COMMUNICATIONS IN COMPUTATIONAL PHYSICS
Vol. **5**, No. 2-4, pp. 730-744

Commun. Comput. Phys.
February 2009

Variable High Order Multiblock Overlapping Grid Methods for Mixed Steady and Unsteady Multiscale Viscous Flows

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Received 21 December 2007; Accepted (in revised version) 26 June 2008

Available online 1 August 2008

Abstract. Flows containing steady or nearly steady strong shocks on parts of the flow field, and unsteady turbulence with shocklets on other parts of the flow field are difficult to capture accurately and efficiently employing the same numerical scheme, even under the multiblock grid or adaptive grid refinement framework. While sixth-order or higher-order shock-capturing methods are appropriate for unsteady turbulence with shocklets, third-order or lower shock-capturing methods are more effective for strong steady or nearly steady shocks in terms of convergence. In order to minimize the short comings of low order and high order shock-capturing schemes for the subject flows, a multiblock overlapping grid with different types of spatial schemes and orders of accuracy on different blocks is proposed. The recently developed single block high order filter scheme in generalized geometries for Navier Stokes and magnetohydrodynamics systems is extended to multiblock overlapping grid geometries. The first stage in validating the high order overlapping approach with several test cases is included.

AMS subject classifications: 65Z05, 65M06, 65M50, 65M55, 65M60, 65M99, 65Y99

Key words: Multiblock grid, overset grids, high order numerical methods, blunt body hypersonic flows, mixed steady and unsteady flows.

1 Introduction

For over two decades, second and third-order shock-capturing schemes employing time-marching to the steady state have enjoyed much success in simulating many transonic,

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supersonic and hypersonic steady aeronautical flows containing strong shocks. Standard second and third-order shock-capturing schemes are formally of second or third order and can degenerate to first-order of accuracy at steep gradients and smooth extrema. In the presence of mixed steady and unsteady multiscale viscous flows, low order (third-order or lower) time-accurate methods are not effective in accurately simulating, e.g., unsteady turbulent fluctuation containing shocklets. At the same time, high order schemes with good unsteady shock-capturing capability suffer from the inability to converge to the proper steady shocks effectively. Attempts to improve the convergence rate of high order methods to strong steady shocks involve order reduction or added numerical dissipation of the scheme in the vicinity of the shocks, thus degrading the true order of the scheme in other parts of the flow. Although extreme grid refinement in conjunction with low order schemes can be used on the unsteady turbulence part of the flow field, increases in CPU time, and instability and stiffness of the overall computations are inevitable. A method to effectively overcome these difficulties for mixed steady and unsteady viscous flows is a multiblock overlapping grid with a different order and different type of numerical scheme on different blocks.

This work concentrates on the finite difference formulation on structured grids. In particular, the aim is to extend our recently developed single block high order filter scheme in generalized geometries [11] to multiblock overlapping grid geometries. Stable SBP (summation-by-parts) energy norm numerical boundary procedures [5] for high order central spatial schemes are employed at physical boundaries. Lagrangian interpolations are used to interpolate grid point values among the block overlapping regions [2]. Matching high order spatial schemes for viscous terms and high order 3-D metric evaluations [10] is used in the presence of physical viscosity and curvilinear grids, respectively. In other words, the metric derivatives of the coordinate transformation are approximated by the same high order finite difference operators as used for to approximate the flux derivatives. These wide high-order finite difference operators for the metric evaluations employ summation-by-parts boundary closure as well. The multiblock option can, e.g., easily accommodate low order shock-capturing schemes in regions of steady shocks and high order schemes in regions containing unsteady turbulence and shocklets.

The interpolation between grids is not conservative, however conservation is less important when solving equations with physical viscosity such as the Navier-Stokes equations. In practical computations with inviscid equations, conservation at interfaces is usually not needed. In some very special cases non-conservation can lead to problems, see [6] for a discussion of this and a description of a conservative interpolation algorithm.

The following presents a description of the approach with some test cases to validate the solver without all the relevant physics included in the model. This is the first step of the development to validate the approach if a smooth transition can be accomplished at multiblock interfaces. The work in progress next step is to apply the solver to practical applications.

An important application for the proposed solver is to simulate blunt body space vehicles at hypersonic speeds with strong steady or nearly steady bow shocks and possi-