ISSUE 1

ARIA Newsletter

July 2020

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***ARIA** aims to form an international and intersectoral network of organizations working on a joint research program in numerical modelling, specifically in the fields of model reduction and convergence between data and models.*

EDITORIAL

Welcome to the first issue of the ARIA newsletter. The objective of this newsletter is to keep the consortium updated with the main activities that are going on during the project, summarize the main interesting results in terms of secondments, training, scientific results and dissemination activities. Additionally, we want to reach a wider audience by communicating our main outcomes in order to find more opportunities of collaborations and ideas exchange with interested readers outside the consortium.

Our newsletter will be published every 6 months. Each issue will be available for download from the ARIA web site at http://www.rise-aria.eu . In this first issue we introduce the project, the consortium, our kick-off event and secondments implemented during the period. We are very happy to have in this issue an interesting article on “the Chimera mesh and ROMs in Computational Fluid Dynamics by Michele Giuliano Carlino, Inria Bordeaux.

The next issue will be published in January 2021 in which we will report results from our secondments, selecting highlights on the major research results.

Stay tuned and happy reading !

The project has received funding from the European Union’s Horizon 2020 research and innovation programme under the Marie Sklodowska-Curie grant No 872442

THE ARIA PROJECT

ARIA (**Accurate Roms for Industrial Applications**) project aims to form an international and intersectoral network of organizations working on a joint research program in numerical modelling, specifically in the fields of **model reduction and convergence between data and models**.

Participants to ARIA project will exchange skills and knowledge through secondments and thematic workshops, to make progress towards key advances in modeling multi-scale nonlinear physical phenomena. ARIA will also strengthen collaborative research between different countries (France, Germany, Italy, Spain) and sectors fostering applications in industrial flow control and optimization, and computer assisted surgery. Advances in flow control and optimization will have potential market opportunities for non-academic participants in the project towards greener terrestrial vehicles, more efficient wind farms, revolutionary cost-efficient prediction software's, and decision-making support tools for diagnostic and prognostic of vascular diseases, with a significant benefit for European society.

ARIA is a Horizon 2020 project under the programme Marie Sklodowska-Curie Actions - Re-search and Innovation Staff Exchange (RISE) for boosting the carrier perspectives of researchers through staff exchange.

THE ARIA PROJECT IN 5 QUESTIONS

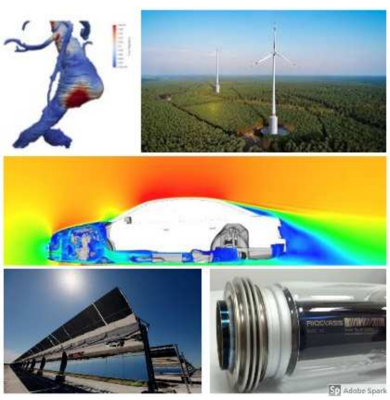
What is Reduced Order Models (ROMs)?

Reduced-order models (ROMs) are simplified mathematical models derived from the full set of partial differential equations governing the physics of the phenomenon of interest. We focus on ROMs that are data-driven as they are based on relevant solution data previously obtained. **With ROMs one trades accuracy for speed and scalability**, and counteracts the curse of dimension by significantly reducing the computational complexity. ROMs represent an ideal building block of systems with real-time requirements, like interactive decision support systems that offer the possibility to rapidly explore various alternatives. For that reason, ROMs are receiving high attention by industrial end-users, e.g., for applications like interactive aerodynamic vehicle design, real-time operational optimization of wind farms, and the optimization of medical devices for patient-specific therapies, as also shown by the **large spectrum of industrial participation** to ARIA project.

What are the key objectives of ARIA project?

The key objectives of ARIA are:

- Advance the state-of-the-art in projection-based ROMs by leveraging ideas from large eddy simulation (LES).
- Enhance data-driven modeling via data-geometry inference tools such as manifold learning, solution classification and clustering, adaptive sampling. Integrate ROMs into a multi-fidelity model chain using rigorous error indicators and assess performance in cases of industrial and applicative interest.



The four case studies to be implemented in ARIA:

- *Nurea - a test case on vascular disease problem*
- *VW – a test case on Ahmed body problem*
- *Valorem – a test case on wind engineering problem*
- *Virtualmech – a test case on heat transfer problem*

How can ARIA form an international collaboration for shared culture of research and innovation ?

ARIA will bring together a sizeable research team, drawn from Europe's universities, research establishments, SMEs and a large company, together with international non-EU academic partners (Stanford University, University of South Carolina, Virgina Tech, USA). The inclusion of a diverse panel of industries such as a multinational car company (VW), of a vascular disease start up (Nurea), data intelligence company (ESTECO) of a wind engineering company (Valorem) and the other companies will increase the innovation capacity of European industry through interaction of different industrial cultures with advanced data-driven modeling tools.

One of the main goals of the project is to create new contacts between the academic and the industrial world. This will give rise to new projects and industrial PhD programmes, thus creating a solid bond between university and industry. Hence, the project will contribute to knowledge, international cooperation, innovation partnerships and help to bring good ideas to market.

How do participants of ARIA project exchange skills and knowledge as well as to strengthen collaborative research?

Participants to ARIA project will exchange skills and knowledge through secondments and thematic workshops, which will allow them to progress towards key advances in modeling multi-scale nonlinear physical phenomena. This project will strengthen collaborative research between different countries (France, Germany, Italy, Spain) and sectors fostering applications in industrial flow control and optimization, and computer assisted surgery. Advances in flow control and optimization will have potential market opportunities for non-academic participants in the project towards greener terrestrial vehicles, more efficient wind farms, revolutionary cost-efficient prediction software's, and decision-making support tools for diagnostic and prognostic of vascular diseases, with a significant benefit for European society.

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The goal of ARIA is to reduce the amount of time taken to develop models, which will enable researchers and engineers to make decisions more quickly. This will also involve employing data that has previously been simulated in prior experiments. The objective is to reduce the time spent on new models, aiming for convergence between data and models.

What are the new and important directions that the project will approach?

Specifically, ARIA aims to expand and take in new and important directions:

- Large-eddy simulation (LES) and filtered ROMs: we propose data-driven modeling and real-time, robust optimization algorithms to develop online-adaptive ROM closure models for realistic turbulent flows.
- Refinement/enrichment of reduced bases: new basis interpolation based on manifold learning, new measure-based sampling methods and Uncertainty Quantification (UQ), rigorous error bounds/indicators.
- Testing of a fairly recent ROM technique, namely the Hierarchical Model (HiMod) reduction, as a procedure per se, and in combination with well-established ROM approaches such as POD and reduced bases.
- Applications to car, wind mills aerodynamics and vascular disease prediction and control.

THE KICK-OFF MEETING

The Kick-off meeting was held online on 4 March 2020. In this first plenary meeting, the leaders and deputies for each Work Package were defined, the most pressing actions points were determined and the next consortium meetings were scheduled. The objectives of this kick-off meeting were:

- To gather consortium members and discuss details on project implementation
- To have a common understanding of the RISE rules, across the consortium
- To identify researchers to be seconded and agree on secondment plan
- To discuss financial arrangements within the consortium and other relevant aspects of the partnership agreement (IPR, Open Access, etc)
- To discuss potential risks and mitigating measures
- To identify/discuss minor changes since the submission of the proposal

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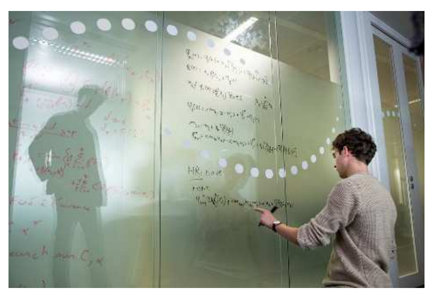
THE SECONDMENTS

Until July 2020, there has been 5 secondments

- 4 secondments from Inria, Bordeaux, France to Optimad, Turin, Italy to work on Work Package 3 – Data topology inference
- 1 secondment from Inria, Bordeaux, France to Standford University, USA to work on Work Package 3 – Data topology inference

The secondments from Inria to Optimad were working on the following subjects:

- high-fidelity monolithic model for the simulation of fluid-structure interactions (FSI)
- discontinuous Galerkin model for shallow water equations



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The secondment from Inria to University of Standford was to investigate the accuracy and the computational cost of a local approach for the stabilization of reduced-order models in presence of strong convection, large gradients and discontinuities for industrial applications.

There will be publications planned after these research visits.

THE CONSORTIUM

Inria Bordeaux, located in France, will provide in ARIA project a reciprocal embedding of junior and senior researchers in industry to understand the structure, the needs, the timings and the constraints actually encountered in real applied mathematics practice.

Volkswagen (VW) Group Research in Germany is looking into the possibility of leveraging ROM for real-time aerodynamic computations of parameterized vehicle geometries. By the end of the project, VW – within the ARIA consortium – will have settled a ready-to-use ROM process for unsteady flows around parameterized vehicles of realistically high dimension.

Valorem in France has high interest in the modelling of the wake of wind turbines that has a significant impact on the production of other wind turbines so the improvement of currently used numeric tools is an actual objective.

Virtualmech in Spain has interest in ROM for Industrial applications related to Renewable Energies: Concentrated Solar Thermal Power and Wind Turbines.

University of Seville (USE) will share its expertise on numerical analysis of ROMs and turbulence models. The USE team has a three-decades experience in mathematical modeling and numerical analysis of turbulent flows, especially by Variational Multiscale (VMS) methods, and on the derivation of certified ROMs (reduced basis models) for incompressible turbulent flows, based upon sound mathematical grounds.

Optimad in Italy has interest in integrating heterogeneous data obtained from different sources into one query model.

Politecnico di Torino (Polito) in Italy will provide insight in the numerical models that will be derived for ROMs based on a sound numerical expertise. On the other hand, Polito will exploit the reduced models themselves and the approaches developed for model sampling in the framework of UQ.

SISSA in Italy will contribute with its expertise on two different topics: reduced Order Modelling for cardiovascular flows and geometrical morphing for shape optimization. SISSA will provide to the consortium state of the art methods and tools that were implemented as open source packages during the last years.

Politecnico di Milano (Polimi) in Italy will offer to the ARIA project partners the expertise gained in ROM techniques and model adaptivity.

IEFLUIDS will contribute to the partnership with its experience in developing and applying LES modeling to practical industrial and environmental problems, for example to wind turbine wake interaction over complex terrain and wind farm micrositing, and in general to high Reynolds number flows in complex geometry.

ESTECO will help manage tools for handling the huge information volumes generated by simulation effectively. On the other hand, ESTECO will develop and evaluate ROM technology to improve the agnostic automated process of design exploration and optimization that represents its core business.

Nurea will bring its medical application expertise to the ARIA project. The development of ROMs is of great interest in order to provide fast and efficient simulations of blood flows in vessels to extract clinical indicators of the evolution of cardiovascular pathologies.

In ARIA project, there are also 3 non-EU academic partners in USA:

Stanford University will contribute with its unique expertise in optimization and ROMs with Grassman interpolated basis

University of South Carolina, Virgina Tech will contribute with their unique expertise on LES-ROM approaches to high Reynolds number flows. In particular Virginia Tech will provide expertise in the development, analysis, and testing of novel LES-ROMs and regularized ROMs (Reg-ROMs).

The Chimera mesh and ROMs in Computational Fluid Dynamics

Michele Giuliano Carlino, Inria Bordeaux, France

Among the challenges involving the computational sciences, and in particular for problems of fluid-structure interaction, the evaluation of the trade-off between the size of the computational domain and the accuracy of the boundary conditions is playing an essential role capable, actually, of modifying, guiding and directing the entire process of creating and designing a numerical method with the ultimate goal of reducing the cost and computational time as much as possible without sacrificing a knowledge of the phenomenon that is being simulated around the boundaries that define the solid structure. As a matter of fact, as has been known for decades in the literature, the most significant information in physical phenomena in which a fluid comes into contact with a solid structure certainly thickens in a certain region confined to the boundary of the structure and, in the case of high speed fluids with a relatively low viscosity (Reynolds' high number simulations), turbulence phenomena can occur precisely as a result of the "fluid-structure interaction".

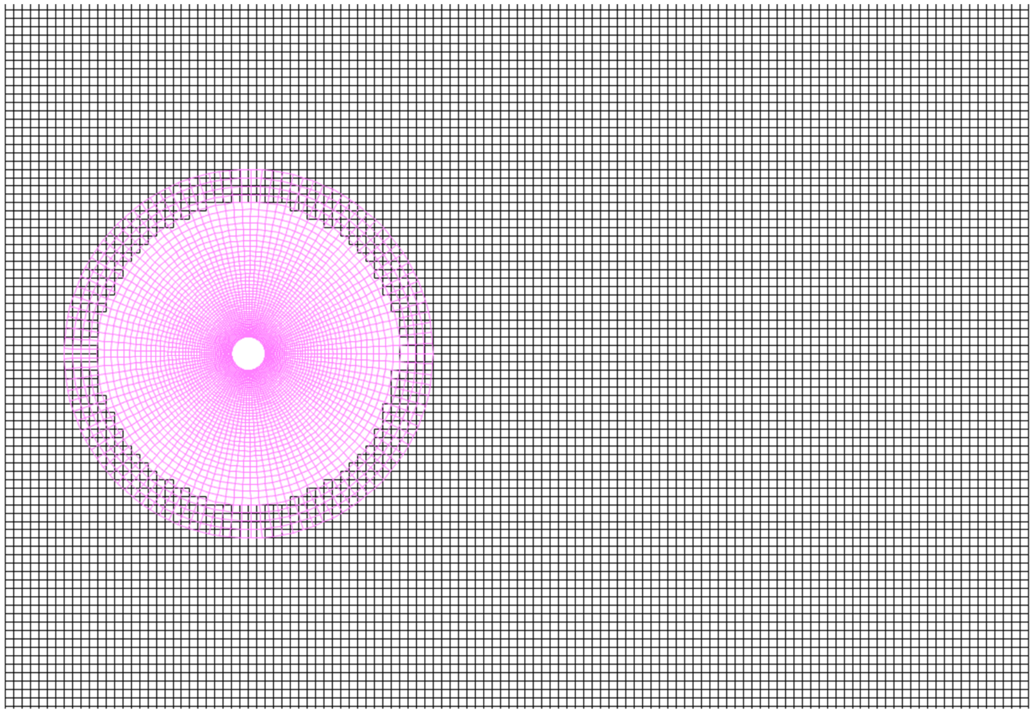
Under this assumption, one numerical strategy consists in decomposing the computational domain into two sub-regions, that are said subdomains, by identifying one that circumscribes the structure and one that is, instead, defined by the points "relatively" far away from the solid structure. Once the two subdomains are identified, a Full Order Model (FOM) is performed in the near-structure zone (high fidelity zone) and a Reduced Order Model (ROM) is employed in the other region (low fidelity zone) where effectively nonlinear, viscous or rotational effects decay due to the non proximity of the solid body. This allows to reduce the computational costs and the consequent CPU times of order of magnitudes with respect to those ones of a FOM computed all over the domain.

The domain decomposition technique induces to design also the partitions (or tessellation) over which the several solutions will be discretised. In fact, in order to increasingly reduce the computation, one could think to cover the two subdomains with two partitions that do not geometrically match at the sub-boundaries (see the figure). As a consequence, a third region appears (overlapping zone) defined as the intersection of both high and low fidelity zones. A patch of partitions like this is known in literature as chimera mesh or overset grid. In this context, the overlapping zone will be a zone for transmitting information from the high fidelity zone to the low fidelity zone and vice versa.

Another advantage of using a chimera mesh coupled with a low/high fidelity approach is the possibility of simulating deforming and moving bodies (e.g. a simulation of a fluid around a wind turbine blade). In this case the high fidelity zone is mobile and its partition adapts on the particular deformation of the body; consequently the low fidelity zone as well as the overlapping zone change in accordance with the movement of the low fidelity zone.

One of the goals within the ARIA project consists in coding and studying the numerical scenario of the mobile zones in order to obtain accurate solutions without incurring in the curse of dimensionality arising from a FOM model in the context of complex fluid-structure interactions for which the structure is deforming due to the interaction itself.

In particular, the two teams INRIA Bordeaux and OPTIMAD Engineering in Turin are collaborating in order to enhance the transmission of data between the two mesh in the overlapping zone by preserving the possibility to parallelise the processes of computation.



A chimera mesh for a cylindric structure. The black partition defines the low fidelity zone. The blue partition circumscribes the high fidelity zone. Where black and blue cells cover the same subregion there is the overlapping zone.

The project has received funding from the European Union's Horizon 2020 research and innovation programme under the Marie Sklodowska-Curie grant No 872442.

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ARIA Contact

contact@rise-aria.eu

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Project Coordinator

Angelo Iollo | angelo.iollo@inria.fr

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