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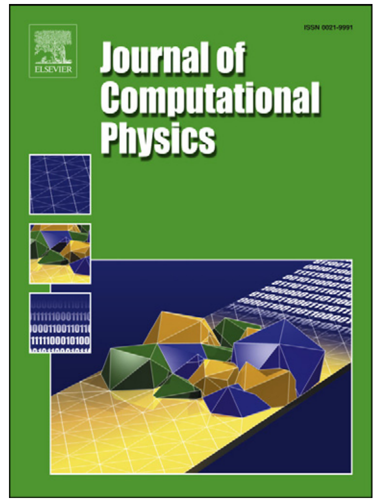

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A Locally Stabilized Immersed Boundary Method for the Compressible Navier-Stokes Equations

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Abstract

A higher-order immersed boundary method for solving the compressible Navier-Stokes equations is presented. The distinguishing feature of this new immersed boundary method is that the coefficients of the irregular finite-difference stencils in the vicinity of the immersed boundary are optimized to obtain improved numerical stability. This basic idea was introduced in a previous publication by the authors for the advection step in the projection method used to solve the incompressible Navier-Stokes equations. This paper extends the original approach to the compressible Navier-Stokes equations considering flux vector splitting schemes and viscous wall boundary conditions at the immersed geometry. In addition to the stencil optimization procedure for the convective terms, this paper discusses other key aspects of the method, such as imposing flux boundary conditions at the immersed boundary and the discretization of the viscous flux in the vicinity of the boundary. Extensive linear stability investigations of the immersed scheme confirm that a linearly stable method is obtained. The method of manufactured solutions is used to validate the expected higher-order accuracy and to study the error convergence properties of this new method. Steady and unsteady, 2D and 3D canonical test cases are used for validation of the immersed boundary approach. Finally, the method is employed to simulate the laminar to turbulent transition process of a hypersonic Mach 6 boundary layer flow over a porous wall and subsonic boundary layer flow over a three-dimensional spherical roughness element.

Keywords: immersed boundary, higher-order finite-difference, numerical stability analysis, compressible flows

1. Introduction and Motivation of the Research

Immersed Boundary Techniques (IBTs) have been developed for many years and have appeared in various forms since they were first introduced by Peskin[1, 2] (see for example Goldstein *et al.*[3], LeVeque and Li[4], Wiegmann and Bube[5], Linnick and Fasel[6], Johansen and Collela[7], Mittal and Iaccarino[8], Zhong[9], Duan *et al.*[10] and many others). These methods were first introduced as a nontraditional approach for

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