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Noise Prediction in Subsonic Flow Using Seventh-Order Dissipative Compact Scheme on Curvilinear Mesh

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Abstract. In this paper, we investigate the performance of the seventh-order hybrid cell-edge and cell-node dissipative compact scheme (HDCS-E8T7) on curvilinear mesh for noise prediction in subsonic flow. In order to eliminate the errors due to surface conservation law (SCL) is dissatisfied on curvilinear meshes, the symmetrical conservative metric method (SCMM) is adopted to calculate the grid metric derivatives for the HDCS-E8T7. For the simulation of turbulence flow which may have main responsibility for the noise radiation, the new high-order implicit large eddy simulation (HILES) based on the HDCS-E8T7 is employed. Three typical cases, i.e., scattering of acoustic waves by multiple cylinder, sound radiated from a rod-airfoil and subsonic jet noise from nozzle, are chosen to investigate the performance of the new scheme for predicting aeroacoustic problem. The results of scattering of acoustic waves by multiple cylinder indicate that the HDCS-E8T7 satisfying the SCL has high resolution for the aeroacoustic prediction. The potential of the HDCS-E8T7 for aeroacoustic problems on complex geometry is shown by the predicting sound radiated from a rod-airfoil configuration. Moreover, the subsonic jet noise from nozzle has been successfully predicted by the HDCS-E8T7.

AMS subject classifications: 76Fxx, 76Qxx

Key words: Aeroacoustics, seventh-order hybrid cell-edge and cell-node dissipative compact scheme (HDCS-E8T7), high-order implicit large eddy simulation (HILES), symmetrical conservative metric method (SCMM), complex geometry.

1 Introduction

Aeroacoustic problem is serious in many engineering applications. It can cause human discomfort and affect the stealth operations of military air vehicles and submarines [1].

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Accordingly, the aeroacoustic noise reduction is an important goal for the commercial and military aviation communities [2]. For evaluation of the performance of the new noise-reducing concepts, reliable methods for modeling of the source mechanisms must be available. However, the nature of aeroacoustic problems is essentially different from that of standard aerodynamic problems [3]. To be able to compute or simulate aeroacoustics problems accurately and efficiently, a computational aeroacoustics (CAA) scheme should have extremely low dispersion and dissipation errors [3]. Traditional second order accurate methods are known to be too dissipative for these problems. Due to the high formal order, good spectral resolution and their flexibility, high-order compact finite difference schemes are the most attractive schemes for CAA [4]. CAA based on high-order compact finite difference scheme has been applied successfully to various aerodynamic noise problems. For example, noise generated by jet flow has been successfully predicted via the direct noise computation approach [5], i.e., simulation of both the unsteady flow and the associated sound should be performed in the same computation [6]. Based on the sixth-order central compact finite difference scheme proposed by Lele [7], noise radiated by wake-airfoil interaction, which helps to understand the mechanism of acoustic radiation in turbo-machine, has been studied [8]. This sixth-order compact scheme is also used by Rizzetta et al. [9] to investigate acoustic suppression of cavity flow.

In order to provide more realistic aeroacoustic prediction, applications of high-order compact finite difference schemes are motivated to increasingly complex configurations of engineering interest. However, applications of these schemes are still challenged by complex meshes which are commonly used for complex geometry. When the accurate numerical simulation of broad spectrum phenomenon is performed by high-order compact scheme on a complex mesh, it is argued that there are many obstacles such as robustness and grid-quality sensitivity [10, 11]. Fortunately, these deficiencies can be largely removed by the researches of the Geometric Conservation Law (GCL) [12–16]. The GCL contains surface conservation law (SCL) and volume conservation law (VCL). The VCL has been widely studied for time-dependent grids, while the SCL is merely discussed for finite difference schemes. If the SCL has not been satisfied, numerical instabilities and even computing collapse may appear on complex curvilinear grids during numerical simulation. In order to fulfill the SCL for high-order finite difference schemes, the conservative metric method (CMM) is derived by Deng et al. [15]. The CMM is achieved by computing grid metric derivatives through a conservative form with the same scheme applied to fluxes. According to the principle of satisfying the CMM, the seventh-order hybrid cell-edge and cell-node dissipative compact scheme (HDCS-E8T7) has been proposed for simulating subsonic flow on complex geometry [17]. The advantages of the HDCS-E8T7 are: (a) it can satisfy the GCL which helps to preserve the accuracy orders on curvilinear meshes, and enhances the ability of the HDCS-E8T7 to handle complex geometry; (b) it has inherent dissipation which is quite useful in dissipating unresolvable wavenumbers; (c) high-order accuracy can be obtained in relatively narrow stencils, thus the boundary and near boundary schemes are easily designed, and the HDCS-E8T7 can be applied on complex multi-block structured grid conveniently. The properties of