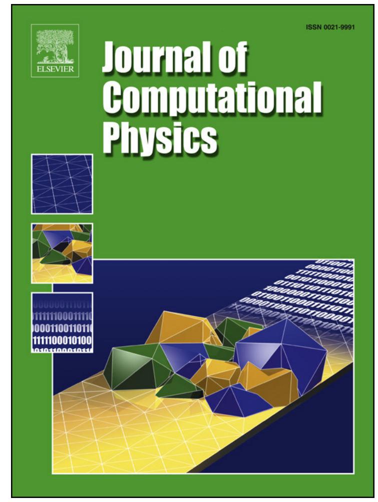
Accepted Manuscript



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PII: S0021-9991(16)30475-2
DOI: http://dx.doi.org/10.1016/j.jcp.2016.09.054
Reference: YJCPH 6865

To appear in: *Journal of Computational Physics*

Received date: 14 January 2016
Revised date: 23 September 2016
Accepted date: 24 September 2016

Please cite this article in press as: B. Xie, F. Xiao, A multi-moment constrained finite volume method on arbitrary unstructured grids for incompressible flows, *J. Comput. Phys.* (2016), http://dx.doi.org/10.1016/j.jcp.2016.09.054

A multi-moment constrained finite volume method on arbitrary unstructured grids for incompressible flows

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Abstract

We proposed a multi-moment constrained finite volume method which can simulate incompressible flows of high Reynolds number in complex geometries. Following the underlying idea of the volume-average/point-value multi-moment (VPM) method (Xie et al. J. Comp. Physic. 277 (2014), 138-162), this formulation is developed on arbitrary unstructured hybrid grids by employing the point values (PV) at both cell vertex and barycenter as the prognostic variables. The cell center value is updated via an evolution equation derived from a constraint condition of finite volume form, which ensures the rigorous numerical conservativeness. Novel numerical formulations based on the local PVs over compact stencil are proposed to enhance the accuracy, robustness and efficiency of computations on unstructured meshes of hybrid and arbitrary elements. Numerical experiments demonstrate that the present numerical model has nearly 3-order convergence rate with numerical errors much smaller than the VPM method. The numerical dissipation has been significantly suppressed, which facilitates numerical simulations of high Reynolds number flows in complex geometries.

Keywords: Finite volume method, unstructured hybrid grid, high Reynolds number, incompressible flow, multi-moment, numerical dissipation.

1. Introduction

As most of the real-case applications of computational fluid dynamics (CFD), including both internal and external flows, involve geometrically complex configurations, unstructured grids have been widely used in numerical models to represent complex geometries with adequate accuracy at affordable computational cost. It is evidenced by the fact that nearly all commercial CFD codes are based on unstructured grids of different shapes, like triangle and quadrilateral in 2D, or tetrahedron, hexagon, pyramid and prism in 3D, which provide great flexibility to represent the computational domains of geometric complexity. Being the basic approach to construct fluid solvers, the finite volume method (FVM) gains the greatest popularity for the spatial discretization on unstructured grids because of its adaptability to any shape of mesh elements, in addition to the numerical conservation as another advantage.

Conventional FVM memorizes and updates the volume integrated average (VIA) for each grid element as the computational variable, which is used to compute the numerical fluxes across the cell boundaries through proper spatial discretization (reconstruction) to update the VIA to the next time step. Since the conventional FVM saves only VIA as the computational variable, any reconstruction beyond the piecewise constant approximation requires the VIA values on other surrounding grid elements. As a reasonable trade-off between accuracy and computational complexity, the linear reconstructions[63, 38, 55] can be done in a relatively straightforward way on the target cell and its immediate neighbors, and thus are widely adopted in the commercial and in-house codes for applications. However, extending the spatial discretization to higher order is not trivial for a FVM on unstructured grids of arbitrary elements. Moreover, the numerical solution of conventional FVM heavily depends on the quality of computational grids, which requires a lot of efforts to generate and modify the grids to obtain acceptable simulation results as shown in [36].

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