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Nonlinearly Stable Flux Reconstruction for Implicit Large Eddy Simulation of Wall-Bounded Flows

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ABSTRACT

The current research aims to demonstrate the simulation of wall-bounded turbulent flows using the Nonlinearly Stable Flux Reconstruction (NSFR). The turbulence models currently used in industry, typically Reynolds-averaged Navier Stokes (RANS), are less computationally expensive than Large Eddy Simulation (LES) and are, therefore, the method of choice. However, the lack of accuracy of these methods is well-known, especially for unsteady problems. High-order methods are particularly suitable for LES, as the increased accuracy of the scheme comes at a comparable computational cost.

In this work, we will investigate the provably stable NSFR schemes proposed by Cicchino et al. [Cicchino, 2022]. The NSFR schemes utilize the Flux Reconstruction (FR) formulation, using correction functions to allow larger explicit time steps than Discontinuous Galerkin (DG). For industrial-size cases, such as flows over aerodynamic profiles, the larger time step from the NSFR scheme constitutes a significant reduction in computational cost. The scheme is also provably nonlinearly stable, yielding a robust scheme that is stable on very coarse meshes. Contrary to conventional DG schemes, the NSFR scheme is also stable without over-integration for nonlinear problems, and stable without upwind-type dissipation. In the case of turbulence simulations, such as LES, this means the scheme does not require the dissipation from an SGS model for stability, and is thus well adapted for ILES.

The transitional flow over a Selig–Donavan (SD) 7003 airfoil at $Re_c = 60,000$ and angle of attack of 8° is simulated. The complex flow case exhibits a laminar region, followed by a laminar separation bubble (LSB) and by a transition in the separated flow and subsequent turbulent reattachment. The complexity of the flow renders conventional techniques, such as (RANS), uncapable of accurately resolving the underlying physics. With the high computational cost of Direct Numerical Simulation (DNS), LES is the most viable solution for these types of flows. The results are verified using previous numerical studies. Pressure distribution and skin friction are computed and match the results obtained by [Beck, 2014]. The velocity and velocity fluctuations are in good agreement with LES by Garmann [Garmann, 2012]. To the author's knowledge, no previous studies have used NSFR to compute wall-bounded turbulent flows on complex geometries.