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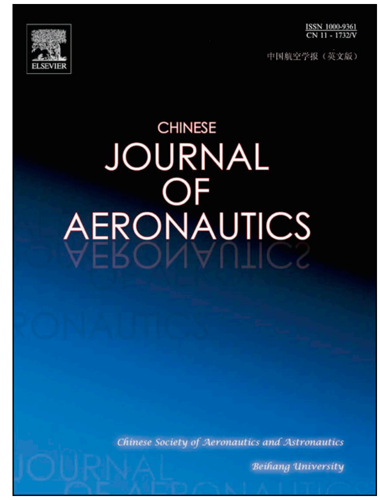

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High-order compact finite volume methods on unstructured grids with adaptive mesh refinement for solving inviscid and viscous flows

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Abstract
In the present paper, high-order finite volume schemes on unstructured grids developed in our previous papers are extended to solve three-dimensional inviscid and viscous flows. The high-order variational reconstruction technique in terms of compact stencil is improved to reduce local condition numbers. To further improve the efficiency of computation, the adaptive mesh refinement technique is implemented in the framework of high-order finite volume methods. Mesh refinement and coarsening criteria are chosen to be the indicators for certain flow structures. One important challenge of the adaptive mesh refinement technique on unstructured grids is the dynamic load balancing in parallel computation. To solve this problem, the open-source library p4est based on the forest of octrees is adopted. Several two- and three-dimensional test cases are computed to verify the accuracy and robustness of the proposed numerical schemes.
Keywords: high-order finite volume scheme, unstructured grids, variational reconstruction, compact stencil, adaptive mesh refinement
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1. Introduction

High-order numerical schemes have shown great potentials in solving multiscale problems in fluid dynamics such as turbulence and vortex-dominated flows. To solve practical problems with complicated geometries, high-order numerical methods on unstructured grids have been extensively studied in the past two decades. Representative numerical methods include the Discontinuous Galerkin (DG) method [1,2], the P_NP_M method [3], the RDG method [4], the DG/FV method [5], the Residual Distribution (RD) method [6], Spectral Volume (SV) [7] or Spectral Difference (SD) [8] methods, and the Correction Procedure via Reconstruction (CPR) method [9].

Historically, High-order finite Volume (FV) methods [10-14] on unstructured grids were among the numerical schemes that received earliest attentions, since they are simpler to construct and apply. Shock-capturing algorithms and implicit time-stepping techniques for high-order FV schemes are also more mature than those of the numerical methods mentioned above. However, high-order FV schemes require a large number of cells or control volumes in the stencil of the reconstruction procedure. The large stencil results in a series of problems [15] including cache missing due to the data in the stencil being far away in memory, difficulty in boundary treatments, and deterioration of the parallel efficiency. Therefore, a very large stencil has been one of the most serious problems for high-order FV schemes.

To solve this bottleneck problem, the authors of the present paper have proposed two new reconstruction procedures, namely the Compact Least Squares Reconstruction (CLSR) [16,17] and the Variational Reconstruction (VR) [18]. The common feature of these two methods is that they can reconstruct arbitrarily high-order polynomials using a compact stencil involving only face-neighboring cells. The VR is superior to the CLSR in that the reconstruction is always non-singular and does not need to reduce the order of accuracy at boundary cells. FV schemes based on the VR presented in Ref. [18] are for two-dimensional problems. In the present paper, this method is extended to solve