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Recent developments in accuracy and stability improvement of nonlinear filter methods for DNS and LES of compressible flows

Recent progress in the improvement of numerical stability and accuracy of the Yee & Sjogreen (JCP-2007) high order nonlinear filter schemes is described. The Yee & Sjogreen adaptive nonlinear filter method consists of a high order non-dissipative spatial base scheme and a nonlinear filter step. The nonlinear filter step consists of a flow sensor and the dissipative portion of a high resolution nonlinear high order shock-capturing method to guide the application of the shock-capturing dissipation where needed. The nonlinear filter idea was first initiated by Yee et al. using an artificial compression method (ACM) of Harten as the flow sensor. The nonlinear filter step was developed to replace high order linear filters so that the same scheme can be used for long time integration of direct numerical simulations (DNS) and large eddy simulations (LES) for both shock-free turbulence and turbulence-shock waves interactions. The improvement includes four major new developments: (a) Smart flow sensors were developed to replace the global ACM flow sensor. The smart flow sensor provides the locations and the estimated strength of the necessary numerical dissipation needed at these locations and leaves the rest of the flow field free of shock-capturing dissipation. (b) Skew-symmetric splittings were developed for compressible gas dynamics and magnetohydrodynamics (MHD) equations to improve numerical stability for long time integration. (c) High order entropy stable numerical fluxes were developed as the spatial base schemes for both the compressible gas dynamics and MHD. (d) Several dispersion relation-preserving (DRP) central spatial schemes were included as spatial base schemes in the framework of our nonlinear filter method approach. With these new scheme constructions, the nonlinear filter schemes are applicable for a wider class of accurate and stable DNS and LES applications, including forced turbulence simulations where the time evolution of flows might start with low speed shock-free turbulence and develop into supersonic speeds with shocks. Representative test cases for both smooth flows and problems containing discontinuities for compressible flows are included.

Biography

H C Yee (NASA Ames Research Center) has over 30 years of fundamental research experience in the fields of Computational Physics, Computational Fluid Dynamics (CFD) and Nonlinear Dynamics. She is well known in numerical algorithm development in high-resolution shock-capturing method and low dissipative high order methods for high speed shock/turbulence/combustion interactions for gas dynamics and MHD systems. She has also worked extensively in the area of "Dynamics of Numerics for Computational Physics" which has important implications on the interpretation and reliability of complex nonlinear numerical simulations in general and on the numerical prediction of flow transition by DNS in particular. Her numerical methods have been incorporated into many production CFD codes both domestically and internationally for applications in aerodynamics, astrophysics, and fluid/plasma dynamics.

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