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Multiderivative Combined Dissipative Compact Scheme Satisfying Geometric Conservation Law II: Applications on Complex Curvilinear Meshes

Yi Jiang[1,2,*], Meiliang Mao[1,2], Xiaogang Deng[3] and Huayong Liu[1]

[1] *State Key Laboratory of Aerodynamics, China Aerodynamics Research and Development Center, P.O. Box 211, Mianyang 621000, China*
[2] *Computational Aerodynamics Institute, China Aerodynamics Research and Development Center, P.O. Box 211, Mianyang 621000, China*
[3] *National University of Defense Technology, Changsha 410073, Hunan, China*

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Abstract. The multiderivative combined dissipative compact scheme (MDCS) is extended to implement applications on complex curvilinear meshes. According to our previous evaluation on the scheme, a fifth-order MDCS, which has coexistent superior resolution power and relatively high efficiency, is chosen to present the performance of the MDCS. The capability of the fifth-order MDCS is evaluated by increasingly complex meshes in three typical tests: acoustic scattering from two cylinders, flow over a rod-airfoil configuration and flow over a landing gear model. On the curvilinear meshes, high resolution power possessed by the representative fifth-order MDCS is demonstrated for resolving acoustic wave. Moreover, the MDCS presents promising capability in simulating multiple scales in turbulent flow.

AMS subject classifications: 76Fxx, 76Gxx

Key words: Multiderivative combined dissipative compact scheme, geometric conservation law, curvilinear mesh, complex geometry, high-order implicit large eddy simulation.

1 Introduction

Computational fluid dynamics (CFD) has been used routinely to complement experimental measurement for engineering applications [1]. At present, most CFD tools are based on second-order method capable of handling complex geometries. These tools are proved to be very useful in predicting mean flow [2]. However, they have frequently failed to predict highly separated flow, viscosity dominant flow and aeroacoustics [3]. In

*Corresponding author.
Email: yijiang@mail.ustc.edu.cn (Y. Jiang)

consideration of these flow phenomena, high-order CFD methods with third or higher order accuracy are required to resolve unsteady vortices of disparate scales [4]. On the ground of developing future CFD tools for engineering applications, the previously proposed multiderivative combined dissipative compact scheme (MDCS) [5] is extended to practical applications on complex curvilinear meshes in this paper. The MDCS is high-resolution scheme possessing the capability of handling complex geometries. According to the previous study [5], the superior resolution power over that of the hybrid cell-edge and cell-center dissipative compact schemes (HDCS) [6] is achieved by the MDCS through multiple derivatives involved in the scheme; the performance of the MDCS on complex curvilinear meshes will be evaluated by the present practical applications.

Various types of high-order methods have been developed to handle a wide range of flow phenomena. These high-order methods were comprehensively discussed in several review articles [3, 7, 8]. Among these methods, compact finite difference schemes, such as the MDCS, are attractive schemes for flows with multiscales due to their high formal order, good spectral resolution and their flexibility [9]. High-order compact finite difference schemes have been widely used in solving diverse problems involving flow separation [10], turbulence [11] and aeroacoutics [12–14]. Although flow phenomena simulated by high-order finite difference schemes are complex in published articles, the employed meshes are rather simple in most of them. Lack of robustness and high grid-quality sensitivity are major obstacles for the applications of high-order schemes on complex meshes [7, 8].

For the purpose of enabling applications of high-order finite difference schemes on complex grids, some fundamental studies have been conducted. It has been found that the geometric conservation law (GCL) is extremely important for successful applications of high-order finite difference schemes on curvilinear meshes [15–19]. With the GCL satisfied, the free-stream preservation can be maintained. This preservation and the satisfaction of the GCL contribute to enhanced robustness of high-order finite difference schemes. In order to satisfy the GCL, the conservative metric method (CMM) was proposed for finite difference schemes [19]. Based on the CMM, the symmetrical conservative metric method (SCMM) was further developed to increase the numerical accuracy on irregular grids [20]. More recently, it has been proved that, on account of the GCL being satisfied, numerical results with higher order of accuracy can be gained by finite difference schemes on non-smooth grids [21].

Another challenge for finite difference schemes applied on engineering problems is grid technique, since a structured single-block grid system can hardly be generated for a complex configuration, which is commonly found in engineering applications. Overset grid [17] and patched grid [22] strategies are two common options for high-order finite difference schemes handling complex geometries. Another choice for this challenge is multi-block structured grid technique with characteristic interface conditions [23]. Recently, the adaptive mesh refinement (AMR) has shown attractive performance in handling complex curvilinear meshes. Numerous high-order finite difference schemes has been combined with the AMR [24]. The combination of the MDCS and the AMR is a