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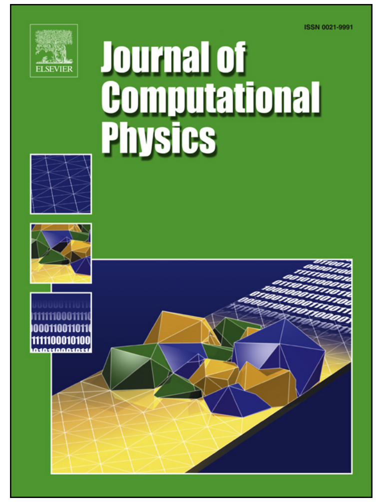

An efficient high-order compact scheme for the unsteady compressible Euler and Navier-Stokes equations

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An efficient high-order compact scheme for the unsteady compressible Euler and Navier-Stokes equations

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Abstract

Residual-Based Compact (*RBC*) schemes approximate the 3-D compressible Euler equations with a 5th- or 7th-order accuracy on a 5x5x5-point stencil and capture shocks pretty well without correction. However for unsteady flows, they require a costly algebra to extract the time-derivative occuring at several places in the scheme. A new high-order time formulation has been recently proposed [A. Lerat, J Comput Phys 303 (2015) 251-268] for simplifying the *RBC* schemes and increasing their temporal accuracy. The present paper goes much further in this direction and deeply reconsiders the method. An avatar of the *RBC* schemes is presented that greatly reduces the computing time and the memory requirements while keeping the same type of successful numerical dissipation. Two and three-dimensional linear stability are analysed and the method is extended to the 3-D compressible Navier-Stokes equations. The new compact scheme is validated for several unsteady problems in two and three dimension. In particular, an accurate DNS at moderate cost is presented for the evolution of the Taylor-Green Vortex at Reynolds 1600 and Prandtl 0.71. The effects of the mesh size and of the accuracy order in the approximation of Euler and viscous terms are discussed.

Keywords: Compact schemes, High order, Unsteady compressible flows, Taylor-Green Vortex

1. Introduction

Among high-order methods for computing compressible flows on structured meshes, compact schemes are attractive because of their narrow grid-stencil that significantly reduces the truncation error for a given accuracy-order and makes easier the treatment of deforming meshes and boundary conditions. Compact schemes for compressible flows have been mainly developed as centered approximations in space, notably in the works by Lele [1], Cockburn and Shu [2], Yee [3] and Visbal and Gaitonde [4], with numerical dissipation based on artificial viscosities, numerical filters or limiters. Upwind compact schemes have also been proposed by Tolstykh [5] and Fu and Ma [6]. Another interesting option is the use of Residual-Based Compact (*RBC*) schemes. In a such a scheme, the consistent part and the numerical dissipation are expressed only in terms of compact approximations of the complete residual, *i.e.* the sum of the terms in the governing equations including the time derivative. These compact approximations are deduced from Padé formulas in which the inverse operators are eliminated. On a Cartesian mesh, a *RBC* scheme can approximate a hyperbolic system of conservation laws in d-dimension with a 5th- or 7th-order accuracy on a 5^d-point stencil and capture shocks pretty well without correction. Description and analysis of these schemes can be found in [7–13]. A related approach developed on unstructured meshes is the residual-distribution method of Abgrall, Deconinck and Ricchiuto [14–18] in which the residuals are distributed to the nodes of triangles or tetrahedrons.

A peculiarity of the *RBC* schemes is the multiple occurrence of the time derivative in the scheme ($\partial w/\partial t$ occurs $d+1$ times in d-dimension). Besides, due to compactness, discrete spatial-operators are applied to each time-derivative. In the first applications of the *RBC* schemes to unsteady problems (see [19, 10, 11, 20]),

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