MODEL ORDER REDUCTION AND SCIENTIFIC MACHINE LEARNING FOR CFD

LEONIDAS GKIMISIS*, MARCO TEZZELE† AND GIANLUIGI ROZZA°

* Computational Methods in Systems and Control Theory Group, Max Planck Institute for Dynamics of Complex Technical Systems, Sandtorstrasse 1, Magdeburg, Germany 39106
E-mail: gkimisis@mpi-magdeburg.mpg.de

† Department of Mathematics, Emory University, 400 Dowman Drive, Atlanta, GA, USA 30322
E-mail: marco.tezzele@emory.edu

° Mathematics Area, mathlab, SISSA (International School for Advanced Studies),
Via Bonomea-265, Trieste, Italy 34136
E-mail: grozza@sissa.it

Key words: Model reduction, data-driven modeling, scientific machine learning, computational fluid dynamics

ABSTRACT

This minisymposium addresses topics at the intersection of model order reduction (MOR) and scientific machine learning (SciML), applied to computational fluid dynamics (CFD).

Developments in hardware enable increasingly more complex and large-scale CFD simulations, however their computational cost often limits their use in real-time and many-query contexts. Such applications include real-time control, optimization, uncertainty quantification, and data assimilation in the context of digital twins, for example. They require inexpensive computational models that can produce fast and accurate predictions. MOR and SciML provide methodologies that can complement or substitute traditional high-fidelity models by reducing model complexity while retaining essential physical behavior [1, 2].

Despite the spread of MOR and SciML methods, several challenges remain, such as achieving robust generalization across different flow configurations, promoting stability and consistency in reduced or learned models, and effectively leveraging available data, which may be limited, noisy, or heterogeneous. The incorporation of physics-based principles into data-driven frameworks remains a key topic, as does the development of reliable approaches for uncertainty quantification, error estimation, and domain decomposition. These aspects are particularly important for further exploring the capabilities and limitations of MOR and SciML tools for predictions used in large-scale, CFD applications.

The minisymposium aims to bring together contributions from applied, computational, and theoretical perspectives that explore some of the aforementioned challenges. Contributions

spanning both intrusive and non-intrusive reduced order modeling are encouraged, reflecting the range of perspectives and current trends in the MOR community. The minisymposium also welcomes presentations addressing scalable computational strategies employing MOR and SciML, including domain decomposition multiscale techniques, as part of broader efforts to tackle large-scale fluid dynamics problems. The goal of the minisymposium is to highlight the potential of MOR and SciML in CFD, foster scientific discussions in the computational engineering community and indicate shared challenges across different schools of thought in this research field.

REFERENCES

[1] F. Chinesta, A. Huerta, G. Rozza, K Willcox, Model Reduction Methods, Encyclopedia of Computational Mechanics Second Edition, 1-36, 2017

[2] P. Benner, S. Gugercin, K. Willcox, A Survey of Projection-based Model Reduction Methods for Parametric Dynamical Systems, SIAM Review 57 (4), 483–531, 2015