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Comparative Study of Three High Order Schemes for LES of Temporally Evolving Mixing Layers*

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Abstract. Three high order shock-capturing schemes are compared for large eddy simulations (LES) of temporally evolving mixing layers for different convective Mach numbers ranging from the quasi-incompressible regime to highly compressible supersonic regime. The considered high order schemes are fifth-order WENO (WENO5), seventh-order WENO (WENO7) and the associated eighth-order central spatial base scheme with the dissipative portion of WENO7 as a nonlinear post-processing filter step (WENO7fi). This high order nonlinear filter method of Yee & Sjogreen is designed for accurate and efficient simulations of shock-free compressible turbulence, turbulence with shocklets and turbulence with strong shocks with minimum tuning of scheme parameters. The LES results by WENO7fi using the same scheme parameter agree well with experimental results compiled by Barone et al., and published direct numerical simulations (DNS) work of Rogers & Moser and Pantano & Sarkar, whereas results by WENO5 and WENO7 compare poorly with experimental data and DNS computations.

AMS subject classifications: 65Z05, 65M06, 65M50, 65M55, 65M60, 65M99, 65Y99

Key words: High order numerical methods, numerical methods for turbulence with shocks, DNS, LES, mixing layer.

1 Introduction

Part of the inaccuracy in direct numerical simulations (DNS) and large eddy simulations (LES) of turbulent flow using standard high order shock-capturing schemes is due to

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the fact that this type of computation involves long time integrations. Standard stability and accuracy theories in numerical analysis are not applicable to long time wave propagations and/or long time integrations [29]. The original construction of modern shock-capturing schemes was developed for rapidly developing unsteady shock interactions and short time integrations. Any numerical dissipation inherent in the scheme, even for high resolution shock-capturing schemes that maintain their high order accuracy in smooth regions (e.g., fifth- or seventh-order WENO schemes (WENO5 and WENO7)), will be compounded over long time integration leading to smearing of turbulence fluctuations to un-recognizable forms.

In compressible turbulent combustion/nonequilibrium flows, the constructions of numerical schemes for (a) stable and accurate simulation of turbulence with strong shocks, and (b) obtaining correct propagation speed of discontinuities for stiff reacting terms on "coarse grids" share one important ingredient - minimization of numerical dissipation while maintaining numerical stability. Here "coarse grids" means standard mesh density requirement for accurate simulation of typical non-reacting flows. This dual requirement to achieve both numerical stability and accuracy with zero or minimal use of numerical dissipation is most often conflicting for existing schemes that were designed for non-reacting flows. In addition to the minimization of numerical dissipation while maintaining numerical stability in compressible turbulence with strong shock, Yee & Sjögreen, Yee and Yee & Sweby [32,33,36,37] discussed a general framework for the design of such schemes. Yee & Sjögreen [41], Sjögreen & Yee [27,28,44] and Wang et al. [30,31], and references cited therein present their recent progress on the subject. In [43], a short overview of this recent progress is given. The discussion addresses three separate yet interwoven types of numerical challenges for high speed turbulent reacting flows containing discontinuities. This paper is confined to the study of turbulent mixing for non-reacting flows. The study for turbulent mixing for reacting flows is planned.

2 Recent progress in numerical methods for turbulence with strong shocks

The current trends in the containment of numerical dissipation in DNS and LES of turbulence with shocks are summarized in Yee & Sjögreen and Yee et al. [**?**,40–42]. See the cited references for details on these current trends. Before presenting the improved filter schemes and their application to the temporally evolving mixing layers (TML) in the next two sections, the key ingredients and the performance of the high order nonlinear filter schemes with pre-processing and post-processing steps in conjunction with the use of a high order non-dissipative spatial base scheme [41,42] are briefly illustrated for two test cases.

2.1 High order nonlinear filter schemes [25,39,41,42]

Before the application of a high order non-dissipative spatial base scheme, the pre-processing step to improve stability had split inviscid flux derivatives of the governing