ISSUE 2

ARIA Newsletter

January 2021

Inside This Issue

***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 second issue of the ARIA newsletter.

In the second half of the first year, we had 4 more secondments implementation that makes the total number of 9 secondments in 2020. All these secondments are related to the work in Work package 3 - Data topology inference. Due to the pandemic, several secondments have been delayed until 2021.

We are also happy that the research results have been published in journal articles. The two recent articles are: A cure for instabilities due to advection-dominance in POD solution to advection-diffusion-reaction equations by Mejdi Azaïez, Tomás Chacón, Samuele Rubino and Efficient estimation of cardiac conductivities: A proper generalized decomposition approach by Alessandro Barone, Michele Giuliano Carlino, Alessio Gizzi, Simona Perotto, Alessandro Veneziani. Our papers are available for download at the project website: https://project.inria.fr/aria/publications/

From May 2021, we will organize free seminars open to public every two month with valuable talks around the topic on Reduced Order Model (ROM) for industrial application. We will give you updates on our technical deliverables with high –profile invited speakers in the domain.

The next issue will be published in July 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

ARIA'S SECONDMENTS

M. Carlino from Inria, France to Optimad, Italy

M. Carlino at Inria had 12 month secondment at Optimad in total. During the first half of his secondment, he worked on the integration of computational tools developed in OPTIMAD with his PhD research study for the numerical solution of Navier-Stokes equations for incompressible fluids over Chimera meshes. On the other hand, the secondment enabled him to achieve additional practical meaning to his thesis topics by providing possible applications not only in the academic but also in the industrial field. He deeply investigated on the stability of the Finite Volume method for the solution of a generic unsteady Diffusion-Convection equation. This new approach combined with a Chimera grid allows to improve the already present technology used in Optimad for revealing the numerical solution of the Navier-Stokes equations in the frame of fluid – structure interaction.

In the second part of his secondment from September 2020 to January 2021, through the industrial knowledge in Optimad, he deeply investigated the algorithm for problems of fluid structure interaction with the use of overlapping and deforming Chimera grids. In particular, the Chimera mesh is able to geometrically fit the shape of the structure and to follow its movements and deformations during the simulation. For this reason a Full Order Model is employed on the foreground (i.e. moving) mesh and a Reduced Order Model is employed on the remaining background (i.e. fixed) mesh, by reducing the computational costs.

A.Iollo and T. Taddei from Inria, France to Optimad, Italy

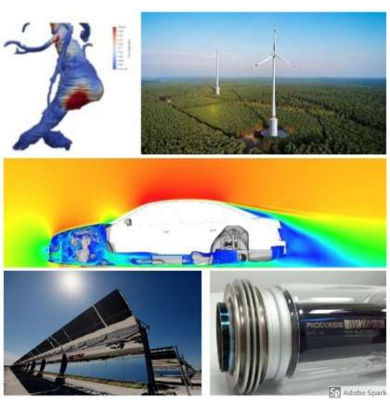
A. Iollo and T. Taddei spent two weeks in Turin in July 2020. They worked with research engineers at Optimad: Edoardo Lombardi, Angela Scardigli and Haysam Telib. Together they focused on the first test case identified by Volkswagen, namely a three-dimensional turbulent flow past a parameterized Ahmed body. Despite its geometric simplicity, the Ahmed body problem represents a standard test case that exhibits key features (flow separation, turbulence, parameterized geometry) of practical parametric problems. During their stay, AI and TT worked on the development of a general registration procedure to "track" relevant features of the solution field, to ultimately simplify and improve performance of the learning process for a given set of data. Current work includes parameter space sampling at Optimad and subsequent analysis at Inria and Optimad.

M. Mrosek from Volkswagen AG, Germany to SISSA, Italy

The purpose of the secondment is to develop a projection-based Reduced Order Model (ROM) for automotive vehicle aerodynamics with geometric parametrization.

During this secondment, M. Mrosek had a training in the application of the ROM library ITHACA -FV for OpenFOAM and application of Proper Orthogonal Decomposition (POD) -Galerkin ROM to the Volkswagen ARIA vehicle aerodynamics test case: Ahmed body. He also investigated the neural network accuracy for turbulent viscosity.

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 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*

Participation of University of Seville in ARIA Project

Tomás Chacón, University of Seville, Spain

The participation of the University of Seville (USE) team within ARIA Project stems from its expertise in turbulence modeling, reduced order approximation (ROM) of turbulence models and numerical analysis of Stabilized and Variational Multi-Scale (VMS) methods for fluid flows. We have applied this knowledge to energy analysis of buildings in an inter-disciplinary collaboration. We have long-lasting collaborations on ROM with several of the teams participating in ARIA, especially with those leaded by M. Azaïez in Bordeaux, G. Rozza in Trieste and the VirtualMech company, leaded by J. Valverde, in Sevilla. The US team is formed by Tomás Chacón (WP2 leader), Macarena Gómez and Soledad Fernández (Senior researchers), Samuele Rubino (post-doctoral researcher), and Alejandro Bandera and Cristina Caravaca (Ph D students).

The main role of USE within the ARIA Project is the management of Work Package Two. Its general objective is to develop advanced ROMs (RB, POD, HiMod) for incompressible turbulent and unsteady flows in CFD, understood as one of the essential tools to perform accurate LES in affordable times and in many-query contexts (e.g., design, optimization, control, sensitivity analysis or parameter identification). The methodology is based upon stability analysis and certified by error estimators constructed on sound mathematical grounds for better prediction and characterization.
The USE team participates in the reduced modeling of wind turbines, flow around cars and blood flow, in collaboration with IEFLUIDS, INRIA, Optimad, Politecnico di Milano, SISSA, Valorem, Volskwagen and VirtualMech.

Several classical and up-to-date LES turbulence models (dynamic subgrid-scale, Smagorinsky, VMS-Variational Multi-Scale, LPS-Local Projection Stabilization) in the context of ROMs are being considered in WP2, in order to derive the most performing ROMs for LES of turbulent and unsteady flows. These are mathematically rather well understood turbulence models, thus able to generate computationally efficient ROM versions by means of numerical analysis. Innovations would be made in the methodology of ROMs implementation to improve their efficiency and accuracy as well as in treating the number of parameters involved.

WP2 is split into 4 technical tasks:

- Analysis of stability and accuracy of ROMs for incompressible convection-dominated laminar and transient flows,
- Development and implementation of ROMs for incompressible turbulent unsteady flows,
- Development and implementation of ROMs for incompressible turbulent flows in multi-parameter frameworks and
- Computational framework for the simulation of realistic industrial flows and in clinical practice.

We expect that the complementary expertise on ROMs, numerical analysis and turbulence modeling of all involved partners in this work package will produce a true breakthrough on one of the major computational hurdles in the development of accurate ROMs for turbulent and unsteady flows. This will enable advanced turbulence ROMs to be applied in realistic industrial flows applications considered in ARIA as well as in the modeling of blood flow in patient-specific geometries in the presence of circulatory diseases.

Reduced Order Models for Interactive Aerodynamic Vehicle Design

Carsten Othmer, Volkswagen AG, Germany

Among the various technical challenges to overcome when developing a new car, the design of the exterior car shape constitutes probably one of the most formidable problems. It is where two disciplines of utmost importance for market success and sustainable mobility meet: aesthetics and aerodynamics. Naturally, the whole car development process consists of negotiating optimal compromises between different, partly contradicting technical objectives and requirements. The peculiarity about the external shape is, however, that one of the objectives – aesthetics – cannot be quantified. The creation of a beautiful yet aerodynamically efficient car shape therefore requires a close and continuous collaboration between the styling department and the aerodynamic experts.

What renders this collaboration even more complicated is the discrepancy in the time scales on which these two disciplines progress: While the stylist in his/her form-finding process is applying model changes in a practically continuous fashion, each single computational aerodynamic evaluation costs a couple of days on significant computer hardware – including geometry preparation, solving and post-processing the results. As a result, the aerodynamic evaluations can hardly keep track with the evolution of the shape styling, and the interplay between aerodynamics and aesthetics can become very inefficient (see Fig. 1, top).
Several approaches have been pursued in the past to address this problem: (i) accelerating the computations by a factor of three to four by switching from Finite-Volume computations on CPU-hardware to the Lattice-Boltzmann method on GPUs [1], or (ii) enriching the information output from each single computation with adjoint-based sensitivity information to not only assess the current shape but to also communicate possible favorable shape changes to the styling colleagues [2].

However, even with those tools systematically integrated into the aerodynamic process, the collaboration between styling and aerodynamics remains an iterative one, slowed down by the still significant computational turnaround time for the aerodynamic assessment. A real game changer would be to run the aerodynamic simulation in real-time, i.e. in a few seconds, and thereby allowing for a truly interactive aerodynamic design process, with stylists and aerodynamics evaluating and optimizing both aesthetics and aerodynamics concurrently in joint sessions (see Fig. 1, bottom).

It is this Interactive Aerodynamic Design (IAD) process that we are heading for at Volkswagen and that motivates our participation in the ARIA project. Because even with further hardware accelerations, real-time aerodynamics with accuracy levels that fulfill industrial requirements will remain out of reach for conventional solver technologies, and a promising path – if not the only one – to real-time capabilities are Reduced Order Models (ROMs). Already before the ARIA start, we experimented with the classical ROM approach of POD+I (Proper Orthogonal Decomposition + Interpolation, [3]), based on a parametric vehicle geometry. While we concluded from this study that ROM is a promising choice as enabling technology for our intended IAD process, we realized at the same time that the lack of physics of pure interpolation is likely to undermine the industrial accuracy requirements especially at the boundaries of the design space. With our partners in ARIA, we are therefore addressing the inclusion of more physics in the model reduction process – among others via residual minimization, Galerkin and/or Petrov-Galerkin projection. Check out Markus' article in this newsletter to learn about our first results on that.

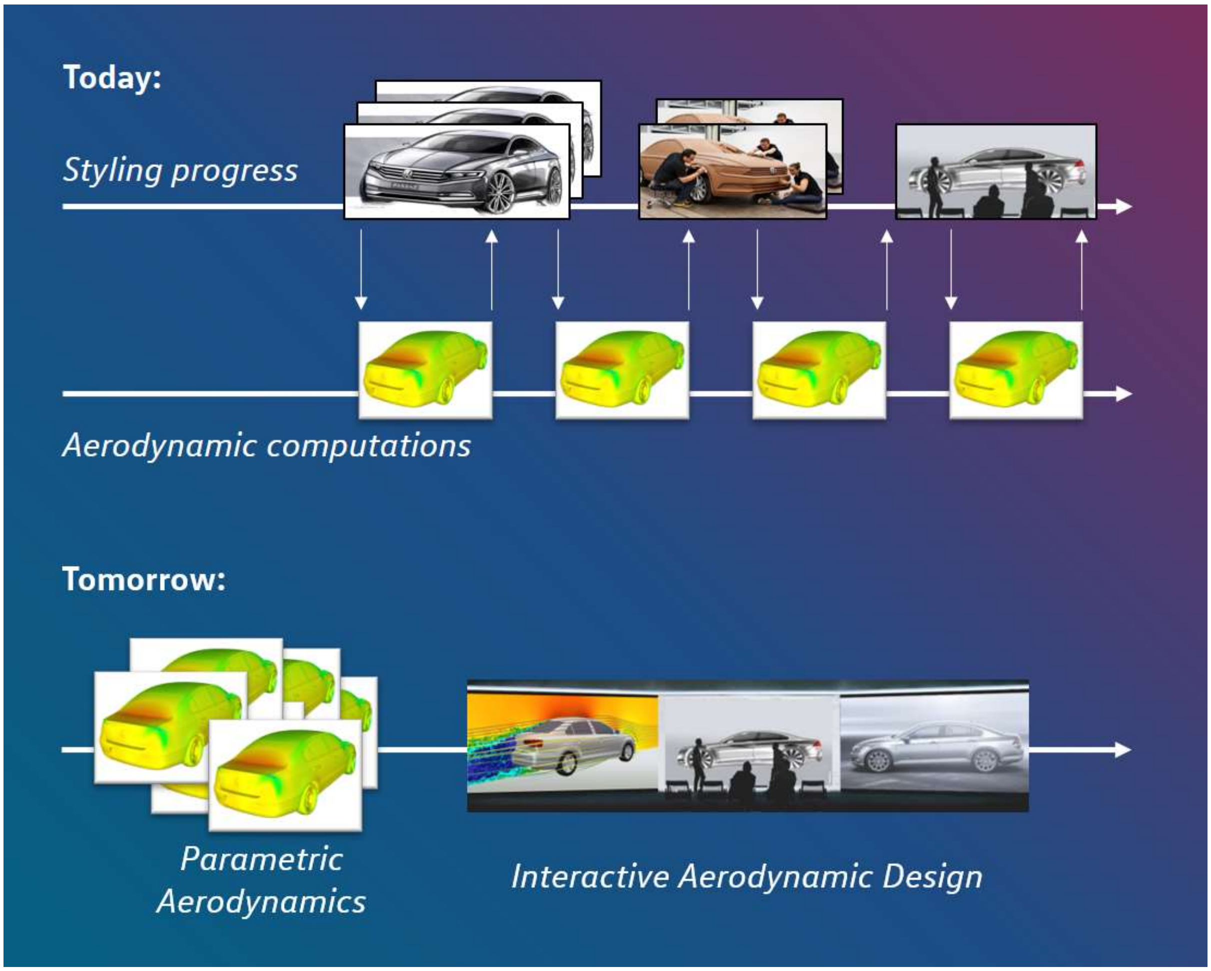


Figure 1: Illustration of the interplay between styling and aerodynamics in the development of an exterior car shape: iterative (top) vs. interactive (bottom).

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Real-time Automotive Aerodynamics for Parametrized Vehicles via Projection-based Reduced Order Models (ROM)

Markus Mrosek, Volkswagen AG

As explained in Carsten's article in this newsletter, already before ARIA, we have seen the well-known ROM Proper Orthogonal Decomposition + Interpolation (POD+I) to deliver accurate and reliable predictions for automotive aerodynamics [1]. However, POD+I – due to its interpolation-based nature – shows deficiencies close to the design space boundaries and for small training data sizes. Projection-based ROMs promise to overcome these shortcomings; additionally, they should, to some extent, enable accurate extrapolation outside of the design space. In collaboration with Gianluigi Rozza's group at SISSA, a projection-based ROM was applied to the Volkswagen ARIA test case, the Ahmed body.

The Ahmed body was equipped with one geometrical parameter – the slant angle with a range from 15 to 35 degrees – using a radial basis function mesh morphing. The parameter range was uniformly sampled with 50 RANS computations using OpenFOAM®, thereby saving every 40th of the total 2000 iterations as snapshots (thus resulting in 50 snapshots per simulated slant angle).

Particular challenges for the projection-based ROM are the geometric parametrization and the turbulence modeling. To deal with the geometrical parametrization, a POD-Galerkin ROM following the approach described by Stabile et al. [2] was created with ITHACA-FV (https://github.com/mathLab/ITHACA-FV), a library for OpenFOAM developed by SISSA. Both the velocity and pressure were projected into the POD subspace and the system of equations in the reduced level is – as for the full order model (FOM) – solved with the SIMPLE algorithm. To make the ROM independent from the employed turbulence model in the FOM, a data-driven approach is employed for the turbulent viscosity: a neural network is trained via the Python library PyTorch that takes the POD coefficients for velocity and the slant angle as the inputs and maps them to the POD coefficients of the turbulent viscosity as the output. This model was assessed in detail and found to be very accurate.

To evaluate the accuracy of the flow field predictions, the 50 RANS computations were divided evenly into 25 train and 25 test samples. As aerodynamicists are mainly interested in the averaged flow fields, the converged solutions were compared between FOM and ROM to assess the ROM accuracy. For a test geometry with slant angle of 17.9 degrees, the ROM predictions matched excellently with the corresponding FOM solution (see Figure 1). Besides the fields, the aerodynamic coefficients, in particular the drag coefficient, are of utmost importance. Currently, SISSA and Volkswagen are enhancing the prediction of surface pressure and wall shear stress to obtain accurate drag coefficients by the integration of these fields over the Ahmed body surface.

SISSA and Volkswagen plan to publish the current status in the special issue "Reduced Order Models for Computational Fluid Dynamics" of the Fluids Journal. While the results so far have been promising, they have – for simplicity – been focused on RANS computation. In the future, the extension to unsteady simulations remains to make the ROM amenable to DES (Detached Eddy Simulations) computations, which have become the state-of-the-art in the automotive industry.

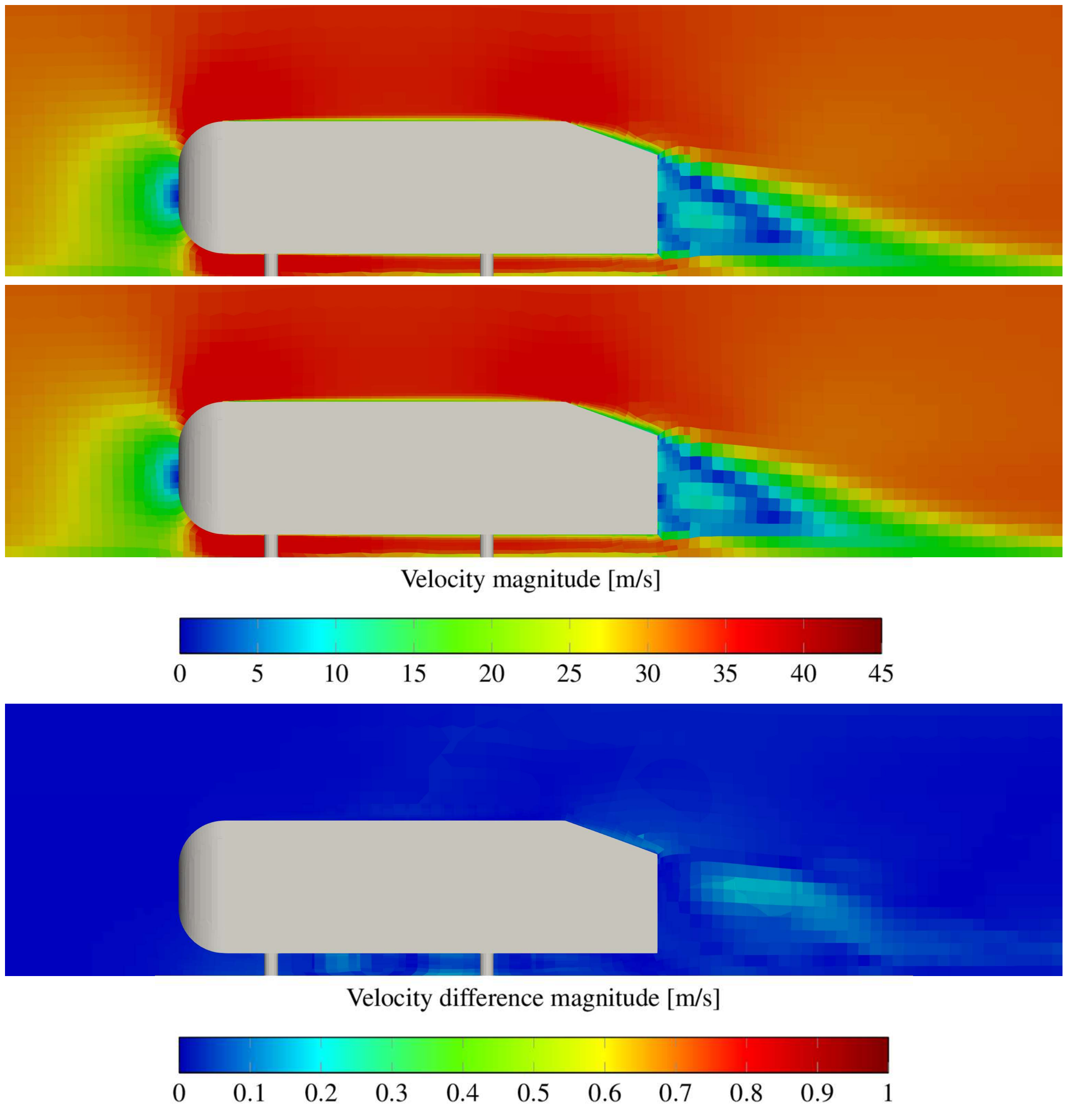

Figure 1: Qualitative comparison of the velocity field in the centerplane of the Ahmed body: Full Order Model (FOM) results (top), Reduced Order Model (ROM) prediction (middle) and the difference (ROM – FOM, bottom) .

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