerical solution at the coupling interface is weakly enforced by mortar projection. A new technique for the computation of the geometrical coefficients is also presented.

5.7 Coupling Hermite-Bezier quadrangular elements and Clough Tocher triangular elements

Participants: H. Guillard, B. Nkonga, F. Rapetti.

The Jorek code [7] for MHD studies uses fourth order C1 quadrangular finite elements. This leads to results with high spatial accuracy. However with this type of elements, the description of the boundary is difficult and moreover with polar meshes, geometrical singularities appear on X-points and magnetic axis. We have begun to study using the Mortar technique the coupling of the Hermite-Bezier quadrangular elements used in Jorek and of Clough Tocher triangular elements that will allow a easier representation of the boundary and solves the problem of mesh singularities.

5.8 High-order Whitney finite elements

Participants: F. Rapetti, A. Alonso Rodriguez (Univ. de Trento, Italy).

We recall the classical tree-cotree technique in magnetostatics. We extend it in the frame of high-order finite elements in general domains. We focus on its connection with the question of the invertibility of the final algebraic system arising from a high-order edge finite element discretization of the magnetostatic problem formulated in terms of the magnetic vector potential. With the same purpose of invertibility, we analyse another classically used condition, the Coulomb gauge. We conclude by underlying that the two gauges can be naturally considered in a high order framework without any restriction on the topology of the domain. (hal-03426096 = [15])

The well-known tree-cotree gauging method for low-order edge finite elements is extended to high-order approximations within the first family of Nédélec finite element spaces. The starting point of the algorithm is a spanning tree of the graph given by vertices and edges of the mesh (the so-called global spanning tree, that is the one used in the low-order case). This global step, interpreted in the high-order sense, is enriched locally, with a loop over the elements of the mesh, with arcs corresponding to edge, face and volume degrees of freedom required in the high-order case. (See [12])

5.9 Coupling Nice-Metis

Participants: J.F. Artaud, C. Boulbe, B. Faugeras.

In [20], a new model describing the evolution of the diamagnetic function f which appears in the right hand side of the well known Grad-Shafranov equation has proposed. This model has been implemented in the free boundary equilibrium code NICE. This new version of the code has been tested. A first version of the coupling of Nice with the fast transport solver has started in Matlab. This coupling should be more robust than the last version of the coupling NICE-METIS which was using the current diffusion equation for the evolution of the right hand side of the Grad-Shafranov equation. This work is done in the framework of the workpackage WPSA EUROFUSION H-EUROPE.

5.10 Equilibrium reconstruction using neural networks

Participants: C. Boulbe, B. Faugeras, G. Gros.

Neural networks have been used to compute the plasma boundary using experimental magnetic measurements on a database of the Tokamak West. As the plasma boundary is not directly avalaible on the machine, we used plasma boundary computed by NICE to train the model. A neural network taking as input the magnetic measurement and providing the plasma boundary has been implemented. The first results are encouraging. Other neural networks has been implemented to compute the 2D magnetic flux and the function p' and ff' appearing in the right hand side of the Grad-Shafranov equation.

5.11 Development of an adjoint code for a reduced MHD model

Participants: H. Guillard, L. Hascoet, Ecuador team.

Non linear MHD simulations for tokamaks are now mature enough to be used for control, optimization or data assimilation purposes. The use of these tool can largely benefit from the possibility to compute gradients of the results of the simulations with respect to initial data or parameters. In collaboration with the ECUADOR team, we have used the automatic differentiation tool TAPENADE to obtain the adjoint code of a reduced MHD model. Several problems related with FORTRAN arrays have been solved and an adjoint code for a reduced MHD model coded in the CTfem framework have been obtained.

5.12 Numerical simulation of nonlinear acoustic streaming in standing waves

Participants: V. Mandikas, Technical University of Crete, A. Delis, Technical University of Crete, H. Guillard.

Acoustic streaming is a secondary mean steady flow generated by and superimposed on a primary oscillatory flow. When a compressible fluid experiences a high-frequency oscillation (e.g. from a sound source) the nonlinear interactions can often lead to a pattern of time-dependent vortical flows or steady circulations in the flow field. We have begun a numerical investigation of acoustic streaming motion (of the Rayleigh type) in a compressible gas inside two-dimensional rectangular enclosures. To numerically study the effects of the sound field intensity on the formation process of streaming structures, the full compressible two-dimensional Navier-Stokes equations have been discretized using a high-order compact scheme. An article describing the numerical method and the results of this investigation has been submitted.

5.13 Diffusive wave approximation of the shallow water equations

Participants: H. Guillard, C. Boulbe.

In the framework of an intership with Master students of the engineering school Polytech'Nice Sophia, we have begun the development of a numerical code based on the diffusive wave approximation of the shallow water equations. Collecting topographic data related to the Vesubie river watershed have been done and some preliminary computations corresponding to the Alex tempest of October 2020 have been realized.

5.14 Shear shallow water model

Participants: B. Nkonga, C. Praveen, J. Iroume, A. Ngatcha.

This year's objectives included field surveys and observations to calibrate the dissipative effects and friction coefficients in the target study basin in the city of Douala. Due to the health crisis, this could not take place and delays the realistic applications of our SSW model. Nevertheless, we have continued the development of the simplified and the more accurate modelling. The results obtained on these themes have being submitted for publication in an international journal [9]. A two-week training course was held in Douala on the derivation of "shallow-water" (SW) equations, attended by a dozen students (M2 and PhD) and four senior researchers. We have anticipated our simulation program by performing the first regularization and refinement of the mesh associated with the Togo-Bassa target basin.

Our goal for next year is to make a significant effort to gather the field data needed to perform the first realistic simulations on a portion of the Tongo-Bassa Basin.This is where there are strong interactions between rainfall run-off and oceanic tidal effects. The SSW model seems to be adapted for these complex interactions that generate turbulence. For simulation purposes, we need a fairly accurate topography, including the internal profile of the rivers. These data will be obtained during measurement campaigns using remote-controlled miniature boats equipped with sonar, as well as flying drones. We also wish to organize a week of sustained work at CIRM on modelling and numerical methods.

5.15 MultiD Riemann solver for non-conservative hyperbolic equations

Participants: B. Nkonga, D. Balsara.

During the scientific stay of D. Balsara in nice in November 2021, we continued our investigation on the derivation of a genuinely multi-dimensional Riemann solver for non-conservative hyperbolic systems. In our first attempts, no difference was made between possible conservative and non-conservative contributions. It turns out that it is desirable, in a high-order MultiD Riemann solver, to preserve the contributions that are expressed in terms of flows. One can thus use Simpson's rules for numerical integrations on the edges of the cells. The theoretical analyses performed for different numerical strategies are very encouraging. This trend will have to be confirmed by future numerical simulations.

5.16 Dynamo instabilities and nonlinear optimal control of MHD flows

Participants: Didier Auroux, Paul Mannix, Florence Marcotte.

Dynamo instabilities power long-lived magnetic fields in the electrically conducting layers of astrophysical flows. The effect of various flow properties, such as the spatial variability of the electrical conductivity, or the intensity of stratification, are studied numerically in simplified flow models motivated by astrophysical, and in particular stellar applications. Particular attention is paid to the case where the flow is linearly stable with respect to the dynamo instability, but unstable to finite-amplitude perturbations. An important part of the work here consists in the development of a flexible adjoint-based optimisation code for fully nonlinear, 3D, unsteady MHD flows, and its application to the identification of subcritical dynamo instabilities. This workpackage involves collaborations with researchers from various institutes, in particular Y. Ponty (Observatoire de la Cote d'Azur), L. Petitdemange (LERMA / Observatoire de Paris), C. Gissinger (ENS), F. Petrelis (ENS), B. Gallet (CEA Saclay).

6 Partnerships and cooperations

6.1 International initiatives

6.1.1 Associate Teams in the framework of an Inria International Lab or in the framework of an Inria International Program

AMFoDUC

Title: Advanced Modeling of Flows in Douala City in the strong Urbanization and Climate

Duration: 2021 ->

Coordinator: Raphael Onguene (ziongra@yahoo.fr)

Partners:

- Université de Douala

Inria contact: Boniface Nkonga

6.1.2 Horizon Europe

Cédric Boulbe and Blaise Faugeras participate to the Eurofusion Workpackage WPSA
Boniface Nkonga and Hervé Guillard participate to the EuroFusion workpackage 01 (Tokamak exploitation)TSVV#8

6.2 National initiatives

6.2.1 ANR Sistem

Member of the ANR SISTEM , Oct. 2019 - Sept. 2023 coordinated by the M2P2 Institute of Aix-Marseille Univ. "SImulations with high-order schemes of tranSport and TurbulencE in tokaMak" programme Modeles numeriques 2019, Contact : Francesca Rapetti

Participants: Didier Auroux, Jacques Blum, Cédric Boulbe, Francesca Rapetti, Blaise Faugeras.

6.2.2 ANR DYNSEED

"Graines minimales de dynamos célestes" May 2020-2022, PI : Florence Marcotte.

Participants: Didier Auroux, Paul Mannix, Florence Marcotte.

7 Dissemination

7.1 Promoting scientific activities

7.1.1 Scientific events: organisation

Didier Auroux has participated to the organisation of a SEME (Semaine d'Etudes Maths Entreprises): SEME

7.1.2 Journal

Member of the editorial boards

- Jacques Blum is member of the editorial board of the Journal Scientific Computing.
- Francesca Rapetti is member of the editorial board of the Advances in Computational Mathematics (ACOM) journal by Springer.
- Cedric Boulbe is managing editor of the journal SMAI Journal of Computational Mathematics.
- Didier Auroux is member of the editorial board of the journal ESAIM Proceedings.

Reviewer - reviewing activities

- Florence Marcotte has been reviewer for the Journal of Fluid Mechanics, and Physical Review Fluids.

7.1.3 Invited talks

- Jacques Blum has been invited to the conference "Diagnostics for Fusion Reactors" in Varenna (Italy).
- Francesca Rapetti has been invited to the conference " ICOSAHOM 2021, Vienna on 12-16/07/2021 (virtual talk : High-order finite elements in tokamak free-boundary plasma equilibrium computations)".

7.1.4 Research administration

F. Marcotte has joined the Conseil Scientifique of Académie « Systèmes Complexes », Université Cote d'Azur.

7.2 Teaching - Supervision - Juries

7.2.1 Teaching

- Ecole d'ingénieur, D. Auroux, Mathématiques financières, 66h équivalent TD, niveau M1, Université Côte d'Azur
- Ecole d'ingénieur, D. Auroux, Probabilités et statistiques, 24h équivalent TD, niveau L3, Université Côte d'Azur
- Licence : F. Rapetti, Mathématiques 2,60h équivalent TD, L2, Université Côte d'Azur
- Licence : F. Rapetti, Introduction au calcul scientifique, 24h équivalent TD, L2, Université Côte d'Azur
- Ecole d'ingénieur, C. Boulbe, Analyse Numérique 1, 45.5h équivalent TD, niveau L3, Université Côte d'Azur
- Ecole d'ingénieur, C. Boulbe, Analyse numérique 2, 45.5h équivalent TD, niveau L3, Université Côte d'Azur
- Ecole d'ingénieur, C. Boulbe, Algèbre linéaire et Scilab, 26h équivalent TD, Université Côte d'Azur
- Ecole d'ingénieur, C. Boulbe et D. Auroux, Projet 1, 48h équivalent TD, Université Côte d'Azur
- Licence : A. Sangam, Fondements Mathématiques, 24h, Semestre 1 de la Licence, Université Côte d'Azur, France
- Licence : A. Sangam, Fondements Mathématiques, 48h, Semestre 3 de la Licence, Université Côte d'Azur, France

- Licence : A. Sangam, Mathématiques Compléments d'Analyse, 4h, Semestre 3 de la Licence, Université Côte d'Azur, France
- Master : A. Sangam, Analyse de Fourier et Distributions, 72h, Semestre 1 des Masters Mathématiques Fondamentales/Mathématiques Pures et Appliquées, Université Côte d'Azur, France
- Master : A. Sangam, Optimisation et Éléments Finis, 18h, Semestre 2 des Masters Mathématiques Fondamentales/Mathématiques Pures et Appliquées, et Ingénierie Mathématique, Université Côte d'Azur, France
- Ecole d'ingénieur/Master: B. Nkonga, Méthode des éléments finis, 24h, M2, Polytech Nice Sophia, Université Côte d'Azur
- Ecole d'ingénieur/Master: B. Nkonga, Eléments finis mixtes, 24h, M2, Polytech Nice Sophia, Université Côte d'Azur
- Ecole d'ingénieur/Master, H. Guillard, Développement durable et enjeux de gouvernance, 16h, M2, Polytech Nice Sophia, Université Côte d'Azur

7.2.2 Supervision

- PhD: Ashish Bole, "Stabilized $C1$-bicubic Finite Element method for nonlinear MHD modeling of tokamak plasma", 17 nov. 2021
- PhD in progress: Louid Lamerand, PhD student fully payed by the ANR project SISTEM, who is working with Didier Auroux and Francesca Rapetti on “data assimilation” and “model reduction”: it consists in developing a simplified model for a physical phenomenon, here the heat transport in a tokamak, whose parameters are calibrated through either experimental measurements or accurate long-run computations with existing codes. With respect to the existing codes, the one based on the reduced model should provide an accurate and physically meaningful solution in a much shorter time, since October 2020.
- PhD in progress: Samy Kerboua Benlarbi, supervised by Blaise Faugeras and Remy Nouailletas (CEA), Region Sud and Altran, “Intelligence artificielle et controle des plasmas de fusion: application au tokamak west”
- Postdoctoral researcher: Paul Mannix (INRIA), 2020-2022, funded by ANR DYNSEED (PI: Florence Marcotte)

7.2.3 Juries

- H. Guillard and B. Nkonga were part of the jury defence of Ashish Bhole, INRIA, November 17, 2021
- F. Rapetti was referee for the Phd jury Anirudh Chauhan, Univ. Grenoble Alpes, mai 2021 (spec. Genie Electrique), "Modélisation en 3D du mouvement des machines électriques avec la méthode des éléments finis d'arêtes"
- B. Faugeras was referee and member of the jury panel, MSc thesis Ana Margarida Jorge dos Santos, Integrated Modeling of the Equlibrium Reconstruction in Tokamaks, Tecnico Lisbao, , Sept 9, 2021
- D. Auroux was president of HDR defense jury of D. La Torre, Skema
- D. Auroux was reviewer and member of PhD defense jury of C. Ghanmi, Grenoble-Tunis

8 Scientific production

8.1 Major publications

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