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A Numerical Investigation of Richtmyer-Meshkov Instability in Spherical Geometry

Jinxin Wu[1], Han Liu[1] and Zuoli Xiao[1,2,3,*]

[1] *State Key Laboratory for Turbulence and Complex Systems, College of Engineering, Peking University, Beijing 100871, China*
[2] *HEDPS and Center for Applied Physics and Technology, College of Engineering, Peking University, Beijing 100871, China*
[3] *Beijing Innovation Center for Engineering Science and Advanced Technology, Peking University, Beijing 100871, China*

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Abstract. Richtmyer-Meshkov Instability (RMI) in a spherical geometry is studied via direct numerical simulation using a high-order three-dimensional in-house solver. Specifically, a six-order compact difference scheme coupled with localized artificial diffusivity method is adopted in order to capture discontinuities with high accuracy. A pure converging shock propagation in a sphere is simulated and the result agrees well with Guderley's theory. For RMI in a spherical geometry, the development of mixing width and its growth rate at different stages are examined and the underlying mechanism is also briefly analyzed. Particularly addressed is the effect of Mach number on the growth rate of perturbations and turbulent mixing process.

AMS subject classifications: 65M10, 78A48

Key words: Richtmyer-Meshkov instability, direct numerical simulation, spherical geometry, Mach number.

1 Introduction

Richtmyer-Meshkov instability (RMI) refers to the situation where the perturbations will be amplified when an initially perturbed interface between two fluids of different densities is accelerated by a shock wave. The heavier fluid falls into the lighter fluid and forms narrow spike structures while the lighter penetrates into the heavier to generate bubble

*Corresponding author.
Emails: albert_wjx@pku.edu.cn (J. X. Wu), z.xiao@pku.edu.cn (Z. L. Xiao)

structures. Then the mixing layer near the interface evolves into mushroom-like structures and the inner flow gradually becomes turbulent. It was first predicted by Richtmyer [1] and then confirmed by Meshkov's experiment [2]. Similar to Rayleigh-Taylor instability (RTI) [3,4] which develops under sustained acceleration, RMI can be regarded as its impulsive counterpart. It should be noted that RTI can only develops when $\nabla\rho\cdot\nabla p<0$ (with $\nabla\rho$ and ∇p being the gradients of fluid density and pressure, respectively), while RMI always appears regardless of the direction of the shock wave. Extensive analytical, experimental and numerical studies have been carried out concerned with RMI during the past half century due to its significance in many fields, such as inertial confinement fusion (ICF) [5] and supernova collapse [6]. However, compared with most of previous studies focusing on planar geometry where only RMI occurs, the research on converging geometry is relatively rare for the reason that the evolution of interfacial perturbations in this case involves more complicated processes. Specifically, the converging shock and interface are radially accelerated or decelerated during propagation subject to geometrical convergence, which is usually referred to as Bell-Plesset (BP) effect [7,8]. Besides, the effect of RTI induced simultaneously by the sustained acceleration can not be ignored, especially in the region near the center.

Previous theoretical studies of RMI in converging geometry can be found in several literatures. Mikaelian [9,10] reported the effects of convergence on the linear stage of RMI occurring in stratified cylindrical and spherical shells. Kim [11] formulated the small amplitude theory of RMI in cylindrical and spherical geometry. Liu et al. [12] developed a nonlinear theory to describe classical cylindrical RMI for arbitrary Atwood numbers. Related experiments are scarce because it is difficult to generate a perfectly converging shock in an ordinary shock tube. Readers are referred to some innovative research works conducted by Biamino et al. [13] and Ding et al. [14]. Instead, many researchers choose numerical simulation to study this issue. Zhang et al. [15] performed a systematic numerical study of RMI driven by cylindrical shocks for both imploding and exploding cases. Lombardini et al. [16] first studied the linear stability of an interface following the passage of a three-dimensional imploding or exploding cylindrical shock wave. Dutta et al. [17] investigated RMI for a spherical axisymmetric flow and demonstrated scaling invariance with respect to shock Mach number for fluid mixing statistics. Recently, Lombardini et al. [18] presented a detailed large-eddy simulation of turbulent mixing driven by spherical implosions with perturbations generated by the spherical harmonics basis. Bhagatwala et al. [19] adopted a more general initial interface perturbation similar to those in planar RMI simulations and studied the effect of shock Mach number on RMI in spherical geometry.

In present study, direct numerical simulation is carried out for RMI in a spherical geometry. The purpose is to study the evolution statistics of the interface and perturbations before and after reshock. Particular focus of this study is on the effect of shock Mach number on the mixing width growth rate and turbulent mixing dynamics. The remaining content of this paper is organized as follows. First, the numerical methods and simulation set-ups are introduced in Section 2. Then, the results and discussions are