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STABILITY-AWARE TIME INTEGRATION FOR REDUCED ORDER MODELS FOR INCOMPRESSIBLE FLOWS

Josep Plana-Riu[*], **Henrik Rosenberger**[†,‡], **Benjamin Sanderse**[†,‡], **and F. Xavier Trias**[*]

[*] Heat and Mass Transfer Technological Center (CTTC), Technical University of Catalonia (UPC)
Carrer de Colom 11, 08222 Terrassa, Spain
e-mail: josep.plana.riu@upc.edu

[†] Centrum Wiskunde & Informatica (CWI)
Science Park 123, 1098 XG Amsterdam, the Netherlands

[‡] Centre for Analysis, Scientific Computing and Applications (CASA)
Eindhoven University of Technology
PO Box 513, 5600 MB Eindhoven, the Netherlands

ABSTRACT

The numerical simulation of reduced order models (ROMs) for incompressible fluid flow, as for any other time-dependent problem, requires the selection of an appropriate timestep. This timestep selection, in case of using an explicit scheme such as the Runge-Kutta family, is usually driven by stability considerations, which has been studied extensively for the full order model (FOM) [1, 2]. Its extension to reduced order models had not been studied in depth, despite being a crucial aspect of the time integration of ROMs for incompressible flows.

In this work, we introduce `RedEigCD` [3], a novel method to estimate the maximum stable timestep of explicit time integration schemes for ROMs for incompressible flows. Unlike traditional error-based adaptive schemes, e.g., [4, 5], `RedEigCD` dynamically adjusts the timestep by directly bounding the eigenvalues of the reduced system to ensure stability throughout the simulation. The method leverages exact spectral information of the reduced convective and diffusive operators, which can be computed efficiently without reverting to FOM-size operations during the online stage, as the computational complexity scales linearly with the number of modes. This ensures that the ROM retains its computational efficiency while adhering to stability constraints.

The proposed method has been tested on a variety of incompressible Navier-Stokes benchmark problems, including periodic shear-layer roll-up and non-homogeneous actuator disk flows. The results demonstrate that `RedEigCD` successfully obtains stable timesteps up to 40 times larger than those required from the FOM, while maintaining accuracy compared to traditional fixed-timestep approaches, with timesteps close to the FOM stability limit. Moreover, given the low computational overhead of `RedEigCD`, the overall simulation time is significantly reduced, making it a promising approach for efficient and stable time integration in ROMs for incompressible flows.

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