Efficient implementation of volume/surface integrated average based multi-moment method

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Abstract

We investigated discretization strategies of the conservation equation in VSIAM3 (volume/surface integrated average based multi-moment method) which is a numerical framework for incompressible and compressible flows based on a multi-moment concept. We investigated these strategies through the lid-driven cavity flow problem, shock tube problems, 2D explosion test and droplet splashing on a superhydrophobic substrate. We found that the use of the CIP-CSLR (constrained interpolation profile-conservative semi-Lagrangian with rational function) method as the conservation equation solver is critically important for the robustness of incompressible flow simulations using VSIAM3 and that numerical results are sensitive to discretization techniques of the divergence term in the conservation equation. Based on these results, we proposed efficient implementation techniques of VSIAM3.

keywords: multi-moment method; VSIAM3; CIP-CSL method; shock tube; droplet splashing

1 Introduction

VSIAM3 [23, 24, 28] is a numerical framework to simulate incompressible and compressible flows, and employs a CIP-CSL method [21, 30, 25, 26] as the conservation equation solver. VSIAM3 has been applied to various fluids problems [23, 24, 28] including droplet splashing [38, 39, 40]. In experiences of one of the authors [38, 39, 40], VSIAM3 is a highly robust and efficient numerical framework. However most of researchers who tried to develop the code could not conduct robust fluid simulations [13]. This is because a multi-moment framework which has been used in VSIAM3 (including the CIP-CSL method) has increased some complexities in the implementation and the full detail of the efficient/robust implementation of VSIAM3 has not been described in any paper. The issue on the robustness in VSIAM3 has also been implied in [9] and a possible solution using the simple CIP interpolation for the issue has been proposed. In the paper, we identify the reasons and supply the full details of efficient implement of VSIAM3. Our approach is fully based on VSIAM3 (without using the simple CIP interpolation) and simple.

VSIAM3 and the CIP-CSL methods can be considered as multi-moment methods. Multi-moment methods are defined as methods which use at least two different types of moments (variables) and update these moments by using different formulations (but the same governing equation). For instance, the CIP-CSL2 (CIP-CSL with 2nd-order polynomial function) method [30] which is a solver of the conservation equation uses boundary value (point value in 1D) and cell average as moments (i.e. two different moments). The boundary value and cell average are updated by using finite difference and finite volume formulations, respectively (i.e. two different formulations). VSIAM3 also uses the same moments with these in CSL2. The CIP method [31, 32, 33], IDO (interpolated differential operator) scheme [1] and MCV (multi-moment constrained finite volume) [6] can also be categorized in multi-moment methods. On the

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