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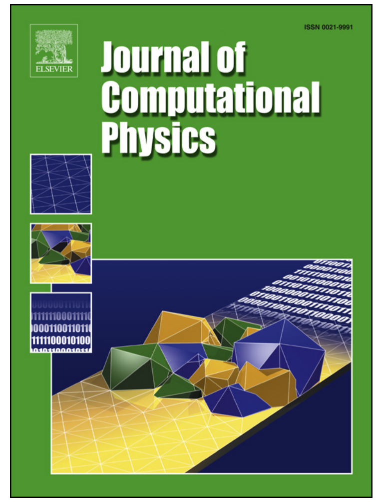

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On a consistent high-order finite difference scheme with kinetic energy conservation for simulating turbulent reacting flows

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Abstract

The main objective of this study is to present an accurate and consistent numerical framework for turbulent reacting flows based on a high-order finite difference (HOFD) scheme. It was shown previously by Desjardins et al. (J. Comput. Phys. 227, 2008) that a centered finite difference scheme discretely conserving the kinetic energy and an upwind-biased scheme for the scalar transport can be combined into a useful scheme for turbulent reacting flows. With a high-order spatial accuracy, however, an inconsistency among discretization schemes for different conservation laws is identified, which can disturb a scalar field spuriously under non-uniform density distribution. Various theoretical and numerical analyses are performed on the sources of the unphysical error. From this, the derivative of the mass-conserving velocity and the local Péclet number are identified as the primary factors affecting the error. As a solution, an HOFD stencil for the mass conservation is reformulated into a flux-based form that can be used consistently with an upwind-biased scheme for the scalar transport. The effectiveness of the proposed formulation is verified using two-dimensional laminar flows such as a scalar transport problem and a laminar premixed flame, where unphysical oscillations in the scalar fields are removed. The applicability of the proposed scheme is demonstrated in an LES of a turbulent stratified premixed flame.

Keywords:
High-order scheme, Finite difference, Turbulent flows, Scalar transport

1. Introduction

Computational fluid dynamics (CFD) has been a powerful tool in science for investigating fundamental physics [1] and in engineering for the design and control of engineering devices, in which complex turbulent reacting and non-reacting flows are found. Accurate, computationally tractable yet robust numerical methods are therefore essential for the simulation of turbulent flows and have become a field of intensive and still ongoing research [2, 3].

Among a number of numerical methods to solve the underlying governing equations of turbulent flows for direct numerical simulation (DNS) or large-eddy simulation (LES), the finite difference (FD) scheme is an appealing technique due to its simplicity, straightforward implementation, and possibility of high-order accuracy. With this method, two considerations make it desirable to employ high-order schemes. The first one is a notion that these lead to more accurate results, which has been shown, for example, by Desjardins et al. [4] in a series of test cases or by Schumacher et al. [5] in an analysis of small-scale turbulence. Most high-order schemes show an improved wavenumber response at high frequencies, which results in a better resolution of small-scale turbulence. Secondly, given a maximum allowable error of a simulation, the use of high-order schemes can reduce the overall computational cost by decreasing the number of grid points, in

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