Mathematics Area, mathLab
Numerical Analysis Activities

International School for Advanced Studies
SISSA, Trieste

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INTRODUCTION

mathLab (founded in 2010):

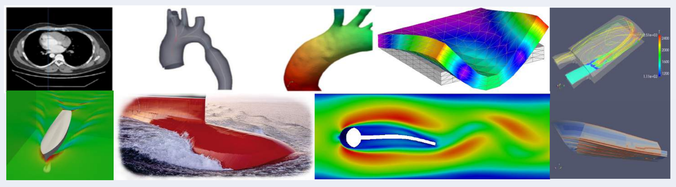
- A laboratory for mathematical modeling and scientific computing devoted to the interactions between mathematics and its applications. An interdisciplinary research center powered by the interest in problems coming from the real world, from industrial applications, and from complex systems.
- A team of scientists pursuing frontier research and new trends in computational mechanics and numerical analysis, while expanding the opportunities for a dialogue across academic and disciplinary boundaries.
- A research group devoted to the development of advanced modeling techniques with focus in Computational Fluid Dynamics (CFD), High Performance Computing (HPC), and Open Source scientific software development, to face and overcome many limitations of the state of the art, and to enable new methodologies for demanding industrial, medical, and applied sciences applications.

Numerical Analysis People:

- Principal Investigators: Luca Heltai, Gianluigi Rozza.
- Postdoc researchers: Francesco Ballarin, Michele Girfoglio, Martin Hess, Efthymios Karatzas, Andrea Mola, Alberto Sartori, Giovanni Stabile.
- Reasearch associates: Nicola Demo, Marco Tezzele.
- PhD students: Shafqat Ali, Giovanni Alzetta, Noe Angelo Caruso, Saddam Hijazi, Nicola Giuliani, Ornela Mulita, Monica Nonino, Federico Pichi, Giuseppe Pitton, Maria Strazzullo, Zakia Zainib, Matteo Zancanaro.
- Master degree students: Stefano Boidi, Jan Gabriel, Giulia Meglioli, Giacomo Zuccarino.
- MHPC students: Cosimo Livi, Simone Martini.

RESEARCH TOPICS

- **Computational Fluid Dynamics** (CFD),
- **Fluid Structure Interaction** (FSI),
- **Control and optimization**,
- **Isogeometric Analysis** (IGA),
- **Uncertainty Quantification** (UQ),
- **Reduced Order Methods** (ROM),
- **High Performance Computing** (HPC),
- **Open Source Software Development**.



More in details: bifurcations and instabilities in flows and structures at moderate/high Reynolds number, turbulent flows, complex geometrical parametrizations, reduced computational and geometrical framework for nonlinear inverse problems, optimal flow control, shape optimization and uncertainty quantification, advanced developments in reduced order modeling, domain decomposition, multiphysics, fluid-structure interaction, general coupled phenomena involving inviscid, viscous and thermal flows, solids and porous media, non-matching discretizations, finite element, finite volume, spectral method and boundary element method.

INDUSTRIAL RESEARCH PROJECTS

- **OpenShip/OpenViewShip**: High-Tech CFD Simulations for Hydrodynamic Performance of the Hull System in OpenSOURCE Environments. Development of a computational ecosystem for the hydrodynamic design of the propeller and hull system. In collaboration with CETENA and eXactLAB.

- **UBE–Underwater Blue Efficiency**: Digital simulation of exhaust emission particles, from the engine, to detachment from the hull, geometries and virtual hydro-aerodynamic appendices, optimal geometries for the exhaust device with the purposes of improving hydrodynamic and environmental emissions efficiency. Innovative configuration of the exhaust manifold, high-fidelity and simplified methods for the prediction of its performance. In collaboration with MonteCarlo Yachts.

- **SOPHYA –Seakeeping Of Planing Hull YAchts**: A research and development project in Maritime Technologies, co-funded by the European Regional Development Fund. General purpose is the study of the correlation between sea-going performance of planed pleasure craft and sea status, with the aim of improving the energy performance of the boat and of the comfort on board. Predicting the parameters of comfort, safety and energy performance in correlation with the waves. Target is to improve the performance of floating hulls in the sea and experiment with new predictive techniques. In collaboration with MonteCarlo Yachts.

- **PRELICA**: Advanced Methods for Hydro-Acoustic Design of Naval Engines which, as a research and development project in Maritime Technologies. The PRELICA project aims at obtaining accurate predictions of the hydro-acoustic emissions of the propulsion that are able to predict irradiated noise at all frequencies, by combining potential methods, RANS and LES, using advanced techniques of numerical modeling and scientific calculus and modern optimization algorithms. In collaboration with CETENA.

- **Danieli**: Collaboration with Danieli Research Center on complex multiphysics and multiphase problems, including turbulence model and fluid-structure interaction.

- **FINCANTIERI Cantieri Navali Italiani**: collaboration in the framework of FSE-HeaD project (European Social Fund, Higher Education and development): Advanced shape optimization and parametrization of hulls for cruise ships.

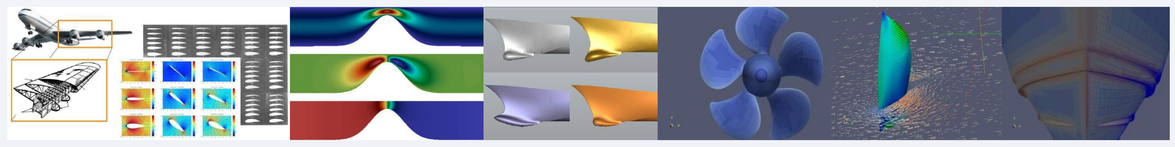
MAIN NATIONAL AND INTERNATIONAL COLLABORATIONS

Politecnico di Milano, Politecnico di Torino, EPFL, ETHZ, MIT, Paris VI, Virginia Tech, Universities of Houston, Toronto, Seville, Trento, Pavia, Brescia, Sapienza–Rome, Ulm, Stuttgart, Muenster, Max Planck Institute Magdeburg, RWTH, Aachen, TU Berlin, TU Eindhoven, École Polythechnique de Paris, Universitat Polythecnica de Catalunia, Penn State University.

We gratefully acknowledge the support provided by:

SCIENTIFIC RESEARCH PROJECTS

Applications in aeronautical, mechanical, naval, off-shore, wind, sport, bio-medical engineering such as cardiovascular surgery, combining high performance computing in dedicated super-computing centers and advanced reduced order modeling, to guarantee real time computing and visualization. Open source software libraries for real time highly advanced computational applications.



- **INDAM–GNCS**: Scientific Computing National Group in the framework of National Institute for Advanced Mathematics, 3 yearly projects (2015-2017) on Reduced order methods and applications with Politecnico di Milano, Politecnico di Torino, Universities of Pavia, Brescia, and Trento.
- **TRIM–INSEAN**: Partnership with CNR-INSEAN, the Italian marine experimental basin, located in Rome in the framework of the technical cluster Trasporti 2020. Development of advanced numerical methods for the simulation, optimization and control of complex systems related with CFD, iso-geometrical techniques, reduced order methods, and parameter space exploration for complex problems.
- **PRIN–Projects of Relevant National Interest**: Mathematical and Numerical Modeling of the Cardiovascular System, and their clinical applications. This project deals with the mathematical and numerical modeling of the cardiovascular system. Applications in medicine and bio-engineering.
- **ERC AROMA–CFD Consolidator Grant**: Advanced Reduced Order Methods with Applications in Computational Fluid Dynamics, advanced methodological developments in numerical analysis, mathematical modeling and extensive exploitation of computational science and engineering, providing attractive capabilities for several industrial and medical applications (PI: G. Rozza).
- **EID ROMSOC**: European Industrial Doctorate, ROMSOC network, Reduced Order Modeling for Simulation, Optimization and Control (H2020 ITN, PI: G. Rozza) with Danieli.
- **MIUR–FARE**: Project on advanced numerical methods for computational and parameter space reduction with application to compressible flows (2017-2021), Italian Government special program as incentive for ERC winners in H2020 (PI: G.Rozza).

OPEN SOURCE SOFTWARE

- **deal.II**: A C++ software library supporting the creation of finite element codes and an open community of users and developers.
- **ITHACA**: In real Time Highly Advanced Computational Applications Reduced Order Modeling implementation in C++.
- **ITHACA–FV**: In real Time Highly Advanced Computational Applications for Finite Volumes is C++ library based on the finite volume solver OpenFOAM. It consists of the implementation of several reduced order modeling techniques for parametrized problems.
- **WaveBEM**: Nonlinear Unsteady Potential Flow Solver for Ship-Wave Interaction Problems is an open source software for ship hydrodynamics simulations currently under development at SISSA mathLab.
- **RBniCS**: Reduced order modeling implementation in FEniCS of several reduced order algorithms including certified reduced basis methods and Proper Orthogonal Decomposition-Galerkin methods for parameterized problems. It is ideally suited for an introductory course on reduced basis methods and reduced order modeling, thanks to an object-oriented approach and an intuitive and versatile python interface.
- **multiphenics**: Python library that aims at providing tools in FEniCS for an easy prototyping of multi-physics problems on conforming meshes. In particular, it facilitates the definition of subdomain/boundary restricted variables and enables the definition of the problem by means of a block structure.
- **PyGeM**: Python package using Free Form Deformation, Radial Basis Functions and Inverse Distance Weighting to parameterize and morph complex geometries. It is ideally suited for actual industrial problems, since it allows to handle: Computer Aided Design files (in .iges, .step, and .stl formats) - Mesh files (in .unv and OpenFOAM formats) - Output files (in .vtk format) - LS-Dyna Keyword files (.k format).
- **π-BEM**: A C++ parallel BEM library, directly interfaced with CAD files, providing Fast Multipole acceleration, high order capabilities, local refinement, and hybrid MPI-multithreaded parallelization.
- **π-DoMUS**: A C++ parallel multi-physics solver, based on the deal.II library, exploiting open source HPC libraries for the fast prototyping of complex multi-physics problems.
- **EZyRB**: Python library for the Model Order Reduction based on barycentric triangulation for the selection of the parameter points and on Proper Orthogonal Decomposition for the selection of the modes. It is ideally suited for actual industrial problems, since its structure can interact with several simulation software simply providing the output file of the simulations.
- **PyDMD**: Python Dynamic Mode Decomposition, a software related to recent mathematical innovation that allows us to solve or approximate dynamical systems in terms of coherent structures that grow, decay, and / or oscillate in time.

https://mathlab.sissa.it/cse-software

EDUCATIONAL INITIATIVES INVOLVING MATHLAB

- **MHPC**: the *Master in High Performance Computing* is an innovative master degree program that combines lectures with hands-on sessions and applied projects to train HPC specialists for both academia and industry.
- **AMMA**: the PhD program in *Mathematical Analysis, Modeling, and Applications* enables PhDs to work as high level researchers in mathematical and numerical analysis.
- **MATH**: mathLab collaborates with the University of Trieste in offering high level training courses for the Master's degree in Mathematics.
- **DSSC**: mathLab contributed to the creation of the new Master's degree in *Data Science and Scientific Computing*, in collaboration with the University of Trieste, the University of Udine, and ICTP.
- **MCS**: mathLab covers some of the classes of the *Master in Science Communication "Franco Prattico"*, a training course to offer the best professional opportunities in an ever-changing context.

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