Full trajectory optimizing operator inference for reduced-order modeling using differentiable programming

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Accurate and inexpensive Reduced Order Models (ROMs) for forecasting turbulent flows can facilitate rapid design iterations and thus prove critical for predictive control in engineering problems. Galerkin projection based Reduced Order Models (GP-ROMs), derived by projecting the Navier-Stokes equations on a truncated Proper Orthogonal Decomposition (POD) basis, are popular because of their low computational costs and theoretical foundations. However, the accuracy of traditional GP-ROMs degrades over long time prediction horizons. To address this issue, we extend the recently proposed Neural Galerkin Projection (NeuralGP) data driven framework to compressibility-dominated transonic flow, considering a prototypical problem of a buffeting NACA0012 airfoil governed by the full Navier-Stokes equations. The algorithm maintains the form of the ROM-ODE obtained from the Galerkin projection; however coefficients are learned directly from the data using gradient descent facilitated by differentiable programming. This blends the strengths of the physics driven GP-ROM and purely data driven neural network-based techniques, resulting in a computationally cheaper model that is easier to interpret. We show that the NeuralGP method minimizes a more rigorous full trajectory error norm compared to a linearized error definition optimized by the calibration procedure. We also find that while both procedures stabilize the ROM by displacing the eigenvalues of the linear dynamics matrix of the ROM-ODE to the complex left half-plane, the NeuralGP algorithm adds more dissipation to the trailing POD modes resulting in its better long-term performance. The results presented highlight the superior accuracy of the NeuralGP technique compared to the traditional calibrated GP-ROM method.

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