A Weighted Essentially Nonoscillatory Implementation of a Reynolds-Averaged Navier–Stokes Model for Richtmyer–Meshkov Instability-Induced Mixing

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Abstract: A high-order, multicomponent, weighted essentially nonoscillatory (WENO) implementation of a two-equation K-ϵ Reynolds-averaged Navier–Stokes model is used to simulate reshocked Richtmyer–Meshkov turbulent mixing at various Atwood and Mach numbers. The predicted mixing layer evolution is compared with several experimental data sets, as well as with the analytical late-time self-similar solution of the transport equations. The sensitivity of the turbulence model solutions and transport equation budgets to variations in the initial conditions, variations in the key model coefficients, and order of flux reconstruction (third- and fifth-order) is explored. In addition, the convergence properties of the solutions is examined as the grid is refined in space.

Keywords: Turbulence Modeling, Reynolds-Averaged Navier–Stokes Model, Richtmyer–Meshkov Instability, High-Energy-Density Physics.

1 Introduction

Shock-induced turbulence and mixing have a crucial role in many high-energy-density and astrophysical applications including inertial confinement fusion (ICF), high-energy laser experiments, supernovae, stellar life cycles, and black hole dynamics. A manifestation of shock-induced turbulence and mixing in these environments is turbulent mixing caused by reshocked Richtmyer–Meshkov instability. To better understand the role of this instability in mixing, numerical simulations are performed using a two-equation Reynolds-averaged Navier–Stokes model. Specifically, a detailed examination of the predictions of a K-ϵ model is presented.

2 Problem Statement

Richtmyer–Meshkov turbulent mixing occurs in supernovae and ICF capsule implosions as shocks traverse perturbed interfaces separating materials of different densities. As a shock interacts with an interface, it imparts a velocity leading to interface acceleration and amplified growth of the interfacial perturbations, and eventually mixing (see Figure 1). In many applications the evolving interface and resulting mixing layer are reshocked by a reflected shock. Thus, the development of more predictive turbulent transport models [1, 2] validated against experimental

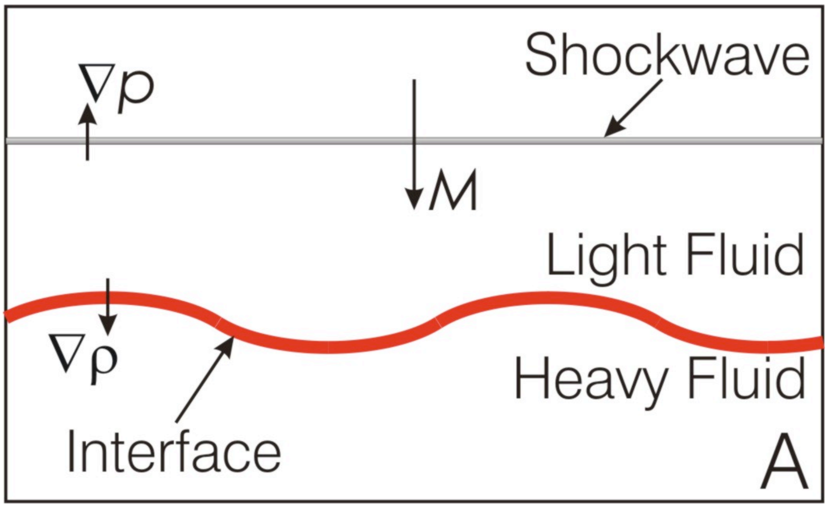

Figure 1: Schematic of Richtmyer–Meshkov instability.

data [3, 4] predicting reshocked mixing layer growth is an important area of contemporary research. The Vetter and Sturtevant experiment [4] is used as an initial validation of the model. The evolution of the mean density, mean pressure, mean and turbulent kinetic energies, turbulent kinetic energy dissipation rate, and turbulent viscosity are also considered.

3 Summary and Future Work

Reshocked Richtmyer–Meshkov turbulent mixing is crucial to the understanding and numerical modeling of many high-energy-density and astrophysical applications. Detailed studies using the K-ϵ model are conducted to explore the predictive capabilities of the model as applied to the mixing layer width evolution in the Vetter–Sturtevant and Poggi experiments. In the future, additional comparisons to experimental data are planned, along with validation for turbulent mixing induced by the Rayleigh–Taylor instability. An extension of the model to describe radiative shocks affected by turbulence will also be developed.

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