IN PARTNERSHIP WITH:
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Université Nice - Sophia Antipolis

Activity Report 2013

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)

RESEARCH CENTERS
Sophia Antipolis - Méditerranée
Grenoble - Rhône-Alpes

THEME
Numerical schemes and simulations

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Project-Team OPALE

Keywords: Scientific Computation, Model Coupling, Shape Optimization

Creation of the Project-Team: 2002 July 01.

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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

Opale now participates in the KIC EIT ICT Labs activity, IMS - Intelligent Mobility and Transportation Systems, “Multimodal Mobility". In this area, a new contract with Autoroute Trafic on "Design and validation of traffic flow models on processed data" has been set up.

In the area of multi-disciplinary optimization, technical collaboration with research and industrial partners (Arcelor Mittal) have been enforced and new axes (nanoelectronics with CEA/LETI Grenoble) developed.

Régis Duvigneau defended his habiltation thesis (HdR).

3. Research Program

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-team since its very beginning. A software integration platform has been designed by the Opale project-team for the definition, co

nfiguration 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 [83].

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. We focus more precisely on developing and validating cell dynamics models. 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 inter-disciplinary 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 and Platforms

5.1. NUM3SIS

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

The Opale project-team has initiated a few years ago the development of NUM3SIS (http://num3sis.inria.fr), which is 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 (by Opale project-team), Computational Electro-Magnetics (by Nachos project-team) and pedestrian traffic simulation (by Opale project-team). Some components of the platform are also used by the Tosca project-team for CO2 market simulation and wind simulation in collaboration with Ciric (Inria-Chile).
NUM3SIS provides innovative software tools to overcome some limitations encountered by classical monolithic simulation codes. In particular, the platform is based on abstract concepts commonly used in scientific computing, such as mesh, fields, finite-elements, linear solvers etc, that can be implemented in plugins. A fast prototyping of algorithms can be achieved using a visual programing interface. A component is dedicated to deployment on parallel architectures. Moreover, the platform relies on a "store" system to foster exchange of plugins, scripts or data.
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. The platform is also used by the Fluid Mechanics Laboratory at Ecole Centrale de Nantes for hydrodynamic design applications and ONERA for multidisciplinary design optimization (MDO). Moreover, it is presently tested by Peugeot Automotive industry for external aerodynamic design purpose.

5.3. Plugins for AXEL

Participant: Régis Duvigneau [correspondant].

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

- 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 ;
- geometrical modeling for design optimization.

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 was Laurentiu Trifan's PhD thesis, defended in October 2013 [37]. (See Fig. 1.)

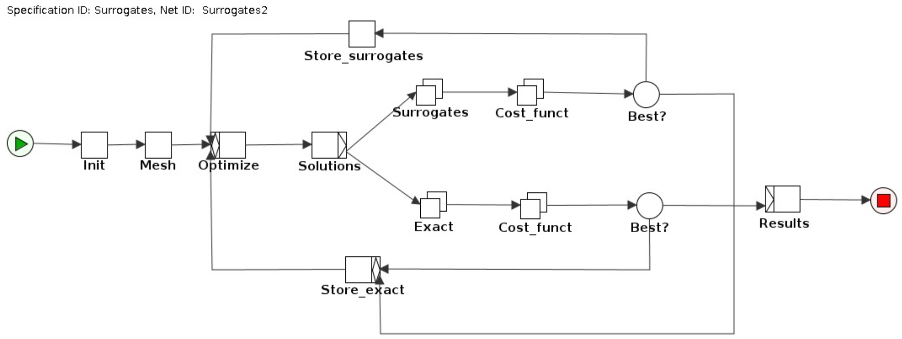


Figure 1. Testcase deployment on the Grid5000 infrastructure.

6. New Results

6.1. Mathematical analysis and control of macroscopic traffic flow models

6.1.1. Vehicular traffic

Participants: Alessandra Cabassi, Maria Laura Delle Monache, Paola Goatin, Alexandre Bayen [UC Berkeley, CA, USA], Legesse Lemecha Obsu [Addis Ababa University, Ethiopia].

In collaboration with UC Berkeley, and as part of the Associated Team ORESTE activity (see http://www-sop.inria.fr/members/Paola.Goatin/ORESTE/index.html), we have proposed a new junction model for ramp metering: we introduce a coupled PDE-ODE model, in which the PDE describes the evolution of the cars flow on the main lane 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. We were able to prove existence and uniqueness of the solution of the corresponding Riemann problem [41]. Relying on the above junction model, we have applied the Discrete Adjoint Method to efficiently compute (locally) optimal ramp-metering parameters to minimize the total travel time on a stretch of highway [80].

In parallel, we have proposed two optimization strategy for instantaneous optimization of total travel times and total waiting times at roundabouts, which give an estimate of the time spent by drivers on the network section. These cost functionals are minimized with respect to the right-of-way parameter of the incoming roads. For each cost functional, the analytical expression is given for each junction, see [72]. This work is part of L.L. Obsu's PhD thesis.

Finally, we designed a new finite volume algorithm to track the trajectory of a bus in the surrounding traffic using a locally non-uniform moving mesh, see [3, 4, 5].

As part of our TRAM3 activity, we also organized the workshop “TRAM2 - Traffic Modeling and Management: Trends and Perspectives", which successfully took place at Inria Sophia Antipolis on March 20-22, 2013 (see https://team.inria.fr/opale/workshop-tram2/).

In the framework of the EIT ITC Labs Multimodal Mobility activity, A. Cabassi's internship was devoted to the calibration and the validation of a first order traffic flow model against processed real data provided by the industrial partners Autoroutes Traffic and VINCI Autoroutes, see [69].

6.1.2. Crowd motion

Participants: Régis Duvigneau, Paola Goatin, Matthias Mimault, Debora Amadori [L'Aquila University, Italy], Christophe Chalons [LJLL, UP7], Massimiliano D. Rosini [ICM, Warsaw University, Poland], Nicolas Seguin [LJLL, UPMC], Monika Twarogowska.

From the analytical point of view, we have been studying the properties of some models in one space dimension. Concerning Hughes' scalar model, we have established a partial existence result in collaboration with D. Amadori and M.D. Rosini (see [75]). M. Mimault's internship in 2012 was devoted to develop a MATLAB code based on wave-front tracking to compute the solutions of Hughes' model with generalized running cost, see [42]. He is currently working on a mixed hyperbolic-elliptic 2x2 system of conservation laws describing two groups of people moving in opposite directions. Finally, in collaboration with C. Chalons and N. Seguin, we generalized previous results on conservation laws with local flux constraints [3], [5] to general flux functions and non-classical solutions arising in pedestrian flow modeling, see [39]. From the numerical point of view, we have implemented some macroscopic models in 2D on unstructured triangular meshes on the Num3sis platform. We provided a comparison between first and second order models in reproducing complex dynamics of crowd motion, such as formation of stop-and-go waves and clogging at bottlenecks. Then, we concentrated on the higher-order model and analyzed the dependence of the behavior of its solutions on some of the parameters of the system. In particular, we produced some examples where placing obstacles in front of the door prevents from blocking and decreases the evacuation time, see [73], [81].

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 disciplines, such as structural mechanics.

Our approach to *competitive optimization* is focused on the two-discipline problem. It 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 [53]. (see also subsectionsubsect:helico).

Our approach to *cooperative optimization*, in theory, is not limited in number of objective functions. It 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 [16] 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-stationary. 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 Pareto-stationary point, and actual Pareto-optimality is then tested [54] (see also subsection 6.2.4).

The two approaches have been combined to explore the Pareto front segment-wise as illustrated on Figure 2.

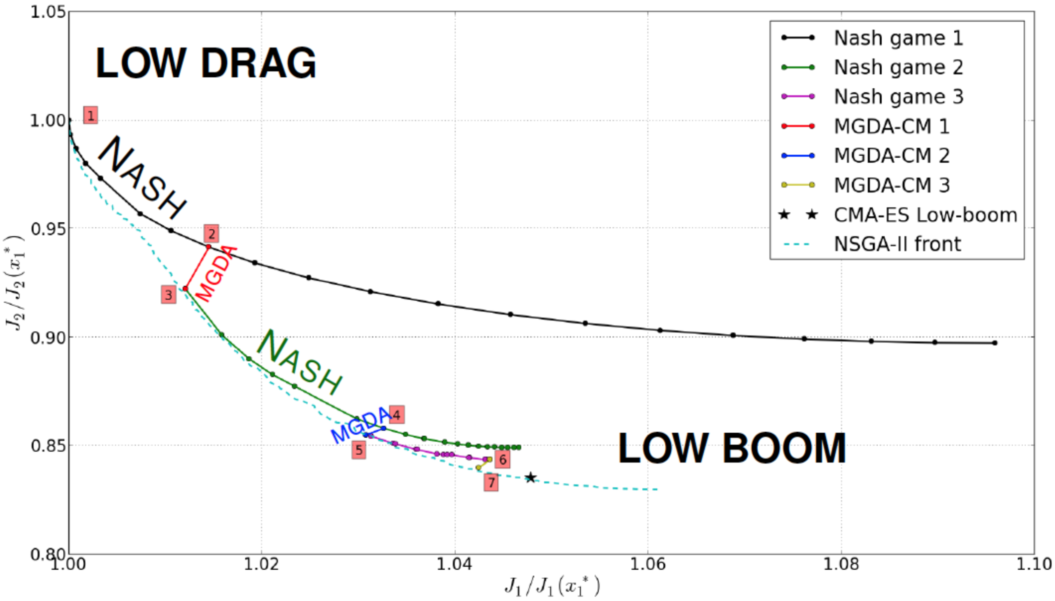


Figure 2. ***Two-discipline optimization of a generic geometry of a supersonic aircraft, for concurrent drag and sonic-boom reduction*** *(from A. Minelli's doctoral thesis). The wave drag is calculated by the ONERA elsA code in 3D finite-volume Eulerian flow mode over a 6M-node mesh and the sonic boom using a three-layer approach. The Nash-game paths have been devised by appropriate territory splitting in order to be tangent to the Pareto front, and they are interrupted whenever the Pareto-stationarity condition is judged excessively violated. The MGDA paths converge rapidly back to the front. The simulation demonstrates how the two algorithms complement each other and provide a potential for a piecewise description of the Pareto front, evaluated more economically than a stochastic algorithm operating on a large population.*

6.2.1. Multiple-Gradient Descent Algorithm (MGDA)

Participants: Jean-Antoine Désidéri, Régis Duvigneau, Matteo Giacomini, Abderrahmane Habbal, 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.

The notion of Pareto-stationarity, originally established to be a necessary condition of optimality in differentiable multi-objective optimization of unconstrained problems, has been extended to problems subject to equality constraints. On this basis, we were able to establish that by augmenting, in a classical manner, the objective-functions of a penalty term equal to the square of the constraint violation, and applying the standard MGDA to it, would result in converged solutions that are Pareto-stationary in the extended sense. Numerical experimentation on this is on-going.

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 [68]. 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. This more difficult problem has been proposed by Renault within the OMD2 ANR project. These studies have been reported in A. Zerbinati's doctoral thesis [38].

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 6.3) 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: Régis Duvigneau, Jérémie Labroquère, Emmanuel Guilmineau [Ecole Centrale de Nantes].

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, we develop a methodology to determine optimal control parameters by coupling the simulation of unsteady actuated flows 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.

In this perspective, unsteady Reynolds Averaged Navier-Stokes equations are solved, with some turbulence closures. Different models for synthetic jet have been implemented to simulate the actuation, and then validated for different turbulence closures [70].

Specific developments have be carried out in the metamodel-based optimizer to include a noise term into Gaussian Process model, which is used to filter errors arising from unsteady simulations. A systematic assessment of modeling and numerical errors has been archived [57], 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 at developing robust design tools for aircraft 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, which consists in minimizing or maximizing statistical moments of the cost function.

In the context of airfoil design, MGDA is used to improve simultaneously the mean and variance of the lift and drag coefficients, yielding a four-objective optimization problem [71].

6.2.4. 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 [82] for the calculation of the Whitham function corresponding to the lowest-boom (axisymmetric) shape. Method and results have been generalized to more general geometries and have been presented internationally in [58].

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 [36]. and [54].

6.2.5. 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. Then, 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 16 geometrical parameters have been 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 the American Helicopter Society Forum [62], and [53].

6.2.6. Optimum design in naval hydrodynamics

Participants: Régis Duvigneau, Louis Blanchard, Elisa Berini [K-Epsilon company].

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.

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. 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 [50].

6.3. Isogeometric analysis and design

Participants: Régis Duvigneau, Bernard Mourrain [Galaad project-team], Alexandros Ginnis [Nat. Tech. Univ. of Athens], Bernd Simeon [Tech. Univ. of Kaiserslautern], Gang Xu [Hangzhou Dianzi Univ.].

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 geometric modeling, computational domain description and solution basis functions. 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 the Galaad project-team and Hangzhou Dianzi University, such as the development of methods for adaptive parameterization including an a posteriori error estimate [46], [47], [48]. A collaborative work has also been carried out with the Technical University of Kaiserslautern, concerning the computation of shape gradients for linear elasticity problems, and with the National Technical University of Athens for hull shape optimization [55].

6.4. Optimum design in structural mechanics

6.4.1. Shape Optimization in Multidisciplinary Non-Linear Mechanics

Participants: Aalae Benki, Jean-Antoine Désidéri, Abderrahmane Habbal, Gael Mathis [ArcelorMittal, CRAA].

In collaboration with the ArcelorMittal's Center for Research in Automotive and Applications (CRAA), 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.

Then, we considered the 3D problem of an automotive twist beam. In this 3D case, we aim to Pareto-optimal shapes for two objectives, the first being to minimize the Von-Mises strain to guarantee the formability of the twist beam, and the second being to maximize the stiffness. For solution with higher stiffness than the initial one, we could decrease the thickness to obtain a mass reduction with the same end-user properties.

We also introduced, to our knowledge for the first time in the structural optimization area, the notion of Kalai-Smorodinky equilibria which is aimed at the selection of equilibria among Pareto-optimal solutions. We applied this notion of equilibria to both industrial cases, and compared the results to Nash equilibria. [56] [64]

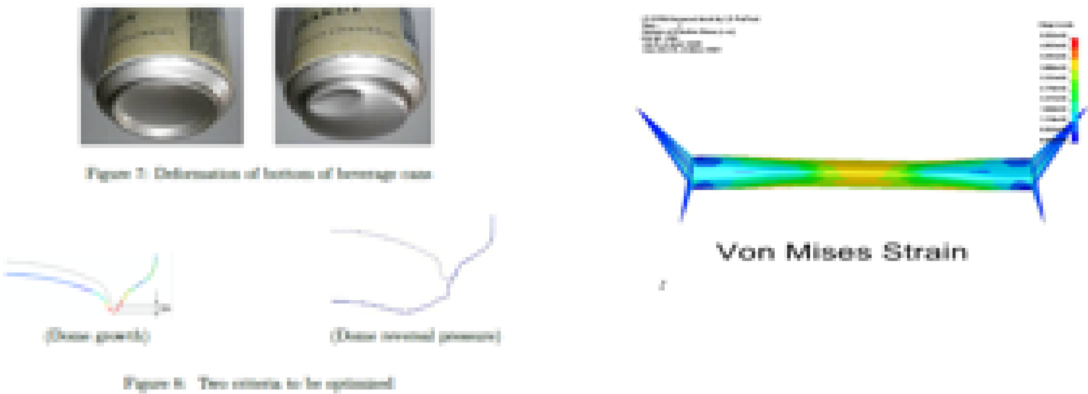


Figure 3. Concurrent design in industrial applications. A packaging problem of commercial cans (left). Automotive twist beam (right)

6.4.2. Optimization of Addendum Surfaces in Stamping

Participants: Fatima Zahra Oujebbour, Rachid Ellaia, Abderrahmane Habbal, Ziheng Zhao.

Within the OASIS Consortium (ArcelorMittal, ErDF, Inria, UTC, EURODECISION, ESILV, NECS, Delta-CAD, SCILAB-DIGITEO), the Opale project-team 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 process parameters (two then four parameters). Then, we considered the more complex shape design of the initial blank. The initial blank design is a critical step in stamping design procedure, therefore it should be optimally designed. Our aim is to find the optimal initial blank shape that avoids or at least minimizes the springback and failure flaws. For this study, the geometry of the blank contour is described by parametric spline curves. Seven control points (P1,...,P7) are used to define the spline curves in order to have a wide variety of geometries. The exact computational evaluation of our criteria, springback and failure, is very expensive (the FE model request around 45 min to predict these two criteria) and the design space is of quite high dimension. Therefore, we considered the recourse to the sparse grid interpolation. Optimization process based on sparse grid interpolation is an optimal alternative in which criteria can be approximated with a suitable interpolation formula that needs significantly less points than the full grid. the obtained metamodel using sparse grid interpolation needs less than 1s to predict springback and failure on the same computation machine. To find the optimal initial blank shape, it was decided to perform the optimization process using the obtained metamodel. The construction of the sparse grid interpolant was based on the Chebyshev Gauss-Lobatto grid type and using the polynomial basis functions. This technique achieves a good accuracy with a competitive number of grid points. The comparison of the obtained fronts shows that we can capture Pareto solutions by NBI and NNCM with fewer points than NSGAII which requires a large number of populations and several generations to obtain the Pareto front. [60] [61] [63] [77]

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

6.5.1. Assessing the ability of the 2D Fisher-KPP equation to model cell-sheet wound closure

Participants: Abderrahmane Habbal, Hélène Barelli [Univ. Nice Sophia Antipolis, CNRS, IPMC], Grégoire Malandain [Inria, EPI Morpheme].

We address in this joint collaboration the ability of the widely used Fisher-KPP equations to render some of the dynamical features of epithelial cell-sheets during wound closure.

Our approach is based on nonlinear parameter identification, in a two-dimensional setting, and using advanced 2D image processing of the video acquired sequences. As original contribution, we lead a detailed study of the profiles of the classically used cost functions, and we address the "wound constant speed" assumption, showing that it should be handled with care.

We study five MDCK cell monolayer assays in a reference, activated and inhibited migration conditions. Modulo the inherent variability of biological assays, we show that in the assay where migration is not exogeneously activated or inhibited, the wound velocity is constant. The Fisher-KPP equation is able to accurately predict, until the final closure of the wound, the evolution of the wound area, the mean velocity of the cell front, and the time at which the closure occurred. We also show that for activated as well as for inhibited migration assays, many of the cell-sheet dynamics cannot be well captured by the Fisher-KPP model. Original unexplored utilizations of the model such as wound assays classification based on the calibrated diffusion and proliferation rate parameters is ongoing.[49] [76]

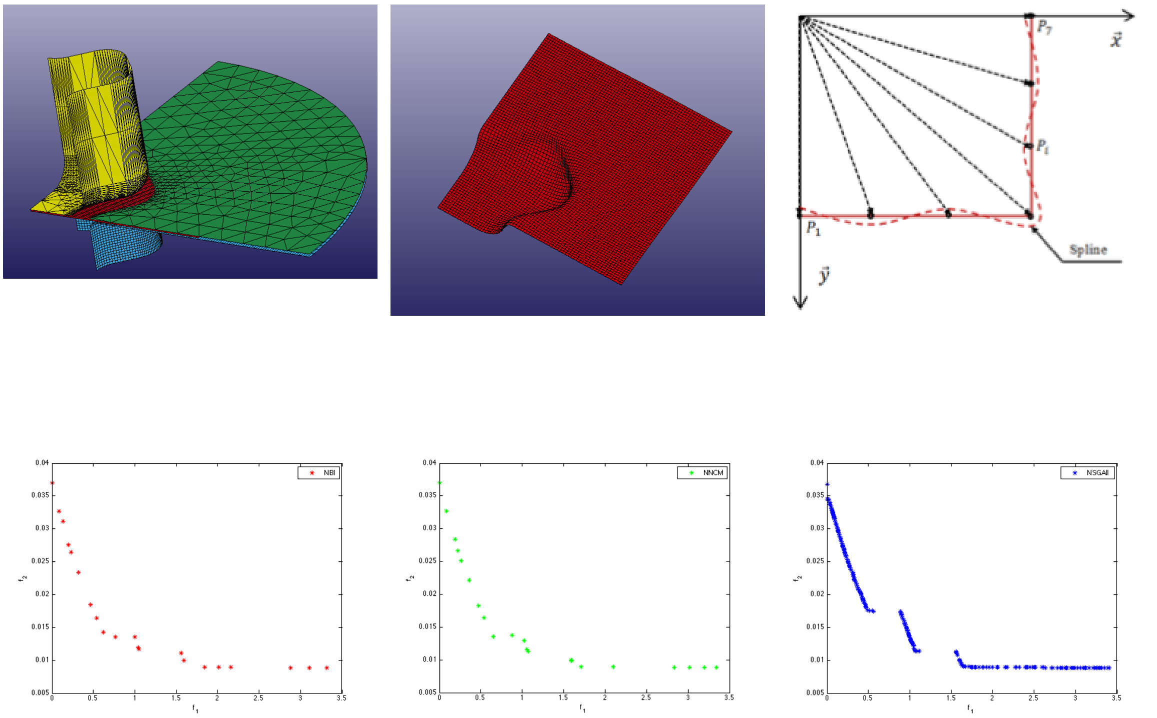
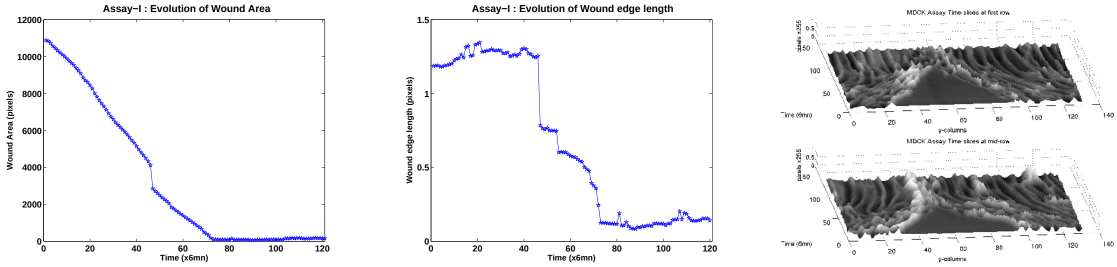
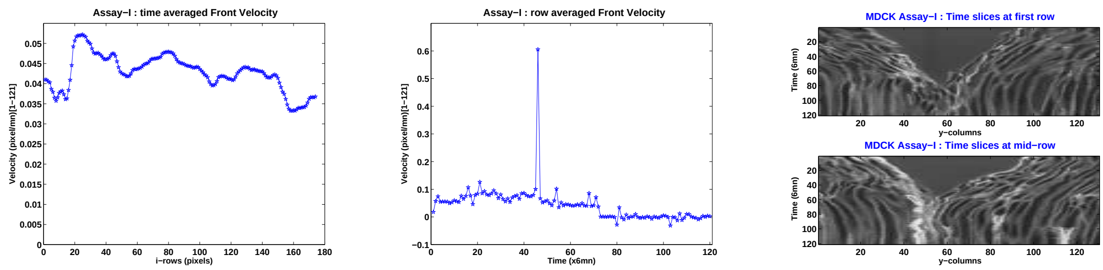


Figure 4. Multiobjective design of the stamping process of a high performance steel sheet. The design variable is the initial blank shape, and the costs are elastic spring-back and failure. Sparse grid approximation of the costs is used. The Pareto front obtained by NBI and NNCM (lower-left) are compared to a NSGA-II one (lower-right).

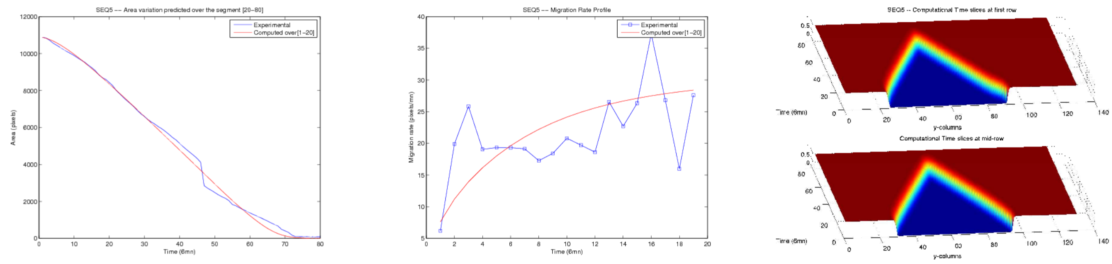


(a) (b) (c)



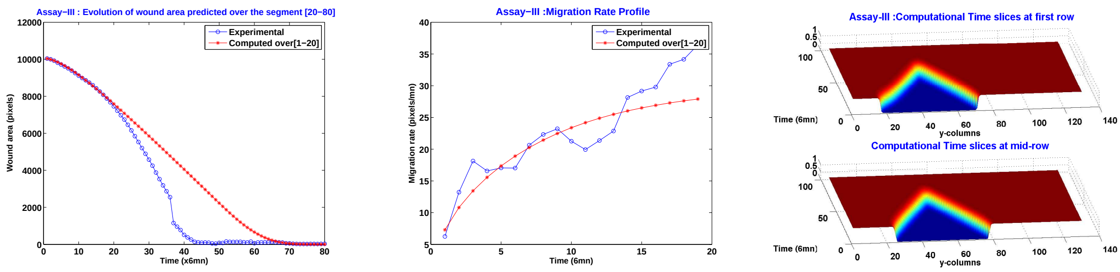
(d) (e) (f)

Figure 5. ***A regular wound assay*** *(a) Time evolution of wound area (in pixel). (b) Time evolution of the leading-edge length (in pixel). (c) 3D XT view at first and mid-rows. (d) Mean (in time) velocity of pixels located at the leading edge (in pixel/min). (e) Averaged (in space) leading-edge velocity (in pixel/min). (f) 2D XT view at first and mid-rows.*



(a) (b) (c)

Figure 6. ***A regular wound assay. Computational vs experimental wound evolution.*** *(a) Time variation of experimental (blue) versus computed (red) wound area (in pixel). (b) Time variation of the experimental (blue-dot) versus computed (red) migration rate (in pixel/min). (c) 3D XT view at first and mid-rows.*



(a) (b) (c)

Figure 7. ***An accelerating activated wound assay. Computational vs experimental wound evolution.*** *(a) Time variation of experimental (blue) versus computed (red) wound area (in pixel). (b) Time variation of the experimental (blue-dot) versus computed (red) migration rate (in pixel/min). (c) 3D XT view at first and mid-rows.*

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 "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. 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).

8.2.1.2. GRAIN 2

Type: COOPERATION

Defi: Transport (incl. Aeronautics)

Instrument: Coordination and Support Action (CSA)

Duration: October 2013 - September 2015

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

Partner: 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/grain2/

Inria contact: Toan Nguyen

Abstract: The main objective of GRAIN2 is to focus its greening activities following the Flight Path 2050 Vision for Aircraft en route to the very ambitious challenge "Protecting the environment and the energy supply" in three major following lines: i) greening the air vehicle, ii) greening the Air transport System and iii) Reducing the carbon foot print of aviation via sustainable alternative fuels. GRAIN2 will identify innovative R & D methods, tools and HPC environments (supercomputers and GPGPUs) in the different KGTs according to the needs of major aeronautical industries to deeper understand the mechanism of engine exhaust emissions, to improve fuel efficiency and environmental performance, to lower noise for landing gear and high lift surfaces, to introduce new materials with multiple functions, to help significantly the development of biofuels for greenhouse gas emission reduction, etc.

8.2.1.3. TraM3

Type: IDEAS

Title: TRaffic Management by Macroscopic Models

Instrument: ERC Starting Grant

Objectif: NC

Duration: October 2010 - September 2015

Coordinator: Inria

Inria contact: Paola Goatin

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

8.2.2. Collaborations in European Programs, except FP7

Program: KIC EIT ITC Labs, IMTS Intelligent Mobility and Transportation Systems

Project title: Multimodal Mobility

Duration: January 2013 - December 2013

Coordinator: Françoise Baude (Inria/UNS), Birgit Kwella (Fraunhofer Fokus)

Other partners: TU Berlin, U. Bologna, Inria, BME, Fraunhofer Gesellschaft,Telecom Italia,Siemens

Abstract: Identify innovation levers and possible joint developments in IMS

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: Paola Goatin

International Partner (Institution - Laboratory - Researcher):

University of California Berkeley (United States) - Electrical Engineering and Computer Science (EECS) - Paola Goatin

Duration: 2012 - 2014

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

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. Inria International Partners

8.3.2.1. Informal International Partners

Jean-Antoine Désidéri maintains close links with Prof. Alfio Borzí (Institut für Mathematik - Universität Würzburg, Germany) on theme of PDE-constrained optimization.

Régis Duvigneau maintains active cooperation with Praveen Chandrashkar (formely Opale post-doctoral fellow, now Assistant Professor at Tata Institute for Fundamental Research, Bangalore, Dept. Applicable Mathematics) on the theme of shape optimization in aerodynamics.

Additionally, Abderrahamane Habbal has a long term thorough collaboration with Moez Kallel from ENIT, Tunis, focusing on new applications of game theory to inverse problems and imaging science. We also have a continuing intensive collaboration with Rajae Aboulaich and Rachid Ellaia, from EMI, Rabat, and their collaborators. The themes addressed are multiobjective optimization, and mathematical modeling in life sciences.

8.3.3. Inria International Labs

- 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. Refer to the website http://www.lirima.uninet.cm/index.php/en/ for more details on the LIRIMA Africa themes and teams.

8.3.4. Participation In other International Programs

- Inria@SILICONVALLEY :

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

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. PhD Students

Legesse Lemecha Obsu

Subject: Macroscopic traffic flow optimization on roundabouts.

Institution: University of Addis Ababa (Ethiopia)

8.4.1.3. Internships

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

- R. Duvigneau is member of the "Conseil National des Universités" (CNU) for the 26th section (applied mathematics and application of mathematics)
- P. Goatin was member of the Organizing Committee of the Workshop *“Traffic Modeling and Management: Trends and Perspectives - TRAM2"*, Sophia Antipolis (France). March 2013. https://team.inria.fr/opale/workshop-tram2/

9.2. Teaching - Supervision - Juries

9.2.1. Teaching

Licence: Introduction to Numerical Analysis, 19.5 hrs, L3 (“Water Resources Engg.” Section), Ecole Polytechnique Universitaire (EPU), Nice Sophia Antipolis (J.-A. Désidéri)

Licence: Numerical Methods, 19.5 hrs, L3 (“Applied Mathematics and Modelling” Section), Ecole Polytechnique Universitaire (EPU), Nice Sophia Antipolis (J.-A. Désidéri)

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).

Licence: Numerical Methods I, 56 hrs tutorials, Ecole Polytechnique Universitaire (EPU), Nice Sophia Antipolis (A. Habbal).

Licence: Summer Project in Mathematical Modeling, 36 hrs, L3, Ecole Polytechnique Universitaire (EPU), Nice Sophia Antipolis (A. Habbal).

Master: Numerical Methods for Partial Differential Equations, 66 hrs, M1, Ecole Polytechnique Universitaire (EPU), Nice Sophia Antipolis (A. Habbal).

Master: Reconstructing lost GPS signals using accelerometrics, 10 hrs, M1, Ecole Polytechnique Universitaire (EPU), Nice Sophia Antipolis (A. Habbal).

9.2.2. Supervision

HdR : Régis Duvigneau, *Conception optimale en mécanique des fluides numérique : approches hiérarchiques, robustes et isogéométriques*, University of Nice Sophia Antipolis, october 2013

PhD : Andrea Minelli, *Aero-acoustic shape optimization of a supersonic business jet*, University of Nice Sophia Antipolis, November 2013, supervisor: Jean-Antoine Désidéri

PhD : Adrien Zerbinati, *Optimisation multidisciplinaire robuste pour application à l’automobile*, University of Nice Sophia Antipolis, April 2013, supervisors: Jean-Antoine Désidéri and Régis Duvigneau.

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

PhD in progress : Maxime Nguyen Dinh (Cifre ONERA/Aibus), *Qualification of numerical simulations by anisotropic mesh adaptation*, October 2011, supervisor : Jean-Antoine Désidéri.

PhD in progress : Sébastien Bourasseau (Cifre ONERA/Snecma), *Goal-oriented hybrid mesh adaptation for turbomachineray*, April 2011, supervisor : Jean-Antoine Désidéri.

PhD in progress : Enric Roca León (Cifre ONERA/Eurocopter), *Helicopter rotor blade multi-objective optimization*, October 2011, supervisor : Jean-Antoine Désidéri.

PhD in progress : Asma Gdhami, *Analyse isogéométrique pour les problèmes hyperboliques*, November 2013, supervisor: Régis Duvigneau.

PhD in progress : Maroua Mokni, *Numerical analysis and computational assessment of variants of the multiple-gradient of descent algorithm*, November 2013, supervisor: Jean-Antoine Désidéri.

PhD in progress : Bouthaina Yahyaoui, *Cell-dynamics modelling : from the Fisher-KPP equations to mechanical-biological-chemical systems*, January 2013, supervisor: Abderrahmane 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 : Aalae Benki, *Méthodes efficaces de capture de front de Pareto en conception mécanique multicritère. Applications industrielles.*, October 2010, supervisor: A. Habbal.

PhD in progress : Fatima Zahra Oujebbour, *Méthodes et applications industrielles en optimisation multicritère de paramètres de processus et de forme en emboutissage*, October 2010, Supervisors: A. Habbal.

PhD in progress : Boutheina Yahyaoui, *Modélisation de la dynamique des cellules : Des équations de Fisher-KPP aux systèmes mécano-bio-chimiques*, January 2013, Supervisors: A. Habbal and M. Ayadi (Tunis).

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

9.3. Popularization

Jean-Antoine Désidéri gave the lecture *"Modelling and simulating, when engineering becomes numerical"* to the Valbonne International High School (CIV) on October 11, 2013.

Paola Goatin was interviewed twice :

- TV interview on evening news, France 3 Côte d'Azur, January 30, 2013 http://www.youtube.com/watch?v=VlW4VgoTjEI&feature=youtu.be.
- Journal interview : *"Une chercheuse au chevet des embouteillages"*, Nice Matin, January 2013 http://www-sop.inria.fr/members/Paola.Goatin/NiceMatin.pdf.

10. Bibliography

Major publications by the team in recent years

[1] J. Cagnol, M. Polis, J. P. Zolésio (editors). , *Shape optimization and optimal design*, Lecture Notes in Pure and Applied Mathematics, Marcel Dekker Inc.New York, 2001, vol. 216, ii+442 p.

[2] L. Almeida, P. Bagnerini, A. Habbal, S. Noselli, F. Serman. *A mathematical model for dorsal closure*, in "Journal of Theoretical Biology", 2011, vol. 268, n^{o} 1, pp. 105 - 119

[3] B. Andreianov, P. Goatin, N. Seguin. *Finite volume schemes for locally constrained conservation laws*, in "Numer. Math.", 2010, vol. 115, n^{o} 4, pp. 609–645, With supplementary material available online, http://dx.doi.org/10.1007/s00211-009-0286-7

[4] É. Baratchart. , *Simulation Numérique en Aérodynamique et Optimisation bi-Objectif par Algorithme de Nash*, Août 2011, Rapport de stage d'application, ENSEIRB MATMÉCA, Bordeaux

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

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[9] R. DUVIGNEAU, M. VISONNEAU. *Optimization of a synthetic jet actuator for aerodynamic stall control*, in "Computers and Fluids", July 2006, vol. 35, pp. 624–638

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[11] J.-A. DÉSIDÉRI. , *Split of Territories in Concurrent Optimization*, Inria, October 2007, n^{o} 6108, 32 p. , http://hal.inria.fr/inria-00127194

[12] J.-A. DÉSIDÉRI. *Hierarchical Shape Optimization : Cooperation and Competition in Multidisciplinary Approaches*, in "24th IFIP TC 7 Conference on System Modelling and Optimization, Buenos Aires (Argentina), 27-31 July 2009", 2009, Invited Plenary Lecture

[13] J.-A. DÉSIDÉRI. , *Modèles discrets et schémas itératifs. Application aux algorithmes multigrilles et multidomaines*, Editions HermèsParis, 1998

[14] J.-A. DÉSIDÉRI. , *Multiple-Gradient Descent Algorithm (MGDA)*, Inria, June 2009, n^{o} RR-6953, 17 p. , http://hal.inria.fr/inria-00389811

[15] J.-A. DÉSIDÉRI. *Cooperation and Competition in Multidisciplinary Optimization : Application to the aero-structural aircraft wing shape optimization*, in "Computational Optimization and Applications", 2011 [*DOI :* 10.1007/S10589-011-9395-1], http://hal.inria.fr/hal-00645787

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[36] A. MINELLI. , *Optimisation de forme aéro-acoustique d'un avion d'affaires supersonique*, Université Nice Sophia Antipolis, November 2013, http://hal.inria.fr/tel-00938396

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[39] C. CHALONS, P. GOATIN, N. SEGUIN. *General constrained conservation laws. Application to pedestrian flow modeling*, in "Networks and Hetereogeous Media", 2013, vol. 8, n° 2, pp. 433-463, http://hal.inria.fr/hal-00713609

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[67] J.-A. DÉSIDÉRI, M. BOMPARD, J. PETER. *Hermitian Interpolation Subject to Uncertainties*, in "Numerical Methods for Differential Equations, Optimization, and Technological Problems", S. REPIN, T. TIIHONEN, T. TUOVINEN (editors), Computational Methods in Applied Sciences, Springer Dordrecht, January 2013, vol. 27, pp. 193-218, The book was dedicated to Professor P. Neittaanmaki on His 60th Birthday [*DOI :* 10.1007/978-94-007-5288-7], http://hal.inria.fr/hal-00765276

[68] A. ZERBINATI, J.-A. DÉSIDÉRI, R. DUVIGNEAU. *Comparison between two multi objective optimization algorithms : PAES and MGDA. Testing MGDA on Kriging metamodels*, in "Numerical Methods for Differential Equations, Optimization, and Technological Problems", S. REPIN, T. TIIHONEN, T. TUOVINEN (editors), Computational Methods in Applied Sciences, Springer Dordrecht, January 2013, vol. 27, pp. 237-252, Book dedicated to Professor P. Neittaanmaki on His 60th Bithday [*DOI :* 10.1007/978-94-007-5288-7], http://hal.inria.fr/hal-00765314

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[72] L. L. OBSU, M. L. DELLE MONACHE, P. GOATIN, S. M. KASA. , *Macroscopic traffic flow optimization on roundabouts*, Inria, April 2013, n° RR-8291, http://hal.inria.fr/hal-00818208

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