Reinforcement learning based optimization of turbulence closures for wall-bounded flows

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Turbulence modeling is a crucial aspect of scientific research that plays a significant role in enhancing the understanding of various physical phenomena related to fluid mechanics. Large-eddy simulation (LES) is a powerful computational tool for simulating turbulent flows, where the large-scale and energy-carrying vortices are resolved, while the small scales have to be modeled. However, it faces several challenges and limitations that must be addressed to be universally applicable. Some of the problems are computational cost, subgrid-scale (SGS) modeling, boundary conditions and numerical interactions.
In particular wall-bounded flows are challenging, since they require increasingly higher grid resolution near walls to resolve the correct behavior, resulting in increased computational cost in the vicinity of walls on the order of direct numerical simulations (DNS). In addition, many SGS models lose their validity in the boundary layer, since the smallest scales can no longer be assumed to be isotropic. Wall-modeled LES (WMLES) approaches try to address these problems and can be classified into hybrid LES/RANS and wall-stress models. In hybrid LES/RANS approaches, the flow is divided into two regions: a near-wall region where RANS equations are solved, and an outer region where LES equations are solved. The basic idea behind wall-stress models is to relate the instantaneous wall-parallel velocity and the resulting wall-parallel shear stress at the wall. The wall-stress models are based on mathematical and physical considerations, nevertheless they feature free parameters which have been calibrated e.g. via experiments or DNS. However, wall stress models are generally not universally applicable if curved walls, pressure gradients, separated flows, surface roughness and non-equilibrium flows are present.
To this end a novel RL approach is presented, that extends traditional wall-stress models to more complex types of flows as detailed above. A reinforcement learning (RL) approach is used to extend the wall stress model for the cases mentioned. For this purpose, the already existing Relexi [3, 4] framework is used. This framework combines the in-house DGSEM code FLEXI [2] with online RL approaches. The Relexi framework has been successfully used in previous work [1] for a similar approach to improve SGS models in free flows. Since the full RL-FLEXI framework is efficiently parallelized on HAWK and its Apollo 6500 ML-extension, we are able to tackle such complex optimization campaigns. The RL agent is trained on generic wall-bounded flows as the channel flow.

References

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