

Designing Adaptive Low Dissipative High Order Schemes

H.C. Yee¹ and B. Sjögren²

¹ NASA Ames Research Center, Moffett Field, CA, 94035, USA

² NADA, The Royal Institute of Technology, 100 44 Stockholm, Sweden

1 Motivation

Proper control of the numerical dissipation/filter to accurately resolve all relevant multiscales of complex flow problems while still maintaining nonlinear stability and efficiency for long-time numerical integrations poses a great challenge to the design of numerical methods. The required type and amount of numerical dissipation/filter are not only physical problem dependent, but also vary from one flow region to another. This is particularly true for unsteady high-speed shock/shear/boundary-layer/turbulence/acoustics interactions and/or combustion problems since the dynamics of the nonlinear effect of these flows are not well-understood. Even with extensive grid refinement, it is of paramount importance to have proper control on the type and amount of numerical dissipation/filter in regions where it is needed.

2 Objective

The objective of this paper is to propose an integrated approach for the control of the numerical dissipation in high order schemes. Among other design criteria, the key idea consists of automatic detection of different flow features as distinct sensors to signal the appropriate type and amount of numerical dissipation/filter where needed and leave the rest of the region free of numerical dissipation contamination. These scheme-independent detectors are capable of distinguishing shocks/shears, flame sheets, turbulent fluctuations and spurious high-frequency oscillations. In addition, these sensors are readily available as an improvement over existing grid adaptation indicators. The detection algorithm is based on an artificial compression method (ACM) [2] (for shocks/shears), and redundant multiresolution wavelets (WAV) [1] (for all types of flow feature). The ACM and wavelet filter schemes using a second-order nonlinear filter with sixth-order spatial central scheme for both the inviscid and viscous flux derivatives and a fourth-order Runge-Kutta method are denoted by ACM66-RK4 and WAV66-RK4. The scheme without any filter is denoted by CEN66-RK4 and the filter scheme using the dissipative portion of the fifth order WENO scheme (WENO5) as the nonlinear filter is denoted by WAVweno66-RK4. Computations blending a second-order nonlinear filter with an eighth-order linear filter using the wavelet as the sensor are denoted by WAV66-RK4-D8. For smooth flows, one of the design criteria to improve nonlinear stability is the use of the entropy splitting of

the inviscid flux derivatives [3]. These schemes are indicated by appending the letters "ENT".

3 Numerical Examples

Extensive grid convergence studies using WAV66-RK4 and ACM66-RK4 for a complex viscous shock/shear/boundary-layer interaction, and a viscous supersonic combustion with four species (a planar Mach 2 shock in air interacting with a circular zone of hydrogen bubble) were conducted (see e.g., Fig. 1). More accurate solutions were obtained with WAV66-RK4 and ACM66-RK4 than with WENO5-RK4, which is nearly three times more expensive. Figure 2 shows an inviscid vortex convection problem at 150 periods on a 81×81 grid. The second-order MUSCL and the Tam & Web DRP method are extremely diffusive whereas WENO5 is more diffusive than the rest of the filter schemes using RK4. The CEN66-ENT-RK4-D8 linear filter scheme preserves the vortex convection beautifully. Figure 3 shows the highly accurate computation by blending of two different filters WAV66-RK4-D8 for a 1-D shock-turbulence problem.

For a comprehensive study of this work, see [4].

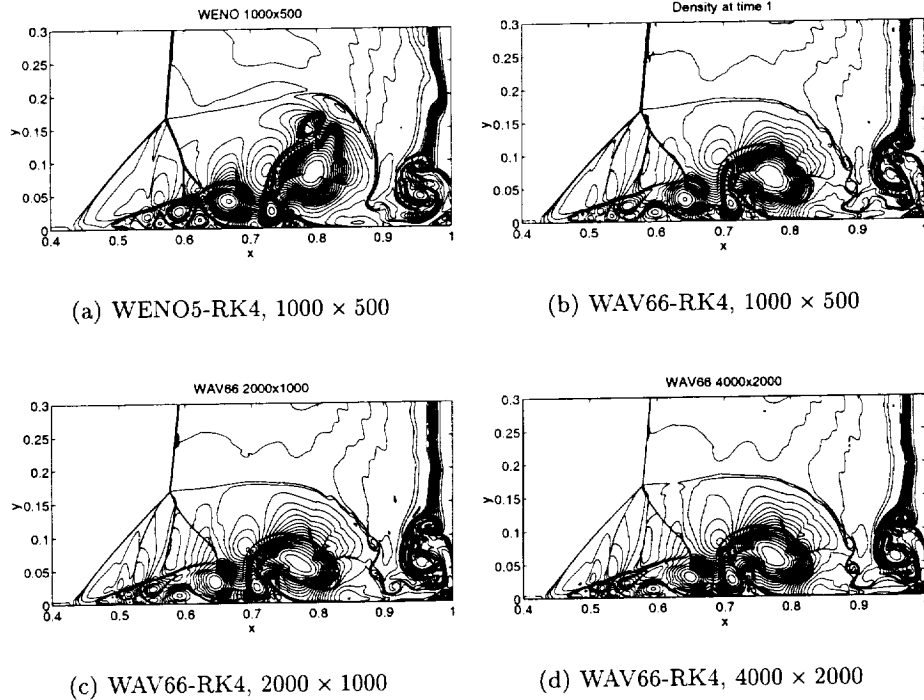


Fig. 1. Density contours of viscous shock/shear/boundary-layer interaction, $Re = 1000$.

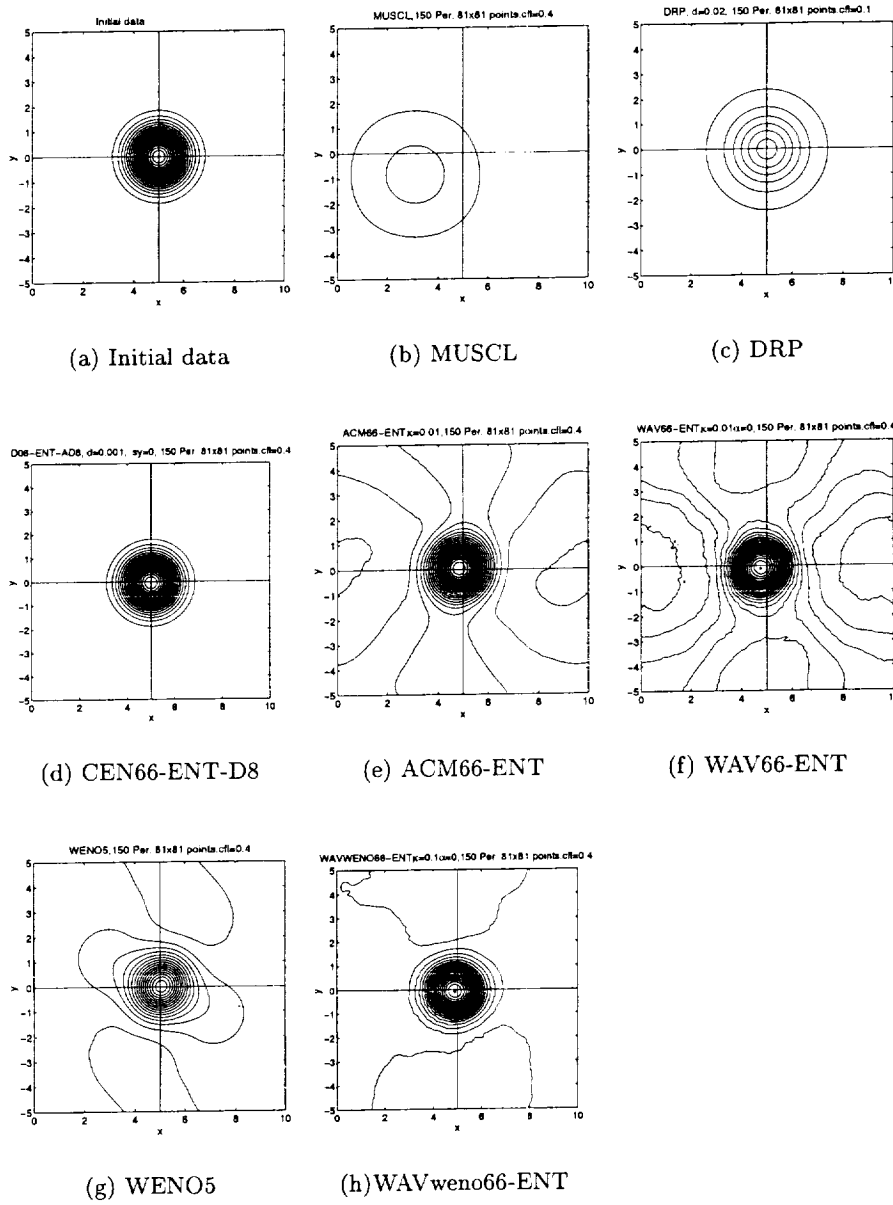


Fig. 2 Vortex convection at 150 Periods, $cfl=0.4$ ($\Delta t \approx 0.01$; DRP 4 times smaller). MUSCL & DRP are extremely diffusive.

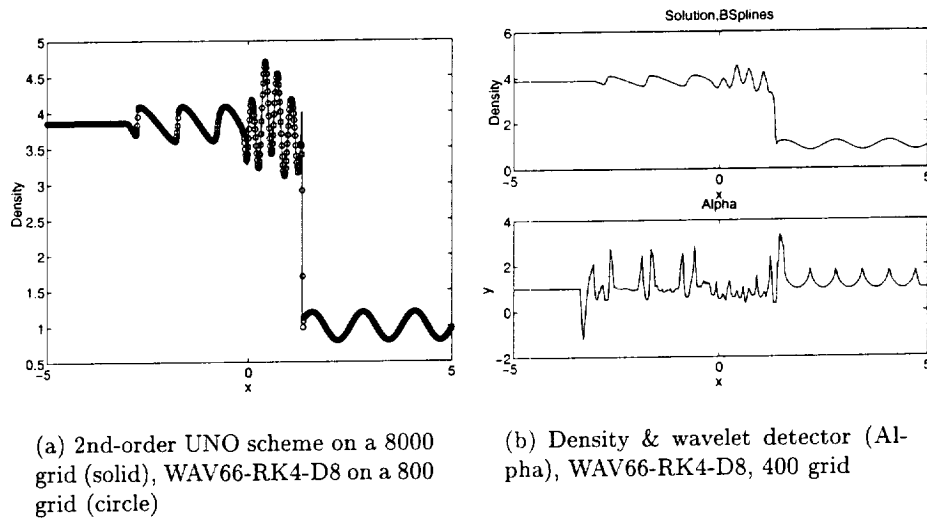


Fig. 3. Blending of two different filters by WAV66-RK4-D8 for a 1-D shock-turbulence problem.

References

1. B. Sjögreen and H. C. Yee: 'Multiresolution Wavelet Based Adaptive Numerical Dissipation Control for Shock-Turbulence Computations'. In: RIACS Report 01.01, NASA Ames research center (Oct 2000).
2. H. C. Yee, N. D. Sandham, and M. J. Djomehri: 'Low Dissipative High Order Shock-Capturing Methods Using Characteristic-Based Filters'. In: *J. Comput. Phys.*, **150**, 199-238 (1999).
3. H.C. Yee, M. Vinokur, and M.J. Djomehri: 'Entropy Splitting and Numerical Dissipation'. In: *J. Comput. Phys.*, **162**, pp. 33-81 (2000).
4. H. C. Yee and B. Sjögreen: 'Designing Adaptive Low-Dissipative High Order Schemes for Long-time Integrations'. In: **Turbulent Flow Computation**, Fluid Mechanics & its Applications, **66**, D. Drikakis & B.J. Geurts, editors, Kluwer Academic, pp. 141-198 (2002).