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Activity Report 2012

Project-Team OPALE

Optimization and control, numerical algorithms and integration of complex multidiscipline systems governed by PDE

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

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THEME
Computational models and simulation

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Project-Team OPALE

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Numerical Mathematics, Optimization and Software for Complex Systems Governed by PDE's.

Creation of the Project-Team: July 01, 2002 .

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2. Overall Objectives

2.1. Research fields

Optimizing a complex system arising from physics or engineering covers a vast spectrum in basic and applied sciences. Although we target a certain transversality from analysis to implementation, the particular fields in which we are trying to excell can be defined more precisely.

From the *physical analysis* point of view, our expertise relies mostly on Fluid and Structural Mechanics and Electromagnetics. In the former project Sinus, some of us had contributed to the basic understanding of fluid mechanical phenomena (Combustion, Hypersonic Non-Equilibrium Flow, Turbulence). More emphasis is now given to the coupling of engineering disciplines and to the validation of corresponding numerical methodologies.

From the *mathematical analysis* point of view, we are concerned with functional analysis related to partial-differential equations, and the functional/algebraic analysis of numerical algorithms. Identifying the Sobolev space in which the direct or the inverse problem makes sound sense, tailoring the numerical method to it, identifying a functional gradient in a continuous or discrete setting, analyzing iterative convergence, improving it, measuring multi-disciplinary coupling strength and identifying critical numerical parameters, etc constitute a non-exhaustive list of mathematical problems we are concerned with.

Regarding more specifically the *numerical aspects* (for the simulation of PDEs), considerable developments have been achieved by the scientific community at large, in recent years. The areas with the closest links with our research are:

1. *approximation schemes*, particularly by the introduction of specialized Riemann solvers for complex hyperbolic systems in Finite-Volume/Finite-Element formulations, and highly-accurate approximations (e.g. ENO schemes),
2. *solution algorithms*, particularly by the multigrid, or multilevel and multi-domain algorithms best-equiped to overcome numerical stiffness,
3. *parallel implementation and software platforms*.

After contributing to some of these progresses in the former project Sinus, we are trying to extend the numerical approach to a more global one, including an optimization loop, and thus contribute, in the long-term, to modern scientific computing and engineering design. We are currently dealing mostly with *geometrical optimization*.

Software platforms are perceived as a necessary component to actually achieve the computational cost-efficiency and versatility necessary to master multi-disciplinary couplings required today by size engineering simulations.

2.2. Objectives

The project has several objectives: to analyze mathematically coupled PDE systems involving one or more disciplines in the perspective of geometrical optimization or control, to construct, analyze and experiment numerical algorithms for the efficient solution of PDEs (coupling algorithms, model reduction), or multi-criterion optimization of discretized PDEs (gradient-based methods, evolutionary algorithms, hybrid methods, artificial neural networks, game strategies), to develop software platforms for code-coupling and for parallel and distributed computing.

Major applications include : the multi-disciplinary optimization of aerodynamic configurations (wings in particular) in partnership with the French or European aeronautical industry and research (Airbus, Dassault Aviation, ONERA, etc), the geometrical optimization of antennas in partnership with France Télécom and Thalès Air Défense (see Opratel Virtual Lab.), the development of *Collaborative, Distributed and High-Performance environments in collaboration with Chinese partners (CAE).*

2.3. Highlights of the Year

Our activity in road traffic modeling is reinforced by the creation of the Associated Team ORESTE with UC Berkeley.

Our activity in pedestrian flow modeling is reinforced by the doctoral thesis of M. Mimault, started in October, and the enrollment of M. Twagorowska on a post-doctoral position.

3. Scientific Foundations

3.1. Functional and numerical analysis of PDE systems

Our common scientific background is the functional and numerical analysis of PDE systems, in particular with respect to nonlinear hyperbolic equations such as conservation laws of gas-dynamics.

Whereas the structure of weak solutions of the Euler equations has been thoroughly discussed in both the mathematical and fluid mechanics literature, in similar hyperbolic models, focus of new interest, such as those related to traffic, the situation is not so well established, except in one space dimension, and scalar equations. Thus, the study of such equations is one theme of emphasis of our research.

The well-developed domain of numerical methods for PDE systems, in particular finite volumes, constitute the sound background for PDE-constrained optimization.

3.2. Numerical optimization of PDE systems

Partial Differential Equations (PDEs), finite volumes/elements, geometrical optimization, optimum shape design, multi-point/multi-criterion/multi-disciplinary optimization, shape parameterization, gradient-based/evolutionary/hybrid optimizers, hierarchical physical/numerical models, Proper Orthogonal Decomposition (POD)

Optimization problems involving systems governed by PDEs, such as optimum shape design in aerodynamics or electromagnetics, are more and more complex in the industrial setting.

In certain situations, the major difficulty resides in the costly evaluation of a functional by means of a simulation, and the numerical method to be used must exploit at best the problem characteristics (regularity or smoothness, local convexity).

In many other cases, several criteria are to be optimized and some are non differentiable and/or non convex. A large set of parameters, sometimes of different types (boolean, integer, real or functional), are to be taken into account, as well as constraints of various types (physical and geometrical, in particular). Additionally, today's most interesting optimization pre-industrial projects are multi-disciplinary, and this complicates the mathematical, physical and numerical settings. Developing *robust optimizers* is therefore an essential objective to make progress in this area of scientific computing.

In the area of numerical optimization algorithms, the project aims at adapting classical optimization methods (simplex, gradient, quasi-Newton) when applicable to relevant engineering applications, as well as developing and testing less conventional approaches such as Evolutionary Strategies (ES), including Genetic or Particle-Swarm Algorithms, or hybrid schemes, in contexts where robustness is a very severe constraint.

In a different perspective, the heritage from the former project Sinus in Finite-Volumes (or -Elements) for nonlinear hyperbolic problems, leads us to examine cost-efficiency issues of large shape-optimization applications with an emphasis on the PDE approximation; of particular interest to us:

- best approximation and shape-parameterization,
- convergence acceleration (in particular by multi-level methods),
- model reduction (e.g. by *Proper Orthogonal Decomposition*),
- parallel and grid computing; etc.

3.3. Geometrical optimization

Jean-Paul Zolesio and Michel Delfour have developed, in particular in their book [6], a theoretical framework for for geometrical optimization and shape control in Sobolev spaces.

In preparation to the construction of sound numerical techniques, their contribution remains a fundamental building block for the functional analysis of shape optimization formulations.

3.4. Integration platforms

Developing grid, cloud and high-performance computing for complex applications is one of the priorities of the IST chapter in the 7th Framework Program of the European Community. One of the challenges of the 21st century in the computer science area lies in the integration of various expertise in complex application areas such as simulation and optimization in aeronautics, automotive and nuclear simulation. Indeed, the design of the reentry vehicle of a space shuttle calls for aerothermal, aerostructure and aerodynamics disciplines which all interact in hypersonic regime, together with electromagnetics. Further, efficient, reliable, and safe design of aircraft involve thermal flows analysis, consumption optimization, noise reduction for environmental safety, using for example aeroacoustics expertise.

The integration of such various disciplines requires powerful computing infrastructures and particular software coupling techniques. Simultaneously, advances in computer technology militate in favor of the use of massively parallel clusters including hundreds of thousands of processors connected by high-speed gigabits/sec networks. This conjunction makes it possible for an unprecedented cross-fertilization of computational methods and computer science. New approaches including evolutionary algorithms, parameterization, multi-hierarchical decomposition lend themselves seamlessly to parallel implementations in such computing infrastructures. This opportunity is being dealt with by the OPALE project since its very beginning. A software integration platform has been designed by the OPALE project for the definition, configuration and deployment of multidisciplinary applications on a distributed heterogeneous infrastructure. Experiments conducted within European projects and industrial cooperations using CAST have led to significant performance results in complex aerodynamics optimization test-cases involving multi-elements airfoils and evolutionary algorithms, i.e. coupling genetic and hierarchical algorithms involving game strategies [70].

The main difficulty still remains however in the deployment and control of complex distributed applications by the end-users. Indeed, the deployment of the computing infrastructures and of the applications in such environments still requires specific expertise by computer science specialists. However, the users, which are experts in their particular application fields, e.g. aerodynamics, are not necessarily experts in distributed and grid computing. Being accustomed to Internet browsers, they want similar interfaces to interact with high-performance computing and problem-solving environments. A first approach to solve this problem is to define component-based infrastructures, e.g. the Corba Component Model, where the applications are considered as connection networks including various application codes. The advantage is here to implement a uniform approach for both the underlying infrastructure and the application modules. However, it still requires specific expertise not directly related to the application domains of each particular user. A second approach is to make use of web services, defined as application and support procedures to standardize access and invocation to remote support and application codes. This is usually considered as an extension of Web services to distributed infrastructures. A new approach, which is currently being explored by the OPALE project, is the design of a virtual computing environment able to hide the underlying high-performance-computing infrastructures to the users. The team is exploring the use of distributed workflows to define, monitor and control the execution of high-performance simulations on distributed clusters. The platform includes resilience, i.e., fault-tolerance features allowing for resource demanding and erroneous applications to be dynamically restarted safely, without user intervention.

4. Application Domains

4.1. Aeronautics and space

The demand of the aeronautical industry remains very strong in aerodynamics, as much for conventional aircraft, whose performance must be enhanced to meet new societal requirements in terms of economy, noise (particularly during landing), vortex production near runways, etc., as for high-capacity or supersonic aircraft of the future. Our implication concerns shape optimization of wings or simplified configurations.

Our current involvement with Space applications relates to software platforms for code coupling.

4.2. Mechanical industry

A new application domain related to the parameter and shape optimization of mechanical structures is under active development. The mechanical models range from linear elasticity of 2D or 3D structures, or thin shells, to nonlinear elastoplasticity and structural dynamics. The criteria under consideration are multiple: formability, stiffness, rupture, fatigue, crash, and so on. The design variables are the thickness and shape, and possibly the topology, of the structures. The applications are performed in collaboration with world-leading industrials, and involve the optimization of the stamping process (Blank Force, Die and Tools shapes) of High Performance steel structures as well as the optimal design of structures used for packaging purposes (cans and sprays under high pressure). Our main contribution relies on providing original and efficient algorithms to capture Pareto fronts, using smart meta-modelling, and to apply game theory approaches and algorithms to propose stable compromise solutions (e.g. Nash equilibria).

4.3. Electromagnetics

In the context of shape optimization of antennas, we can split the existing results in two parts: the two-dimensional modeling concerning only the specific transverse mode TE or TM, and treatments of the real physical 3-D propagation accounting for no particular symmetry, whose objective is to optimize and identify real objects such as antennas.

Most of the numerical literature in shape optimization in electromagnetics belongs to the first part and makes intensive use of the 2-D solvers based on the specific 2-D Green kernels. The 2-D approach for the optimization of *directivity* led recently to serious errors due to the modeling defect. There is definitely little hope for extending the 2-D algorithms to real situations. Our approach relies on a full analysis in unbounded domains of shape sensitivity analysis for the Maxwell equations (in the time-dependent or harmonic formulation), in particular, by using the integral formulation and the variations of the Colton and Kreiss isomorphism. The use of the France Telecom software SR3D enables us to directly implement our shape sensitivity analysis in the harmonic approach. This technique makes it possible, with an adequate interpolation, to retrieve the shape derivatives from the physical vector fields in the time evolution processes involving initial impulses, such as radar or tomography devices, etc. Our approach is complementary to the “automatic differentiation codes” which are also very powerful in many areas of computational sciences. In Electromagnetics, the analysis of hyperbolic equations requires a sound treatment and a clear understanding of the influence of space approximation.

4.4. Biology and medicine

A particular effort is made to apply our expertise in solid and fluid mechanics, shape and topology design, multidisciplinary optimization by game strategies to biology and medicine. Two selected applications are privileged: solid tumors and wound healing.

Opale's objective is to push further the investigation of these applications, from a mathematical-theoretical viewpoint and from a computational and software development viewpoint as well. These studies are led in collaboration with biologists, as well as image processing specialists.

4.5. Traffic flow

The modeling and analysis of traffic phenomena can be performed at a macroscopic scale by using partial differential equations derived from fluid dynamics. Such models give a description of collective dynamics in terms of the spatial density $\rho(t,x)$ and average velocity $v(t,x)$. Continuum models have shown to be in good agreement with empirical data. Moreover, they are suitable for analytical investigations and very efficient from the numerical point of view. Finally, they contain only few variables and parameters and they can be very versatile in order to describe different situations encountered in practice.

Opale's research focuses on the study of macroscopic models of vehicular and pedestrian traffic, and how optimal control approaches can be used in traffic management. The project opens new perspectives of interdisciplinary collaborations on urban planning and crowd dynamics analysis.

4.6. Multidisciplinary couplings

Our expertise in theoretical and numerical modeling, in particular in relation to approximation schemes, and multilevel, multi-scale computational algorithms, allows us to envisage to contribute to integrated projects focused on disciplines other than, or coupled with fluid dynamics, such as structural mechanics, electromagnetics, biology and virtual reality, image processing, etc in collaboration with specialists of these fields. Part of this research is conducted in collaboration with ONERA.

5. Software

5.1. NUM3SIS

Participants: Régis Duvigneau [correspondant], Nora Aïssiouene, Babett Lekouta.

NUM3SIS (http://num3sis.inria.fr) is a modular platform devoted to scientific computing and numerical simulation. It is not restricted to a particular application field, but is designed to host complex multidisciplinary simulations. Main application fields are currently Computational Fluid Dynamics (CFD), Computational Electro-Magnetics (CEM, in collaboration with Nachos Project-Team) and pedestrian traffic simulation.
The most important concept in NUM3SIS is the concept of node. It is a visual wrapper around derivatives of fundamental concepts such as data, algorithm or viewer. Atomic nodes are provided for convenience in order to manipulate computational data (such as grids or fields), apply computational methods (such as the building of a finite-element matrix or the construction of a finite-volume flux) and visualize computational results (such as vector or tensor fields, on a screen or in an immersive space). For a given abstract node, different implementations can be found, each of them being embedded in a plugin system that is managed by a factory.

The second important concept in NUM3SIS is the concept of composition. It consists of the algorithmic pipeline used to link the nodes together. The use of these two concepts, composition and nodes, provides a highly flexible, re-usable and efficient approach to develop new computational scenarii and take benefit from already existing tools. This is a great advantage with respect to classical monolithic softwares commonly used in these fields.

This work is being carried out with the support of two engineers in the framework of an ADT (Action de Développement Technologique) program.

5.2. FAMOSA

Participant: Régis Duvigneau [correspondant].

Opale team is developing the software platform FAMOSA (C++), that is devoted to multidisciplinary design optimization in engineering. It integrates the following components:

- an optimization library composed of various algorithms : several descent methods from steepest-descent method to quasi-Newton BFGS method (deterministic, smooth), the Multi-directional Search Algorithm (deterministic, noisy), the Covariance Matrix Adaption Evolution Strategy (semi-stochastic, multi-modal) and the Efficient Global Optimization method (deterministic, multi-modal). It also contains the Pareto Archived Evolution Strategy to solve multi-objective optimization problems ;
- an evaluation library managing the performance estimation process (communication with external simulation tools) ;
- a metamodel library that contains tools to build a database and kriging models that are used to approximate the objective function for different purposes;
- a scenario library that allows to use the previous components to achieve various tasks:
  - Construct a design of experiments ;
  - Construct a metamodel ;
  - Find the design that minimizes a cost functional ;
  - Find the Pareto front for two cost functionals
  - Play a Nash game to find the equilibrium between two criteria ;
  - Apply a multiple gradient descent strategy to improve simultaneously two criteria.

The FAMOSA platform is employed by Opale Project-Team to test its methodological developments in multidisciplinary design optimization (MDO). The platform is also used by the Fluid Mechanics Laboratory at Ecole Centrale de Nantes and by the K-Epsilon company (http://www.k-epsilon.com) for hydrodynamic design applications. Moreover, it is presently tested by Peugeot Automotive industry for external aerodynamic design purpose.

5.3. Plugins for AXEL

Participants: Régis Duvigneau [correspondant], Louis Blanchard.

Opale team is developing plugins in the framework of the algebraic modeler Axel, in collaboration with GALAAD team. These developments correspond to two research axes :

- methods for isogeometric analysis and design. In particular, two simulation tools for heat conduction and compressible flows have been implemented, in conjunction with some deterministic and semi-stochastic optimization algorithms for optimum-shape design ;
- methods for geometrical modeling of bow shapes for trawler ships.

5.4. Integration platform for multidiscipline optimization applications

Participants: Toan Nguyen, Laurentiu Trifan.

A prototype software integration platform is developed and tested for multidiscipline optimization applications. It is based on a workflow management system called YAWL (http://www.yawlfoundation.org). The goal is to design, develop and assess high-performance distributed scientific workflows featuring resilience, i.e., fault-tolerance and exception-handling capabilities. The platform is used to experiment new resilience algorithms, including monitoring and management of application-level errors. Errors include time-outs and out of bounds data values. They can be added and modified by the users. The platform is tested against use-cases provided by the industry partners in the OMD2 project supported by the French Agence Nationale de la Recherche. For example, an optimization of a car air-conditioning pipe was implemented and deployed on the Grid5000 infrastructure. It also takes into account run-time errors related to resource consumption, e.g., memory overflow, to automatically and dynamically relocate the appplications tasks involved on the various clusters. This work is part of Laurentiu Trifan's PhD thesis that is to be defended in 2013. (See Fig. 1.)

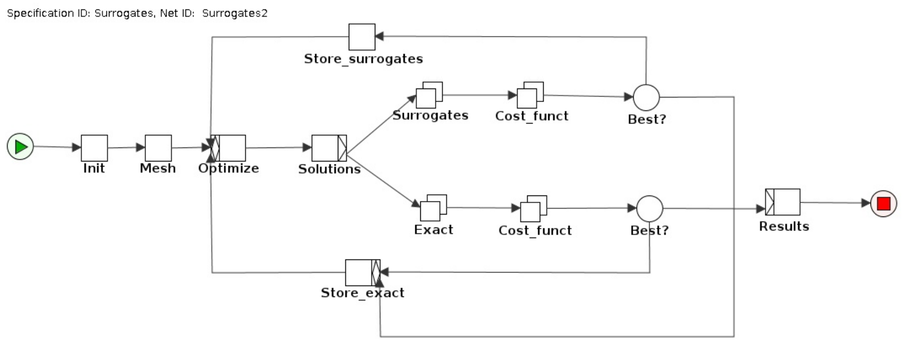


Figure 1. Testcase deployment on the Grid5000 infrastructure.

6. New Results

6.1. Mathematical analysis and control of macroscopic traffic flow models

6.1.1. Vehicular traffic

Participants: Maria Laura Delle Monache, Paola Goatin, Mauro Garavello [Piedmont University, Italy], Alexandre Bayen [UC Berkeley, CA, USA].

The activity in traffic flow modeling has being reinforced by the creation of the Associated Team ORESTE between OPALE and the UC Berkeley teams Mobile Millennium and Integrated Corridor Management (ICM) lead by Prof. A. Bayen (see http://www-sop.inria.fr/members/Paola.Goatin/ORESTE/index.html). In this framework, three PhD students from US visited Inria during August and September, and M.L. Delle Monache spent two and half months at UC Berkeley.

During this first year of common research we proposed a new junction model for ramp-metering in the continuous and discrete settings. We focused on a junction consisting in a mainline, an on-ramp and an off-ramp. In particular, we introduced a coupled PDE-ODE model, in which the PDE describes the evolution of the cars flow on the mainline and the ODE describes the evolution of the queue length on the on-ramp, modeled by a buffer, which ensures that boundary conditions are satisfied in strong sense. At the junction we imposed the maximization of the outgoing flux together with a fixed priority parameter for incoming roads. We were able to prove existence and uniqueness of the solution of the corresponding Riemann problem. This approach has then been extended to networks and discretized using the Godunov scheme. The corresponding discrete optimization problem has been solved using the Adjoint Method and it is now being implemented into a MATLAB code. This model will serve as starting point for a subsequent model for optimal rerouting, which includes multi-commodity flow and partial control.

Besides that, we studied a a coupled PDE-ODE system modeling the interaction of a large slow moving vehicle with the surrounding traffic flow. The model consists in a scalar conservation law with moving density constraint describing traffic evolution coupled with an ODE for the slow vehicle trajectory. The constraint location moves due to the surrounding traffic conditions, which in turn are affected by the presence of the slower vehicle, thus resulting in a strong non-trivial coupling. The existence result is given in [60].

The paper [41] is devoted to the study of a traffic flow model on a network composed by an arbitrary number of incoming and outgoing arcs connected together by a node with a buffer. We define the solution to the Riemann problem at the node and we prove existence and well posedness of solutions to the Cauchy problem.

6.1.2. Crowd motion

Participants: Nora Aïssiouene, Christophe Chalons [LJLL, UP7], Régis Duvigneau, Paola Goatin, Matthias Mimault, Massimiliano D. Rosini [ICM, Warsaw University, Poland], Nicolas Seguin [LJLL, UPMC], Monika Twarogowska.

The activity on in pedestrian flow modeling is reinforced by the doctoral thesis of M. Mimault, started in October, and the enrollment of M. Twagorowska on a post-doctoral position.

Concerning crowd motion modeling, we are interested in the optimization of facilities design, in order to maximize pedestrian flow and avoid or limit accidents due to panic situations. To this aim, we are now studying first and second order macroscopic models for crowd movements consisting in one or two scalar conservation law accounting for mass conservation and momentum balance, coupled with an Eikonal equation giving the flux direction depending on the density distribution. From the theoretical point of view, and as a first step, we are studying the problem in one space dimension (for applications, this case corresponds to a crowd moving in a corridor). In collaboration with M. Rosini (supported by the project CROM3, funded by the PHC Polonium 2011), we have established entropy conditions to select physically relevant solutions, and we have constructed explicit solutions for some simple initial data (these results are presented in [40]). We are now studying existence of solutions of the corresponding initial boundary value problem, using the wave-front tracking approach. In this framework, M. Mimault's internship was devoted to develop a MATLAB code based on wave-front tracking to compute the solutions of Hughes' model of pedestrian motion with generalized running cost. This model displays a non-classical dynamic at the splitting point between the two directions of motion. The wave-front tracking scheme provides us with reference solutions to test numerically the convergence of classical finite volume schemes, which do not treat explicitly the dynamics at the turning point (see [66]). The code can be downloaded at the following URL: http://www-sop.inria.fr/members/Paola.Goatin/wft.html

From the numerical point of view, we are implementing some macroscopic models in two space dimensions on triangular meshes on the Num3sis platform. This was partly done by N. El-Khatib (postdoc at Inria from January to August 2011), and is now being completed by M. Twarogowska, with the support of N. Aïssiouene. This will provide a performing numerical tool to solve the related optimization problems arising in the optimization of facilities design, such as the position and size of an obstacle in front of (before) a building exit in order to maximize the outflow through the door and avoid or limit over-compression.

Finally, in collaboration with C. Chalons and N. Seguin, we have generalized the results on conservation laws with local flux constraint obtained in [3], [5] to general flux functions and nonclassical solutions arising for example in pedestrian flow modeling. We first define the constrained Riemann solver and the entropy condition, which singles out the unique admissible solution. We provide a well posedness result based on wave-front tracking approximations and Kruzhkov doubling of variable technique. We then provide the framework to deal with nonclassical solutions and we propose a “front-tracking” finite volume scheme allowing to sharply capture classical and nonclassical discontinuities. Numerical simulations illustrating the Braess paradox are presented as validation of the method. The results are collected in [65].

The above researches were partially funded by the ERC Starting Grant "TRAM3 - Traffic management by macroscopic models".

6.2. Optimum design and control in fluid dynamics and its couplings

In computational sciences for physics and engineering, Computational Fluid Dynamics (CFD) are playing one of the major roles in the scientific community to foster innovative developments of numerical methodologies. Very naturally, our expertise in compressible CFD has led us to give our research on numerical strategies for optimum design a particular, but not exclusive focus on fluids.

The framework of our research aims to contribute to numerical strategies for PDE-constrained multi-objective optimization, with a particular emphasis on CPU-demanding computational applications in which the different criteria to be minimized (or reduced) originate from different physical disciplines that share the same set of design variables. These disciplines are often fluids, as a primary focus, coupled with some other discipline, such as structural mechanics.

Our approach to *competitive optimization* is based on a particular construction of *Nash games*, relying on a *split of territory* in the assignment of individual strategies. A methodology has been proposed for the treatment of two-discipline optimization problems in which one discipline, the primary discipline, is preponderant, or fragile. Then, it is recommended to identify, in a first step, the optimum of this discipline alone using the whole set of design variables. Then, an orthogonal basis is constructed based on the evaluation at convergence of the Hessian matrix of the primary criterion and constraint gradients. This basis is used to split the working design space into two supplementary subspaces to be assigned, in a second step, to two virtual players in competition in an adapted Nash game, devised to reduce a secondary criterion while causing the least degradation to the first. The formulation has been proved to potentially provide a set of Nash equilibrium solutions originating from the original single-discipline optimum point by smooth continuation, thus introducing competition gradually. This approach has been demonstrated over a test-case of aero-structural aircraft wing shape optimization, in which the eigensplit-based optimization reveals clearly superior [38].

While the two-discipline method is currently being applied to various complex physical multi-objective situations (see in particular 6.2.4, 6.2.5, 6.2.6), the method has been extended to situations involving more than two objectives when the initial point is Pareto-optimal. Then, a particular convex combination of the criteria is locally stationary, and the two-discipline strategy can be applied using this combination as preponderant criterion, and a particular other criterion as secondary one. Whence, the proposed split of territory produces a continuum of Nash equilibrium points *tangent* to the Pareto set. This theoretical result has been illustrated in the context of a simpler numerical experiment by E. Baratchart during his internship [4], see Fig. 2.

Our approach to *cooperative optimization* is based on a result of convex analysis established for a general unconstrained mult-iobjective problem in which all the gradients are assumed to be known. The theorem [39] states that in the convex hull of the gradients, there exists a unique vector of minimal norm, ω; if it is nonzero, the vector ω is a descent direction common to all criteria; otherwise, the current design point is Pareto-optimal. This result led us to generalize the classical steepest-descent algorithm by using the vector ω as search direction. We refer to the new algorithm as the multiple-gradient descent algorithm (MGDA). The MGDA yields to a point on the Pareto set, at which a competitive optimization phase can possibly be launched on the basis of the local eigenstructure of the different Hessian matrices. This general formulation fosters several connected studies detailed in 6.2.1.

6.2.1. Multiple-Gradient Descent Algorithm (MGDA)

Participants: Jean-Antoine Désidéri, Régis Duvigneau, Matteo Giacomini, Adrien Zerbinati.

6.2.1.1. Theory and numerical experimentation of the MGDA construction

In multi-objective optimization, the knowledge of the Pareto set provides valuable information on the reachable optimal performance. A number of evolutionary strategies (PAES, NSGA-II, etc), have been proposed in the literature and proved to be successful to identify the Pareto set. However, these derivative-free algorithms are very demanding in terms of computational time. Today, in many areas of computational sciences, codes are developed that include the calculation of the gradient, cautiously validated and calibrated.

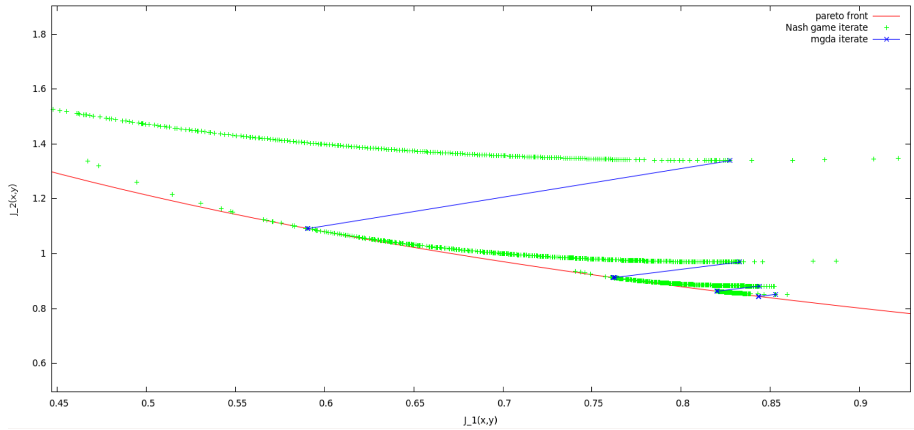


Figure 2. Combination of cooperative and competitive optimization algorithms: in red the Pareto set, in blue MGDA steps directed to the Pareto set, in green steps by Nash games with split of territory tangent to the Pareto set.

In the original report [14], and in [39], we have introduced the notion of *Pareto-stationarity*, and given a first proof that it was the natural necessary condition for Pareto-optimality when the objective-functions are locally smooth in some open domain about the design-point. This report has been revised to provide a more rigorous, and extended proof. In particular, in the revised version [14] (version 3, 2012), the number of objective-functions n and the dimension of the design space compare arbitrarily. The objective-functions are assumed to be locally convex.

Additionally, we had established that MGDA converges to Pareto-stationary design-points. This had been confirmed by numerical experiments in which MGDA had been tested over a number of classical multi-objective optimization test-cases, and found successful to converge to Pareto-optimal solutions in situations of either convex or concave Pareto sets. Additionally, MGDA [57] and PAES [69] were found to have complementary merits, making a hybrid method promising.

The method was tested successfully in a domain partition model problem in which the sub-solutions to the Poisson equation are matched at the interfaces by minimization of the integral along the interface of the squared normal-derivative jump. This academic exercise has permitted to illustrate the importance of applying an appropriate scaling to the gradients prior to calculating the descent direction [61] [47]. This has led us to define, a novel form of MGDA, consisting of a direct algorithm [62] based on a Gram-Schmidt orthogonalization conducted with a special normalization. The direct method was found more accurate and more efficient. Subsequently, we proposed two enhancements [63], the first to define the order in which the gradients are introduced in the Gram-Schmidt process uniquely and to interrupt the process as soon as the current estimate of the search direction is proved to satisfy the descent property, and the second to optimally scale the gradients when the Hessians are known, or approximated (e.g. by the BFGS estimate).

6.2.1.2. Meta-model-assisted CFD optimization by MGDA

Using MGDA in a multi objective optimization problem requires the evaluation of a large number of points with regard to criteria, and their gradients. In the particular case of a CFD problems, each point evaluation is very costly since it involves a flow computation, possibly the solution of an adjoint-equation. To alleviate this difficulty, we have proposed to construct meta-models of the functionals of interest (lift, drag, etc) and to calculate approximate gradients by local finite differences. These meta-models are updated throughout the convergence process to the evaluation of the new design points by the high-fidelity model, here the 3D compressible Euler equations.

This variant of MGDA has been tested successfully over a problem of external aerodynamic optimum-shape design of an aircraft wing consisting of reducing wave-drag, and augmenting lift. After only a few cycles of database updates, the Pareto front visibly forms, and this result is achieved at a very moderate computational cost. This variant has been extended successfully to an internal flow optimization problem related to an automobile air-conditioning system and governed by the Navier-Stokes equations [55]. This more difficult problem has been proposed by Renault within the OMD2 ANR project.

6.2.1.3. Exact shape gradients

MGDA has successfully been tested over a two-objective optimization problem governed by two-dimensional elasticity. The deformation of a plate is calculated using an isogeometric approximation (see 6.6) and compliance derived from it. The exact parametric shape gradient is calculated, yielding the gradient of the objective function in two antagonistic situations differing by the loading. Pareto-fronts are thus identified.

6.2.1.4. Perspectives

MGDA offers the possibility to handle in a rational way several objective-functions for which gradients are known or approximated concurrently. This potential opens methodological paths to several themes of interest in high-fidelity simulation-based optimization: optimization of complex systems whose performance is evaluated w.r.t. several criteria originating from different, coupled disciplines; optimization under uncertainties, by introducing sensitivities as additional objectives; optimization of time-dependent systems, such as optimization of flow-control devices that generate a periodic flow (see next subsection), by converting the problem into a multi-point problem by time-discretization of the time and parameter-dependent functional; etc.

6.2.2. Flow control

Participants: Jean-Antoine Désidéri, Régis Duvigneau, Jérémie Labroquère.

Shape optimization methods are not efficient to improve the performance of fluid systems, when the flow is characterized by a strong unsteadiness related to a massive detachment. This is typically the case for the flow around an automotive body or a wing in stall condition. To overcome this difficulty, flow control strategies are developed, that aim at manipulating vortex dynamics by introducing some active actuators, such as periodic blowing/suction jets. In this context, the choice of the control parameters (location, amplitude, frequency) is critical and not straightforward. Therefore, a numerical study is conducted to i) improve the understanding of controlled flows ii) develop a methodology to determine optimal control parameters by coupling the controlled flow simulation with optimization algorithms. Two research axes have been considered :

- the resolution of the unsteady sensitivity equations derived from the state equations, to exhibit the dependency of the flow dynamics with respect to the control ;
- the optimization of control parameters using a statistical metamodel-based strategy[37].

In this perspective, unsteady Reynolds Averaged Navier-Stokes equations are considered, with the Spalart-Allmaras turbulence closure. A numerical model for synthetic jets has been implemented to simulate the actuation[48], based on imposed velocity boundary conditions. Particular developments have then be carried out to include a noise term into Gaussian Process metamodels, which is used to filter errors arising from unsteady simulations/citelabroquere:hal-00742940. First results have demonstrated the feasibility of the proposed method. A systematic assessment of modeling and numerical errors is in progress, for a backward facing step test-case, with the objective of controlling the re-attachment point location.

This activity is conducted in collaboration with the CFD team of Ecole Centrale de Nantes.

6.2.3. Robust design

Participants: Jean-Antoine Désidéri, Régis Duvigneau, Daïgo Maruyama.

This work aims to develop robust design tools for aircraft design w.r.t. aerodynamic performance subject to uncertainties arising from geometrical features and fluctuations of inflow conditions. The robust design process is considered as a multi-objective optimization problem consisting of minimizing statistical quantities such as mean and variance of a cost function, typically the drag coefficient under lift constraint. MGDA is used for this purpose.

At present, analytical test cases have been tested, confirming the validity of our approach to identify the Pareto set.

One aspect of the problem is that the evaluation of these statistics and performing their optimization is very cost demanding. One solution could be, for aerodynamic design, to identify the most important variables to be treated as uncertain, possibly by the ANOVA approach, and construct adequate meta-models.

6.2.4. Aero-structural optimization

Participants: Gérald Carrier [Research Engineer, ONERA/DAAP], Jean-Antoine Désideri, Imane Ghazlane.

In industry, aircraft wings are designed by accounting for several multidisciplinary couplings. Certainly of greatest importance is the coupling, or concurrency, between aerodynamic optimization and structural design. At ONERA, in the former thesis of M. Marcelet, the aerodynamic gradient has been extended to account for (the main terms of) static fluid-structure interaction, commonly referred to as the "aeroelastic gradient".

In her thesis, I. Ghazlane has extended M. Marcelet's work to take into account, in the aeroelastic gradient, the terms originating from the differentiation of the wing-structural model. In this development, the wing structure is treated as an equivalent Euler-Bernoulli beam. These formal extensions have been validated by an extensive experimentation. Additionally, special post-processing procedures have been set up to evaluate accurately the various physical contributions to drag. As a result, a realistic aircraft wing optimization has been conducted using a configuration provided by Airbus France as initial design. I. Ghazlane defended successfully her doctoral thesis thesis in December 2012 [34].

Besides, I. Ghazlane has realized a two-objective optimization (drag and mass reduction) via a Nash game using our optimization platform FAMOSA. These results will be included in a common publication on Nash games in preparation.

6.2.5. Sonic boom reduction

Participants: Gérald Carrier [Research Engineer, ONERA/DAAP], Jean-Antoine Désideri, Andrea Minelli, Itham Salah El Din [Research Engineer, ONERA/DAAP].

When an aircraft flies at supersonic speed, it generates at ground level an N-shaped shock structure which can cause serious environmental damage ("sonic boom"). Thus a problem of interest in aerodynamic optimization is to design such an aircraft to reduce the intensity of the sonic boom while maintaining the aerodynamic performance (drag minimization under lift constraint). Andrea Minelli aimed at contributing to this two-discipline optimization problem. In the first part of his work, an inverse problem has been formulated and solved for "shaped sonic boom" and found in excellent agreement with the George-Seebass-Darden theory [68] for the calculation of the Whitham function corresponding to the lowest-boom (axisymmetric) shape. Method and results for more general geometries have been presented internationally in [50].

Besides, aero-acoustic optimizations have been realized successfully by coupling the aerodynamic optimizer (based on Euler calculations by the elsA software) with the sonic-boom computation in a Nash game formulation. These experiments, conducted with our optimization platform FAMOSA, have demonstrated that starting from the shape optimized aerodynamically, one could retrieve smoothly a shape corresponding to nearly-optimal sonic-boom reduction. These results will be included in a common publication on Nash games in preparation.

6.2.6. Helicopter rotor blade optimization in both situations of hovering and forward flight

Participants: Michel Costes [Research Engineer, ONERA/DAAP], Jean-Antoine Désideri, Arnaud Le Pape [Research Engineer, ONERA/DAAP], Enric Roca Leon.

E. Roca Leon is conducting a CIFRE thesis supported by EUROCOPTER (Marignane) at ONERA DAAP. This thesis follows the doctoral thesis of A. Dumont in which the adjoint-equation approach was used to optimize a rotor blade in hovering flight. The goal of this new thesis is to solve a two-objective optimization problem in which the hovering-flight criterion is considered preponderant, but a new criterion that takes into account the forward-flight situation is also introduced, concurrently. The second criterion is the power necessary to maintain the forward motion. The first phase of thesis work has been devoted to the set up of a hierarchy of models from low to high fidelity, in order to calibrate appropriate functional criteria. In the current work, actual two-objective optimizations are conducted via our Nash game approach to competitive optimization with territory splitting based on reduced Hessian diagonalization. A first successful experiment has been realized in which the twist angle along the wing is optimized to reduce the power in forward motion while maintaining sub-optimality of the drag in hover. These results have been accepted for presentation at a forthcoming AIAA Conference, and will also contribute to a common publication on Nash games in preparation.

6.2.7. Optimum design in naval hydrodynamics

Participants: Régis Duvigneau, Louis Blanchard.

Naval hydrodynamics field has recently shown a growing interest for optimum design methods. The computational context is especially complex because it implies unsteady two-phase turbulent flows, with possibly very high Reynolds number (up to 10^9). The use of automated design optimization methods for such problems requires new developments to take into account the large CPU time necessary for each simulation and the specificity of the geometries considered.

In collaboration with GALAAD Project-Team, some developments have been initiated on the geometrical modelling of hull shapes by parametric surfaces. The objective was to be able to modify existing hull shapes by controlling a small number of parameters, that are meaningful for naval architects. We have considered as test-case the bow shape for trawler ships[58]. As a second step, an optimum shape procedure has been set up, based on a metamodel-based optimizer, the developed CAD model and the simulation tool for free-surface flows provided by K-Epsilon company. The objective was to reduce the wave drag of a trawler ship by adding a bow, whose parameters are optimized.

6.3. Optimum design in structural mechanics

6.3.1. Shape Optimization in Multidisciplinary Non-Linear Mechanics

Participants: Aalae Benki, Jean-Antoine Désidéri, Abderrahmane Habbal.

In collaboration with the ArcelorMittal's Center for Research in Automotive and Applications, we study the multidisciplinary shape and parameter design of highly non linear mechanical 2D and 3D structures. We have developed methods adapted to the approximation of Pareto Fronts such as Normal Boundary Intersection NBI and Normalized Normal Constraint Method NNCM. Due to the time consuming cost evaluation, the use of cheap to evaluate surrogate models is mandatory. We have studied the consistency of the approach NBI or NNCM plus surrogates, which turned out to be successful for a broad panel of standard mathematical benchmarks. The coupling is successfully applied to a small scale industrial case, namely the shape optimization of a can bottom vis à vis dome reversal pressure and dome growth criteria. We have then defined a Nash game between criteria where the latter are approximated by the RBF metamodels. First, we validated the computation of a Nash equilibrium for mathematical functions, then we computed Nash equilibria for the small scale industrial case of the shape optimization of the can bottom. In both cases, only arbitrary territory splitting was used. Application to large scale 3D industrial problems, and the study of intelligent territory splitting algorithms is ongoing.

6.3.2. Optimization of Addendum Surfaces in Stamping

Participants: Fatima Zahra Oujebbour, Jean-Antoine Désidéri, Abderrahmane Habbal.

Within the OASIS Consortium (ArcelorMittal, ErDF, Inria, UTC, EURODECISION, ESILV, NECS, Delta-CAD, SCILAB-DIGITEO), Opale Project leads the Optimization task. Our aim is to develop decentralized decision-making algorithms dedicated to find efficient solutions (Pareto optimal) in a complex multidisciplinary framework (forming, stamping, welding non-linear processes, spring-back, vibration, in-function linear processes, crash and fatigue non linear and non differentiable processes) for several (between three and five) criteria. An important difficulty when trying to identify the Pareto Front, even when using adapted methods such the Normal Boundary Intersection, is that the criteria involved (thanks to the high nonlinearity in the mechanical models) exhibit many local optima. So one must use global optimization methods. We have studied the hybrid approach Simulated Annealing with Simultaneous Perturbation SASP for a suite of mathematical test-cases. To envisage the application of our method to the complex CPU time consuming stamping process, we lead an intermediate phase dedicated to the validation of the SASP method for the minimization of the spring-back that follows the stamping of a metal sheet, the design variable being the thickness distribution.

We have successfully applied the NBI approach coupled to the hybrid SA+SPSA minimizer (Simulated Annealing with local search using the Simultaneous Perturbation Stochastic Approximation) to capture the Pareto front of a simple cross stamping of a high performance steel sheet. The use of cubic spline approximation of the costs (spring-back and failure criteria) turned out to be more reliable than e.g. a krigeage method.

6.4. Application of shape and topology design to biology and medicine

6.4.1. Mathematical modeling of dorsal closure DC

Participants: Abderrahmane Habbal, Luis Almeida [University of Nice-Sophia Antipolis], Patrizia Bagnerini [Genova University], Fanny Serman [University of Nice-Sophia Antipolis], Stéphane Noselli [University of Nice-Sophia Antipolis], Glenn Edwards [Duke University].

A mathematical model for simulation of actin cable contraction, during wound closure for Drosophila embryo, which contains an extra term in addition to the curvature flow is developed. The basic mathematical model introduced and validated in [2] is extended in order to include the non-homogeneous wound healing or non-homogeneous dorsal closure The new model is obtained by adding extra terms that describe the particular process we want to model (lamellipodial crawling, granulation tissue contraction, extension of actin protrusions, epithelial resistance, etc.). We concentrate on the treatment of non-homogeneous forces, i.e. non-constant boundary terms which can be associated with a non-uniform cable, internal pull or zipping force due to the non-uniformity of the biological or physical properties of the boundary cells or of the connective tissue [35].

We also consider a particular yet major aspect of wound healing, namely the one related to the movement of wounded epithelial cell monolayers. The epithelial monolayer cell population, also referred to as cell-sheet, can be seen as a 2 dimensional structure, although it is well known that apical and basal sites play distinctive important roles during the migration, as well as the substrate itself. Immediately after a wound is created, the cells start to move in order to fill in the empty space. This movement, the wound closure, is a highly-coordinated collective behavior yielding a structured cohesive front, the wound leading edge. Even though wound closure involves biochemical and biomechanical processes, still far from being well understood, which are distributed over the whole monolayer, much specific attention was paid to the leading edge evolution, seen as the front of a traveling wave of the cell density function. We show that, for non inhibited wound assays, closure occurs at constant speed of the leading edge, a fact that is commonly shared by biologists and biomathematicians. But we also show that the leading edge may exhibit accelerated profiles, and that when inhibited, then the F-KPP has poor performances in modeling the leading edge dynamics.

6.5. Particular applications of simulation methods

6.5.1. Hermitian interpolation under uncertainties

Participants: Jean-Antoine Désideri, Manuel Bompard [Doctoral Student, ONERA/DSNA until December 2011; currently post-doctoral fellow in Toulouse], Jacques Peter [Research Engineer, ONERA/DSNA].

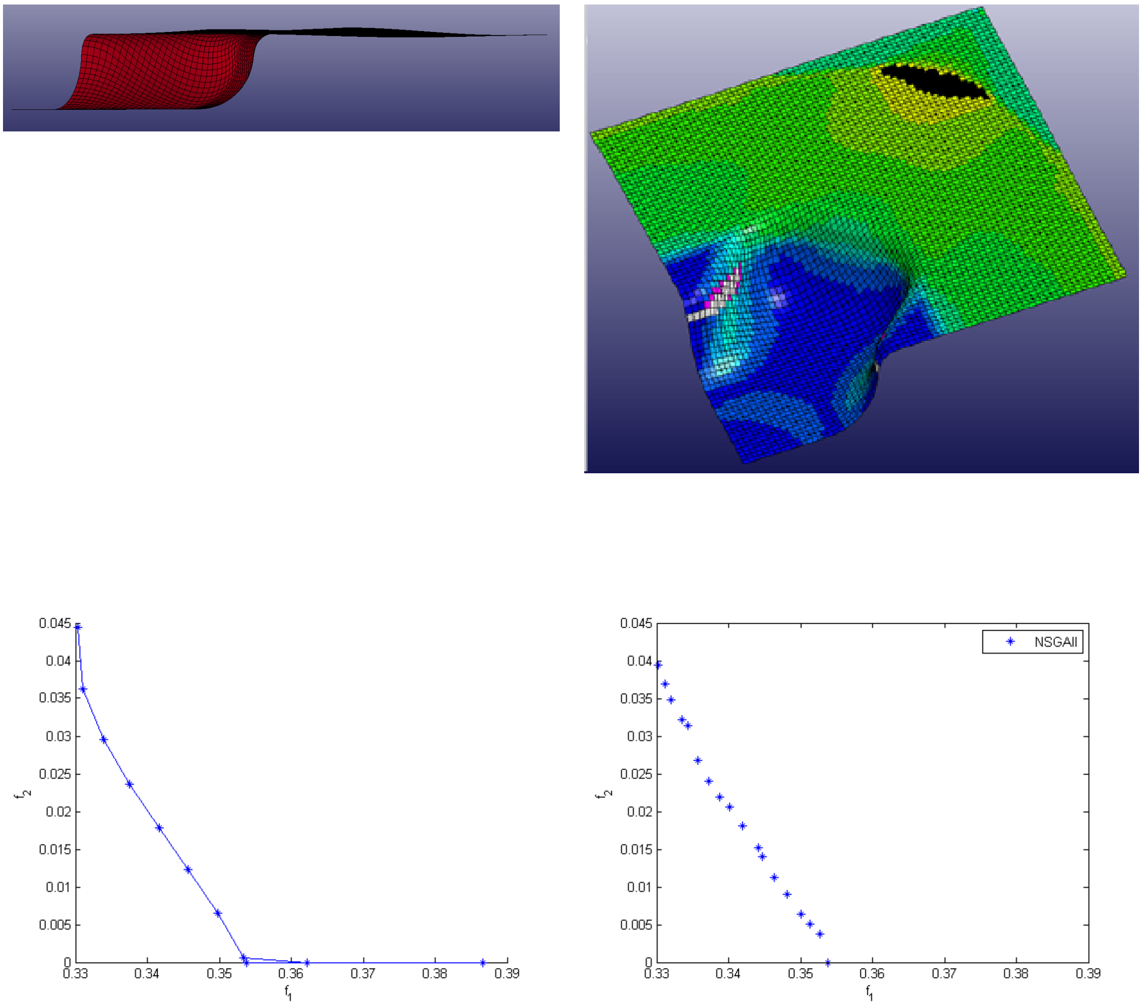
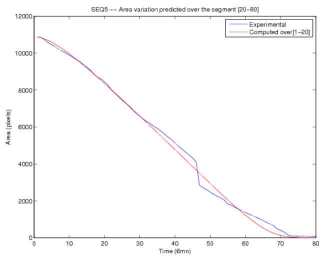
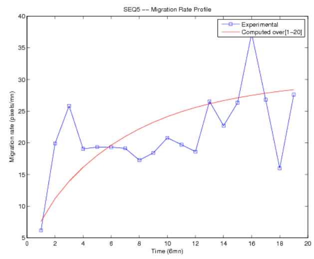
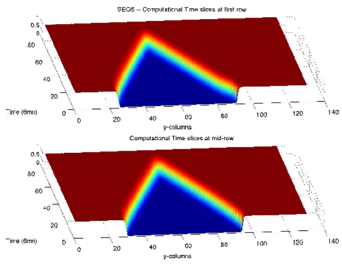


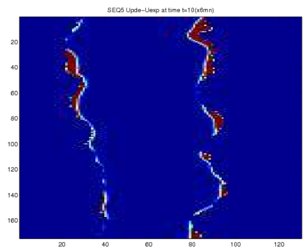
Figure 3. Multiobjective design of the stamping process of a high performance steel sheet. The costs are elastic spring-back (upper-left) and failure (upper-right). The Pareto front obtained by NNCM (lower-left) is compared to a NSGA-II one (lower-right).

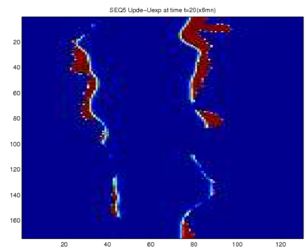


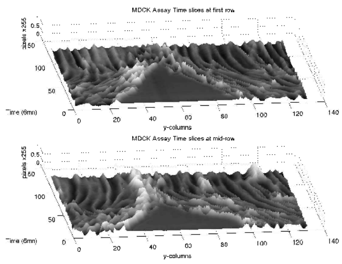




(a) (b) (c)







(d) (e) (f)

Figure 4. ***Sequence-5. Computational vs experimental wound evolution.*** *(a) Time variation of experimental (blue) versus computed (red) wound area (in pixels). (b) Time variation of the experimental (blue-dot) versus computed (red) migration rate (in pixels/mn). (c) Computed 3D XT view at first and mid-rows. (d) (e) (f) Traces of the difference between the experimental segmented and binarized cell-sheet images and the computed ones at different times, respectively 1hour (d), and 2hours (e) after the wounding. (f) Experimental 3D XT view at first and mid-rows.*

In PDE-constrained global optimization, iterative algorithms are commonly efficiently accelerated by techniques relying on approximate evaluations of the functional to be minimized by an economical, but lower-fidelity model (meta-model), in a so-called Design of Experiment (DoE). Various types of meta-models exist (interpolation polynomials, neural networks, Kriging models, etc). Such meta-models are constructed by pre-calculation of a database of functional values by the costly high-fidelity model. In adjoint-based numerical methods, derivatives of the functional are also available at the same cost, although usually with poorer accuracy. Thus, a question arises : should the derivative information, available but known to be less accurate, be used to construct the meta-model or ignored ? As a first step to investigate this issue, we have considered the case of the Hermitian interpolation of a function of a single variable, when the function values are known exactly, and the derivatives only approximately, assuming a uniform upper bound ε on this approximation is known. The classical notion of best approximation has been revisited in this context, and a criterion introduced to define the best set of interpolation points. This set was identified by either analytical or numerical means. If $n+1$ is the number of interpolation points, it is advantageous to account for the derivative information when $\varepsilon \leq \varepsilon_0$, where ε_0 decreases with n, and this is in favor of piecewise, low-degree Hermitian interpolants. In all our numerical tests, we have found that the distribution of Chebyshev points is always close to optimal, and provides bounded approximants with close-to-least sensitivity to the uncertainties [56].

6.5.2. Mesh qualification

Participants: Jean-Antoine Désideri, Maxime Nguyen, Jacques Peter [Research Engineer, ONERA/DSNA].

M. Nguyen Dinh is conducting a CIFRE thesis at ONERA supported by AIRBUS France. The thesis topic is the qualification of CFD simulations by anisotropic mesh adaption. Methods for refining the 2D or 3D structured mesh by node movement have been examined closely. Secondly, it is investigated how could the local information on the functional gradient $\|dJ/dX\|$ be exploited in a multi-block mesh context. This raises particular questions related to conservation at the interfaces.

Several criteria have been assessed for mesh qualification in the context of inviscid-flow simulation and are currently being extended to the RANS context. These results have been presented internationally in the communication [54] and the publication [44].

6.5.3. Hybrid meshes

Participants: Sébastien Bourasseau, Jean-Antoine Désideri, Jacques Peter [Research Engineer, ONERA/DSNA], Pierre Trontin [Research Engineer, ONERA/DSNA].

S. Bourasseau has started a CIFRE thesis at ONERA supported by SNECMA. The thesis is on mesh adaption in the context of hybrid meshes, that is, made of both structured and unstructured regions. Again, the aim is to exploit at best the function gradient provided by the adjoint-equation approach. Preliminary experiments have been conducted on geometries of stator blade yielding the sensitivities to global shape parameters.

The on-going developments are related to the extension to the hybrid-mesh context of the full shape gradient in a 3D Eulerian flow computation.

6.5.4. Data Completion Problems Solved as Nash Games

Participants: Abderrahmane Habbal, Moez Kallel [University of Tunis].

The Cauchy problem for an elliptic operator is formulated as a two-player Nash game.

- Player (1) is given the known Dirichlet data, and *uses as strategy variable the Neumann condition* prescribed over the inaccessible part of the boundary.
- Player (2) is given the known Neumann data, and *plays with the Dirichlet condition* prescribed over the inaccessible boundary.
- The two players solve in parallel the associated Boundary Value Problems. Their respective objectives involve the *gap between the non used Neumann/Dirichlet known data and the traces of the BVP's solutions* over the accessible boundary, and are *coupled through a difference term*.

We prove the existence of a unique Nash equilibrium, which turns out to be the reconstructed data when the Cauchy problem has a solution. We also prove that the completion algorithm is stable with respect to noise. Many 3D experiments were performed which illustrate the efficiency and stability of our algorithm [42].

6.6. Isogeometric analysis and design

Participants: Louis Blanchard, Régis Duvigneau, Bernard Mourrain [Galaad Project-Team], Gang Xu [Galaad Project-Team].

Design optimization stands at the crossroad of different scientific fields (and related software): Computer-Aided Design (CAD), Computational Fluid Dynamics (CFD) or Computational Structural Dynamics (CSM), parametric optimization. However, these different fields are usually not based on the same geometrical representations. CAD software relies on Splines or NURBS representations, CFD and CSM software uses grid-based geometric descriptions (structured or unstructured), optimization algorithms handle specific shape parameters. Therefore, in conventional approaches, several information transfers occur during the design phase, yielding approximations that can significantly deteriorate the overall efficiency of the design optimization procedure. Moreover, software coupling is often cumbersome in this context.

The isogeometric approach proposes to definitely overcome this difficulty by using CAD standards as a unique representation for all disciplines. The isogeometric analysis consists in developing methods that use NURBS representations for all design tasks:

- the geometry is defined by NURBS surfaces;
- the computation domain is defined by NURBS volumes instead of meshes;
- the solution fields are obtained by using a finite-element approach that uses NURBS basis functions
- the optimizer controls directly NURBS control points.

Using such a unique data structure allows to compute the solution on the exact geometry (not a discretized geometry), obtain a more accurate solution (high-order approximation), reduce spurious numerical sources of noise that deteriorate convergence, avoid data transfers between the software. Moreover, NURBS representations are naturally hierarchical and allows to define multi-level algorithms for solvers as well as optimizers.
In this context, some studies on elliptic problems have been conducted in collaboration with GALAAD Project-Team, such as the development of methods for adaptive parameterization including an a posteriori error estimate[46], [45]. A collaborative work has also been carried out with the Technical University of Kaiserslautern, concerning the computation of shape gradients for linear elasticity problems[59].

7. Bilateral Contracts and Grants with Industry

7.1. Bilateral Contracts with Industry

ArcelorMittal-Inria industrial contract n. 5013 : Opale started a thorough collaboration in optimal design of high performance steel with the mentioned world leader industrial. The aim of the collaboration is to develop and study new and efficient tools dedicated to multicriteria shape optimization of structures which undergo large non-linear elasto-plastic deformations.

The present contract has three years duration and funds the Ph.D. thesis of Aalae Benki and Research financial support.

8. Partnerships and Cooperations

8.1. National Initiatives

8.1.1. ANR

8.1.1.1. Project "OMD2", Optimisation Multi-Disciplinaire Distribuèe (Distributed Multidisciplinary Optimization)

This project funded by ANR deals with the development of a software platform devoted to Multidisciplinary Design Optimization (MDO) in the context of distributed computing.

The notion of optimization platform based on distributed and parallel codes is undertaken with a distributed workflow management system running on a grid infrastructure using the GRID5000 middleware from Inria.

Renault is the coordinator of this project, which involves also EMSE, ENS Cachan, EC Nantes, Université de Technologie de Compiègne, CD-Adapco, Sirehna, Activeon, and Inria project TAO, OASIS and OPALE. This contract provides the grant supporting two PhD theses (A. Zerbinati and L. Trifan)

8.1.2. Project "OASIS"

The OASIS project, Optimization of Addendum Surfaces In Stamping, is an R&D consortium (CS, Arcelor-Mittal, ErDF, Inria, UTC, EURODECISION, ESILV, NECS, DeltaCAD, SCILAB-DIGITEO) of the Pole Systemtic Paris-Region dedicated to develop an optimal design framework (methods-software platforms-applications) for stamping processes. The EPI OPALE/Inria is the leader within the consortium for the Optimization work-package (one of six WP), the role of which is to develop efficient tools well adapted to Pareto front identification of the multicriteria-dependent stamping processes.

The OASIS project yields 2.4 Meuro total financial support (one Ph.D thesis, two post-doctoral positions and 12 months internship for OPALE).

8.1.3. Project "Bulbe"

This project is funded by the Ministry of Fishing and gathers OPALE Project-Team, K-Epsilon company (specialized in CFD for naval hydrodynamics) and PROFIL compagnie (naval architect). The objective is to design and optimize bow shapes for trawler ships, in order to reduce the fuel consumption during fishing campaigns. Our role is to construct an automated optimization loop to improve bow efficiency, on the basis of CFD tools provided by K-Epsilon company and naval architect recommendations.

8.1.4. Project "Memoria"

This project is funded by the National Foundation for Aeronautics and Space (FNRAE). The partners are the University of Toulouse Paul-Sabatier and the CERFACS. The objective is to study optimization methods under uncertainty in the context of aerodynamic problems.

8.2. European Initiatives

8.2.1. FP7 Projects

8.2.1.1. EXCITING

Title: Exact Geometry Simulation for Optimized Design of Vehicles and Vessels

Type: COOPERATION (TRANSPORTS)

Instrument: Specific Targeted Research Project (STREP)

Duration: October 2008 - Mars 2012

Coordinator: Jozef Kepler universitet (Austria)

Others partners: SINTEF (SW), SIEMENS (GER), NTUA (GR), HRS (GR), TUM (GER), HYDRO (AUS), DNV (NOR)

See also: http://exciting-project.eu/

Abstract: The objective is to develop simulation and design methods and software based on the isogeometric concepts, that unify Computer-Aided Design (CAD) and Finite-Elements (FE) representation bases. Applications concern hull shape, turbine and car structure design.

8.2.1.2. GRAIN

Title: GReener Aeronautics International Networking

Type: CAPACITIES (TRANSPORTS)

Instrument: Coordination and Support Action (CSA)

Duration: October 2010 - December 2012

Coordinator: CENTRE INTERNACIONAL DE METODES NUMERICS EN ENGINYERIA (Spain)

Others partners: AIRBUS (SP), ALENIA (I), EADS-IW (F), Rolls-Royce (UK), INGENIA (SP), NUMECA (B), U. SHEFFIELD (UK), U. BIRMINGHAM (UK), CIRA (I), VKI (B), AIRBORNE (NL), LEITAT (SP), CERFACS (F), U. CRANFIELD (UK), CAE (CN), GTE (CN), ARI (CN), FAI (CN), ASRI (CN), SAERI (CN), BIAM (CN), ACTRI (CN), BUAA (CN), NPU (CN), PKU (CN), NUAA (CN), ZJU (CN).

See also: http://www.cimne.com/grain

Abstract: The GReener Aeronautics International Networking (GRAIN) is a 24 month project co-funded by the 7th Framework Programme of the European Community (EC) and by the Chinese Ministry of Industry and Information Technology (MIIT). It is managed by the European Commission as a Coordination and Support Action. The main objectives of GRAIN are to identify and assess the future development of large scale simulation methods and tools needed for greener technologies reaching the Vision 2020 environmental goals. GRAIN will prepare the R&T development and exploitation with new large scale simulation tools used on distributed parallel environments to deeper understand and minimize the effects of aircraft/engine design on climate and noise impact. This objective can be met by supporting joint Europe-China networking actions for defining the necessary technologies to improve green aircraft performance.

8.2.1.3. MARS

Title: Manipulation of Reynolds Stress

Type: COOPERATION (TRANSPORTS)

Instrument: Specific Targeted Research Project (STREP)

Duration: October 2010 - September 2013

Coordinator: CENTRE INTERNACIONAL DE METODES NUMERICS EN ENGINYERIA (Spain)

Others partners: USFD (UK), AIRBUS (SP), FOI (SW), ALENIA (IT), DLR (GER), CNRS (FR), DASSAULT (FR), NUMECA (BEL), UNIMAN (UK), EADS (UK)

See also: http://www.cimne.com/mars/

Abstract: The objective is to study flow control devices for aeronautical applications. This project gathers twelve European partners and twelve Chinese partners for a common work that includes both experimental and numerical studies. Opale Project-Team is in charge of developing numerical algorithms to optimize flow control devices (vortex generators, synthetic jets).

8.2.1.4. TraM3

Title: TRaffic Management by Macroscopic Models

Type: IDEAS

Instrument: ERC Starting Grant (Starting)

Duration: October 2010 - September 2015

Coordinator: Inria (France)

See also: http://www-sop.inria.fr/members/Paola.Goatin/tram3.html

Abstract: The project intends to investigate traffic phenomena from the macroscopic point of view, using models derived from fluid-dynamics consisting in hyperbolic conservation laws. The scope is to develop a rigorous analytical framework and fast and efficient numerical tools for solving optimization and control problems, such as queues lengths control or buildings exits design.

8.2.2. Collaborations in European Programs, except FP7

Program: PHC Polonium

Project acronym: CROM3

Project title: Crowd Motion Modeling and Management

Duration: jan. 2011 - dec. 2012

Coordinator: P. Goatin (France), M.D. Rosini (Poland)

Other partners: ICM, Warsaw University (Poland)

Abstract: The aim of this collaboration is to provide new analytical and numerical tools for solving control and optimization problems arising in pedestrian traffic management. Our scope is to develop a rigorous analytical framework and fast and efficient numerical tools for solving optimization and control problems, such as buildings exits design. This will allow to elaborate reliable predictions and to optimize traffic fluxes. To achieve this goal, we will study in details the structure of the solutions of the partial differential equations modeling traffic dynamics, in order to construct ad hoc methods to tackle the analytical and numerical difficulties arising in this study.

8.2.3. Collaborations with Major European Organizations

Partner 1: organisme 1, labo 1 (pays 1)

Sujet 1 (max. 2 lignes)

Partner 2: organisme 2, labo 2 (pays 2)

Sujet 2 (max. 2 lignes)

8.3. International Initiatives

8.3.1. Inria Associate Teams

8.3.1.1. ORESTE

Title: Optimal REroute Strategies for Traffic managEment

Inria principal investigator: PaolaGoatin

International Partner (Institution - Laboratory - Researcher):

University of California Berkeley (United States) - Electrical Engineering and Computer Science (EECS) - Alexandre M. Bayen

Duration: 2012 - 2014

See also: http://www-sop.inria.fr/members/Paola.Goatin/ORESTE/

ORESTE is an associated team between OPALE project-team at Inria and the Mobile Millennium / Integrated Corridor Management (ICM) team at UC Berkeley focused on traffic management. With this project, we aim at processing GPS traffic data with up-to-date mathematical techniques to optimize traffic flows in corridors. More precisely, we seek for optimal reroute strategies to reduce freeway congestion employing the unused capacity of the secondary network. The project uses macroscopic traffic flow models and a discrete approach to solve the corresponding optimal control problems. The overall goal is to provide constructive results that can be implemented in practice. Both teams have actively contributed to recent advances in the subject, and we think their collaboration is now mature enough to take advantage of the associate team framework. The Inria team and its theoretical knowledge complement the Berkeley team, with its engineering knowledge anchored in practice.

8.3.2. Participation In International Programs

- Inria@SILICONVALLEY :

  ORESTE Associated Team with UC Berkeley takes part to the program.

- LIRIMA Team ANO 2010-2014:

  The agreement governing the creation of the International Laboratory for Research in Computer Science and Applied Mathematics (LIRIMA) was signed on 24th November 2009 in Yaoundé. LIRIMA enables cooperation between Inria research teams and teams in Africa (Sub-Saharan Africa and the Maghreb) to be reinforced. It is the continuation of the major operation undertaken by the SARIMA program (2004-08 Priority Solidarity Fund created by the French Ministry of Foreign & European Affairs).

  The LIRIMA team ANO : Numerical analysis of PDEs and Optimization is a partnership between Opale project and the EMI engineering college, Rabat / National Centre for Scientific and Technical Research (CNRST) Morocco. The Team leader is Prof. Rajae Aboulaïch, EMI. Other french participants are the Project Commands at Saclay, Palaiseau and the team-project DRACULA at Inria Lyon.

  The ANO team is composed of ten senior researchers from Morocco and ten senior researchers from France and more than fifteen PhD students.

  The themes investigated are biomathematics (Models for plants growth, cardiovascular and cerebral diseases, cardio image segmentation), mathematical finance (optimal portfolio, risk management, Islamic finance), multiobjective optimization in structural mechanics, and vehicle traffic and crowd motion.

8.4. International Research Visitors

8.4.1. Visits of International Scientists

8.4.1.1. Senior Researchers

Pr. Ellaia Rachid

Subject: Theory and algorithms for global and multiobjective optimization.

Institution: Ecole Mohammadia d'Ingénieurs (EMI) , Rabat (Morocco)

8.4.1.2. Internship

Bouthaina Yahyaoui, Asma Ghdami and Marwa Mokni

Subject: Multiobjective optimization of laminated composite Mindlin-Reissner plates

Institution: Institut Supérieur des Mathématiques Appliquées et d'Informatique, Kairouan, (Tunisia)

9. Dissemination

9.1. Scientific Animation

- P. Goatin is member of the Organizing Committee of the 14th International Conference on Hyperbolic Problems: Theory, Numerics and Applications (HYP2012). Padova (IT). June 2012. http://www.hyp2012.eu/
- T. Nguyen is member of the PRACE expert pool since November 2012 (Partnership for Advanced Computing in Europe)
- T. Nguyen is member of the Program Committee for the 9th Intl. Conf. in Cooperative Design, Visualization and Engineering (CDVE2012). Osaka (JP). September 2012.
- T. Nguyen is member of the Program Committee for the 8th Intl. Conf. on Networking, Grids and Virtualization (CLOUD COMPUTING2012). Nice (FR). July 2012. http://www.iaria.org/conferences2012/CLOUDCOMPUTING12.html

- T. Nguyen is Advisory Chair and member of the Program Committee for the 8th Intl. Conf. on Cloud Computing and Services (ICNS2012). Saint-Maarten (NL). March 2012. http://www.iaria.org/conferences2012/ICNS12.html
- T. Nguyen is member of the Program Committee for the 1st Intl. Conf. on Smart Grids and Green IT Systems (SMARTGREENS2012). Porto (PT). April 2012. http://www.smartgreens.org/CallForPapers.aspx
- T. Nguyen is member of the Program Committee for the 2nd International Conference on Cloud and Green Computing (CGC2012), Xiangtan (China), November 2012. http://kpnm.hnust.cn/confs/cgc2012
- T. Nguyen is member of the Program Committee of the 3rd Intl. Conf. on Parallel, Distributed, Grid and Cloud Computing for Engineering. Pécs, Hungary, March 2013. http://www.civil-comp.com/conf/pareng2013.htm
- T. Nguyen is member of the Editorial Board of the Intl. Journal on Advances in Intelligent Systems (IARIA Eds.)
- T. Nguyen is member of the Editorial Board of the Intl. Journal on Advances in Software (IARIA Eds.)

9.2. Teaching - Supervision - Juries

9.2.1. Teaching

Licence: Introduction to Numerical Analysis, 71,5 hrs, Ecole Polytechnique Universitaire (EPU), Nice Sophia Antipolis (J.-A. Désidéri, A. Zerbinati).

Licence: Numerical Methods I, 19.5 hrs, Ecole Polytechnique Universitaire (EPU), Nice Sophia Antipolis (J.-A. Désidéri).

Licence: Solid Mechanics (statics, kinematics, dynamics, energetics), 45.5 hrs, Ecole Polytechnique Universitaire (EPU), Nice Sophia Antipolis (F. Z. Oujebbour).

Licence: Linear Systems, 39 hrs, L3, Ecole Polytechnique Universitaire (EPU), Nice Sophia Antipolis (R. Duvigneau).

Licence: Partial Differential Equations, 36 hrs, L3, Ecole Polytechnique Universitaire (EPU), Nice Sophia Antipolis (R. Duvigneau).

Master: Advanced Optimization, 40.5 hrs, M2, Ecole Polytechnique Universitaire (EPU), Nice Sophia Antipolis (J.-A. Désidéri, R. Duvigneau).

Master: Multidisciplinary Optimization, 22.5 hrs, joint ISAE ("Complex Systems") and M2 (Mathematics), Toulouse (J.-A. Désidéri, R. Duvigneau).

Master: Conservation laws and traffic flow models, 32 hrs, M2, Ecole Polytechnique Universitaire (EPU), Nice Sophia Antipolis (P. Goatin).

9.2.2. Supervision

PhD & HdR :

PhD : Imane Ghazlane, *Optimisation aérodynamique et structurale de la voilure d'un avion de transport avec la méthode adjointe*, University of Nice Sophia Antipolis, December 2012, supervisors: J. A. Desideri and Gérald Carrier (ONERA/DAAP).

PhD : Samira El Moumen, *Portfolio Management in Finance*, Ecole Mohammadia d'Ingénieurs (EMI), Rabat, September 2012, supervisors: R. Aboulaich, R. Ellaia (Rabat) and A. Habbal.

PhD in progress : Sébastien Bourasseau, *Méthodes de raffinement de maillages non structurés basées sur le vecteur adjoint pour le calcul de coefficients aérodynamiques*, October 2011, Supervisors: Jean-Antoine Désidéri and Jacques Peter (ONERA/DSNA).

PhD in progress : Aalae Benki, *Optimisation concurrente de forme de coque mince en régimes élastoplastique et de crash*, October 2010, supervisor: A. Habbal.

PhD in progress : Maria Laura Delle Monache, *Traffic flow modeling by conservation laws*, October 2011, supervisor: P. Goatin

PhD in progress : Mohamed Kaicer, *Group lending : analysis of asymetric information using game theory. Analysis design and implementation of a simulator adapted to microfinance market*, October 2009, Supervisors: R. Aboulaich (Rabat) and A. Habbal.

PhD in progress : Jérémie Labroquère, *Optimization of Flow Control Devices*, October 2010, Supervisors: Jean-Antoine Désidéri and Régis Duvigneau.‘

PhD in progress : Matthias Mimault, *Crowd motion modeling by conservation laws*, October 2012, supervisor: P. Goatin

PhD in progress : Andrea Minelli, *Optimisation simultanée des performances aérodynamiques et du bang sonique d'un aéronef supersonique*, October 2010, Supervisors: Jean-Antoine Désidéri and Itham El Salah Dinh (ONERA/DAAP).

PhD in progress : Maxime Nguyen Dinh, *Qualification des simulations numériques par adaptation anisotropique de maillages*, October 2011, Supervisors: Jean-Antoine Désidéri and Jacques Peter (ONERA/DSNA).

PhD in progress : Fatima Zahra Oujebbour, *Modèles de jeux en optimisation de forme en emboutissage*, October 2010, Supervisors: A. Habbal.

PhD in progress : Enric Roca Leon, *Simulation aéromécanique pour l'optimisation de rotor d'hélicoptère en vol d'avancement*, October 2011, Supervisors: Jean-Antoine Désidéri and Arnaud Le Pape (ONERA/DAAP).

PhD in progress : Laurentiu Trifan, *Plateforme collaborative pour l'optimisation multidiscipline*, December 2009, Supervisors: Jean-Antoine Désidéri and Toan Nguyen.

PhD in progress : Adrien Zerbinati, *Optimisation multidisciplinaire robuste pour application à l'automobile*, January 2010, Supervisors: Jean-Antoine Désidéri and Régis Duvigneau.

9.2.3. Juries

- T. Nguyen was member of the PhD Defense Jury of Mr. Balaji Raghavan, Université de Technologie de Compiègne, December 2012.
- P. Goatin was referee and member of the PhD Defense Jury of Aude Hofleitner, Université Paris-Est, December 2012.

9.3. Popularization

J.-A. Désidéri has delivered the conference *"Modélisation et simulation : lorsque l'ingénierie devient numérique"* ("Modelling and simulation : when engineering becomes numerics") to engineering students in Avignon (May 2012).

P. Goatin has delivered the conference "Comment les mathématiques contribuent-elles à la gestion du trafic routier?" to the Université d'été de mathématique "Modèles mathématiques et réalité" organised by the Creteil Academy in Sourdun (August 2012).

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Major publications by the team in recent years

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[5] R. M. COLOMBO, P. GOATIN. *A well posed conservation law with a variable unilateral constraint*, in "J. Differential Equations", 2007, vol. 234, n° 2, p. 654–675, http://dx.doi.org/10.1016/j.jde.2006.10.014.

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