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REVIEW ARTICLE

High-Order and High Accurate CFD Methods and Their Applications for Complex Grid Problems

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Abstract. The purpose of this article is to summarize our recent progress in high-order and high accurate CFD methods for flow problems with complex grids as well as to discuss the engineering prospects in using these methods. Despite the rapid development of high-order algorithms in CFD, the applications of high-order and high accurate methods on complex configurations are still limited. One of the main reasons which hinder the widely applications of these methods is the complexity of grids. Many aspects which can be neglected for low-order schemes must be treated carefully for high-order ones when the configurations are complex. In order to implement high-order finite difference schemes on complex multi-block grids, the geometric conservation law and block-interface conditions are discussed. A conservative metric method is applied to calculate the grid derivatives, and a characteristic-based interface condition is employed to fulfil high-order multi-block computing. The fifth-order WCNS-E-5 proposed by Deng [9, 10] is applied to simulate flows with complex grids, including a double-delta wing, a transonic airplane configuration, and a hypersonic X-38 configuration. The results in this paper and the references show pleasant prospects in engineering-oriented applications of high-order schemes.

AMS subject classifications: 76M20

Key words: WCNS, complex configurations, geometric conservation law, conservative metric methods, characteristic-based interface conditions.

Contents

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1 Introduction

Over the past 20 to 30 years, there have been a lot of studies in developing and applying high-order and high accurate numerical methods for computational fluid dynamics (CFD). Although low-order schemes (second-order schemes) are widely used for engineering applications, they are insufficient for turbulence, aeroacoustics, and many viscosity dominant flows, such as boundary layer flows, vortical flows, shock-boundary layer interactions, heat flux transfers, etc. An effective approach to overcome the obstacle of accurate numerical simulations is to employ high-order methods [1]. In [2, 3], Shu and Cheng gave profound reviews on high-order weighted essentially non-oscillatory (WENO) schemes and discontinuous Galerkin (DG) schemes. A comprehensive review was also given by Ekaterinaris [4] for high-order difference schemes, ENO and WENO schemes, DG schemes, and spectral volume (SV) schemes.

It is generally believed that the accurate simulation of fluid flow with multiple and wide range of spatial scales and structures is a difficult task except through spectral approximations. However, the use of spectral approximations is limited to simple geometries with generally periodic boundary conditions. Compact schemes make it possible to devise, on a given stencil, finite difference schemes that have much better resolution properties than conventional explicit finite difference schemes of comparable order of accurate. Compact schemes with spectral-like resolution properties are more convenient to use than spectral and pseudo-spectral schemes, and are easier to handle, especially when nontrivial geometries are involved [5]. Deng et al. [6] have proposed a type of one-parameter linear dissipative compact schemes (DCS). DCSs are derived for high-order accurate simulation of shock-free problems while damping out the dispersive and parasite errors in the high-wave-number regions. Visbal and Gaitonde [7] use filters to prevent numerical oscillations of central compact schemes. In order to dealing with shock wave problems, Adams and Shariff [74] have developed a compact-ENO scheme. Pirozzoli [75] have developed a compact-WENO scheme which was further improved by Ren et al. [73]. Deng et al. have developed compact nonlinear schemes [8] and weighted compact nonlinear schemes (WCNS) [9, 10]. The WCNSs have been successfully applied to a wide range of flow simulations so far to show its flexibility and robustness [11, 16, 32, 99, 100]. Some results on using the fifth-order WCNS (WCNS-E-5) [9, 10] for complex grid problems are presented in this paper to further show its engineering prospects.