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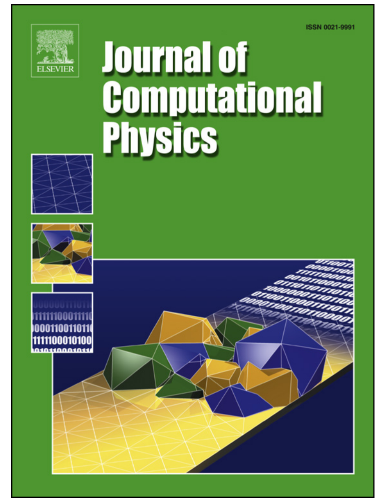

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On numerical instabilities of Godunov-type schemes for strong shocks

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Abstract

It is well known that low diffusion Riemann solvers with minimal smearing on contact and shear waves are vulnerable to shock instability problems, including the carbuncle phenomenon. In the present study, we concentrate on exploring where the instability grows out and how the dissipation inherent in Riemann solvers affects the unstable behaviors. With the help of numerical experiments and a linearized analysis method, it has been found that the shock instability is strongly related to the unstable modes of intermediate states inside the shock structure. The consistency of mass flux across the normal shock is needed for a Riemann solver to capture strong shocks stably. The famous carbuncle phenomenon is interpreted as the consequence of the inconsistency of mass flux across the normal shock for a low diffusion Riemann solver. Based on the results of numerical experiments and the linearized analysis, a robust Godunov-type scheme with a simple cure for the shock instability is suggested. With only the dissipation corresponding to shear waves introduced in the vicinity of strong shocks, the instability problem is circumvented. Numerical results of several carefully chosen strong shock wave problems are investigated to demonstrate the robustness of the proposed scheme.

Keywords: Godunov-type schemes, carbuncle, Riemann solver, shock instability, finite volume, hypersonic

1. Introduction

In the last decades, great progress has been made in computational fluid dynamics. However, there are still challenging issues that need to be addressed with caution, especially in hypersonic flows. One of them is the accurate prediction of hypersonic heating which relies heavily on the performance of shock-capturing schemes used in a finite-volume Euler/Navier–Stokes code. Approximate Riemann solvers are popular shock-capturing methods for hypersonic flow computations. Not only should a desirable Riemann solver capture all kinds of discontinuities accurately and sharply, but it also should own a high level of robustness against the shock anomalies, including the carbuncle phenomenon. However, it is

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