Gray Area Mitigation by Turbulence Injection for Hybrid RANS/LES Simulation of Complex Flows

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ABSTRACT

Hybrid RANS/LES (HRL) models are suitable for the simulation of complex flows, since they use a LES behaviour in the outer flow to represent vortices, shear layers, and separated flows for which RANS is ill suited, while limiting costs by representing the near-wall behaviour with RANS. However, HRL has issues in the region where the change from one paradigm to the other occurs, the so-called gray zone, which leads to incorrect velocity profiles and turbulent quantities.

Models like Detached-Eddy Simulation (DES) and its subsequent iterations do not transfer modelled turbulence kinetic energy (TKE) from the RANS part to resolved turbulence in the LES part. Instead, the modelled turbulence is artificially destroyed to make place for resolved turbulence. However, in doing so, the physical TKE balance is violated: the total TKE should be conserved. This issue is linked with the gray zone problems.

This paper proposes a mechanism in DES-type models, to transfer artificially destroyed modelled TKE to resolved eddies. The approach uses a volume forcing based on the method of Lundgren (2003) which amplifies already existing velocity fluctuations. The forcing is tuned so that the modeled TKE, which is dissipated by the DES method to transition to the LES mode, is compensated by generating the equivalent amount of resolved kinetic energy. In Monot et al. (2024), this solution is evaluated on a turbulent boundary layer over a flat plate. Here, we study how to determine the turbulent scales in which the TKE is injected, and evaluate how to distinguish between artificial dissipation of modelled TKE (which should be reinjected), and physical dissipation (which should not).

The method is then applied to two test cases. First, a backward-facing step flow shows that the method is effective both for the DES and Delayed DES (DDES) models, providing better agreement of velocity and TKE with experiments than when these models are used without injection. The same case is used to test the injection approach with the adaptive meshing strategy of Mozaffari et al. (2022). Finally, the method will be tested on the DTMB 5415 destroyer in 10^{o} sideslip conditions. This test is intended to find out if the injection will improve the prediction of such a complex, realistic flow. Furthermore, it will be used as a diagnostic tool, to see how much normal DDES simulations for this case suffer from unphysical dissipation of modelled turbulence.

References

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