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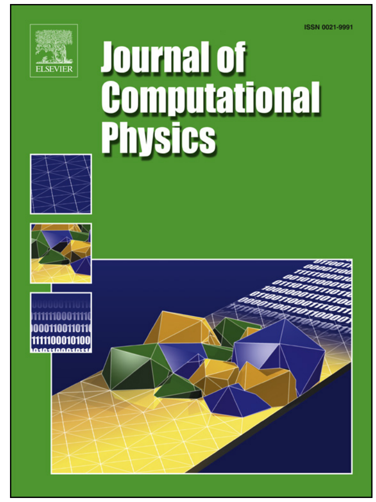


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# An enhanced FIVER method for multi-material flow problems with second-order convergence rate

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**Abstract**

The finite volume (FV) method with exact two-material Riemann problems (FIVER) is an Eulerian computational method for the solution of multi-material flow problems. It is robust in the presence of large density jumps at the fluid-fluid interfaces, and the presence of large structural motions, deformations, and even topological changes at the fluid-structure interfaces. To achieve simplicity in implementation, it approximates each material interface by a surrogate surface which conforms to the control volume boundaries. Unfortunately, this approximation introduces a first-order error of the geometric type in the solution process. In this paper, it is first shown that this error causes the original version of FIVER to be inconsistent in the neighborhood of material interfaces and degrades its global order of spatial accuracy. Then, an enhanced version of FIVER is presented to rectify this issue, restore consistency, and achieve for smooth problems the desired global convergence rate. To this effect, the original definition of a surrogate material interface is retained because of its attractive simplicity. However, the solution at this interface of a two-material Riemann problem is enhanced with a simple reconstruction procedure based on interpolation and extrapolation. Next, the extrapolation component of this procedure is equipped with a limiter in order to achieve nonlinear stability for non-smooth problems. In the one-dimensional inviscid setting, the resulting FIVER method is also shown to be total variation bounded. Focusing on the context of a second-order FV semi-discretization, the nonlinear stability and second-order global convergence rate of this enhanced FIVER method are illustrated for several model multi-fluid and fluid-structure interaction problems. The potential of this computational method for complex multi-material flow problems is also demonstrated with the simulation of the collapse of an air bubble submerged in water and the comparison of the computed results with corresponding experimental data.

*Keywords:* embedded boundary method, finite volume method, immersed boundary method, large density jump, multi-material, multi-phase, total variation bounded, two-phase Riemann solver

## 1. Introduction

FIVER (finite volume method with exact two-material Riemann problems) is a finite volume (FV) method for the solution of multi-material, fluid and fluid-structure interaction (FSI) problems. Its underlying semi-discretization procedure is based on the solution of local, one-dimensional, two-material Riemann problems. It was originally developed in [1], in the context of explicit time-discretizations, for the solution of compressible, inviscid, two-phase flow problems characterized by simple equations of state (EOS) but large contact discontinuities (density jumps). However, it is equally applicable to the solution of incompressible,

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