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Spectral element methods for under-resolved DNS of turbulent flows

Rodrigo C. Moura[1], Gianmarco Mengaldo[2], Spencer J. Sherwin[3] and J. Peiro[3]

[1] Instituto Tecnológico de Aeronáutica, Brazil, rodrigomoura.t10@gmail.com
[2] Caltech, Pasadena, California, USA, gianmarco.mengaldo@gmail.com
[3] Department of Aeronautics, Imperial College London, UK, {s.sherwin; j.peiro}@imperial.ac.uk

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We present an overview of our recent attempts at devising spectral element methods for under-resolved computations of turbulent flows where small-scale regularisation at very large Reynolds numbers is achieved through numerical dissipation. In such an approach, solution quality and numerical robustness could strongly depend on discretisation variables such as polynomial order, appropriate mesh spacing, Riemann solver, SVV parameters, de-aliasing strategy and alternative stabilisation techniques. It is therefore of paramount importance to understand their effect on solution stability and accuracy. We will highlight how linear temporal and spatial eigen-analysis is helpful in explaining why and informing how to use spectral element methods in uDNS. This analysis has helped us to devise a simple criterion named “the 1% rule” to estimate the effective resolution power of the discontinuous Galerkin (DG) method in spectral space. This criterion is shown to pinpoint the wavenumber beyond which a numerically induced dissipation range appears in the energy spectra of Burgers turbulence simulations in one dimension. Further validation of the rule is obtained for the inviscid Taylor-Green vortex model problem and we will discuss the performance of various Riemann solvers employed in the DG solver. We will also discuss how the lessons learnt from the analysis of the DG dissipation helped us devise an improved, more robust, version of the spectral vanishing viscosity for the incompressible flow solver. We will illustrate this with the under-resolved DNS of the flow past a race car.