RESHOCK OF SELF-SIMILAR MULTIMODE RICHTMYER–MESHKOV INSTABILITY AT HIGH ATWOOD NUMBER IN HEAVY-LIGHT AND LIGHT-HEAVY CONFIGURATIONS

Michael Probyn[1] & Ben Thornber[1]
[1]*Department of Engineering Physics, Cranfield University, MK43 0AL, England*

Abstract
Richtmyer–Meshkov instability (RMI) promotes turbulent mixing and is seen across a variety of events ranging from supernova to inertial confinement fusion[4]. In particular understanding RMI is important for ICF where enhanced mixing tends to drive down the yield or reduce power output in energy applications. In many applications multiple shockwaves pass through the mixing layer, for instance due to reflections from the centre of a spherical capsule, thus causing further enhanced mixing

To the best of the author's knowledge we present the first ever results for a simulation of very high Atwood number reshocked Richtmyer–Meshkov instability using high order accuracy 3D methods (5$^{\text{th}}$ order in space and 2$^{\text{nd}}$ time) at high resolution (512 x 512 x 860). First an initial shock passes from the heavy gas to the light gas and the simulation is run until the mixing layer achieves self-similarity. Two different reshock cases are then run, the first with the second shock passing from light-to-heavy (the opposite direction to the original shock) and the second with the shock passing from heavy-to-light. Both shock Mach numbers are calculated to give the same impulse to the layer.

These latest results are presented for visualisations of the flow fields, comparing and contrasting the effects of shock passage in alternating directions, as well as a comparison of reshock at high Atwood number with reshocks at more commonly tested Atwood numbers. Turbulent kinetic energy spectra are also examined as well as the nature of the turbulence across the layer, including numerous mixing parameters and the progress from a highly anisotropic flow to one with behaviour more analogous to homogeneous decaying turbulence as the layer becomes self-similar.

INTRODUCTION

Numerous previous test cases have been demonstrated for reshocked Richtmyer–Meshkov at reasonable Atwood number under a variety of conditions, both experimentally[2, 10, 3] and numerically[8, 11]. Numerical simulation of Richtmyer–Meshkov instability offers many advantages, such as accurate evaluation of mixing parameters throughout the development of the flow and the ability to accurately control reshock times and properties.

INITIAL CONDITIONS AND COMPUTATIONAL SETUP

The test case used in this work is an Atwood number of 0.9 ($\rho_H = 20, \rho_L = 1$)) using a multimode initialisation with a "top hat" power spectrum for wavenumber $2\pi/32\Delta x < k < 2\pi/16\Delta x$. A shock of Mach number 1.91 is passed through the layer and causes the initial Richtmyer–Meshkov instability to develop. Full details of these initial conditions can be found in previous work[8, 11].

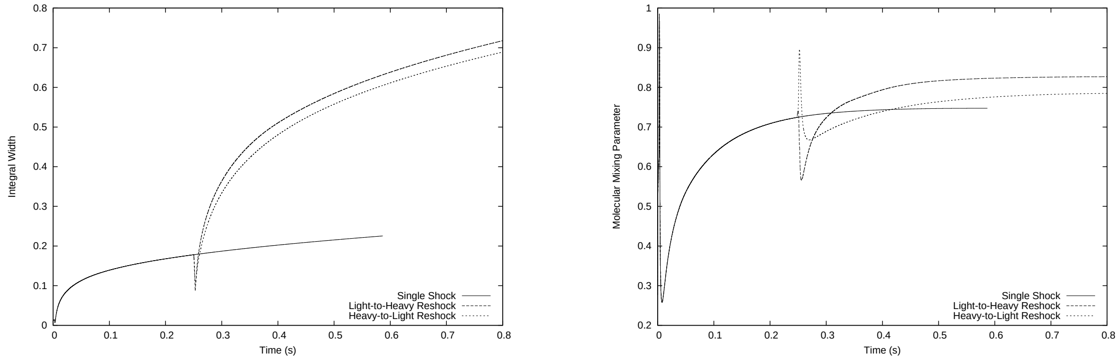
The reshock from light-to-heavy uses a shock of the same Mach number (1.91) and imparts an impulse of 185.9 ms^{-1}. The reshock from heavy-to-light is calculated to provide the same impulsive acceleration thus requiring a shock Mach number of 1.93. In this way the initial development of a layer governed by Richtmyer's initial growth rate formula ($da/dt = k\Delta \mathrm{u} a_0^+ \mathrm{At}^+$) [7]. Although this initial layer is no longer necessarily a small linear layer matching the impulse should maximise the similarity between both layers.

The solution is calculated using a Cranfield University in-house implicit large eddy simulation (ILES) solver, `Flamenco`, using high order accuracy 3D methods (5$^{\text{th}}$ order in space and 2$^{\text{nd}}$ time). Volume fraction progession is based on the method of Allaire [1] and a low-mach number correction is used in accordance with Thornber *et. al* [9].

RESULTS

A comparison of the growth rates is given between both a layer without reshock (integral width and mixing paramaters illustrated in Figure 1, and with a second shock from light-to-heavy gas and heavy-to-light gas. Sample slices illustrating the density can be seen in Figure 2. Figure 2a shows the density of the layer at the point at which the second shock is initiated (note in this case the second shock is in the light gas) whilst Figure 2b and c show the a sample density slice 0.16 seconds after the reshocks from light-to-heavy and heavy-to-light respectively.

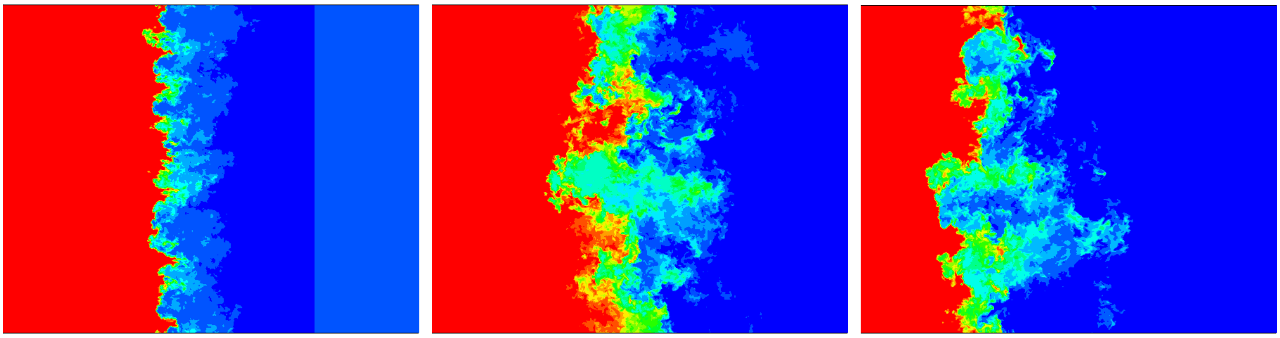
Full results will be presented including detailed growth rates and comparison of these rates with analytical solutions and previous equations such as those of Mikaelian[5, 6]. The difference between the reshocks including Atwood number effects are investigated and finally a breakdown of kinetic energy spectra and the self-similarity across the layer as the layers develop are shown.



(a) Integral Width

(b) Molecular Mixing Parameter

Figure 1. Plots of various mixing parameters against time.



(a) Conditions at Reshock

(b) Light-to-Heavy Reshock after 0.16s

(c) Heavy-to-Light Reshock after 0.16s

Figure 2. Visualisations of density fields of flows pre- and post-reshocks.

Acknowledgements

Many thanks to Prof. D. Youngs and Dr. R.Williams of AWE Plc for their useful technical insight. We also acknowledge that the results in this paper have been achieved using the PRACE Research Infrastructure resource `Curie` based in France at the TGCC and the Cranfield University HPC facility `Astral`. Project funded by AWE Plc/EPSRC.

References

[1] G. Allaire, S. Clerc, and S. Kokh. A five-equation model for the simulation of interfaces between compressible fluids. *J.Comp.Physics*, **181**:577–616, 2002.

[2] B. D. Collins and J. W. Jacobs. Plif flow visualization and measurement of the Richtmyer–Meshkov instability of an air/sf$_6$ interface. *J.Fluid.Mech*, **464**:113–136, 2002.

[3] E. Leinov, G. Malamud, Y. Elbaz, L. A. Levin, G. Ben-Dor, D. Shvarts, and O. Sadot. Experimental and numerical investigation of the Richtmyer–Meshkov instability under re-shock conditions. *J.Fluid.Mech.*, **626**:449–475, 2009.

[4] J. D. Lindl, R. L. McCrory, and E. Michael Campbell. Progress toward ignition and burn propagation in inertial confinement fusion. *Physics Today*, **45**(9):32–40, 1992.

[5] K. O. Mikaelian. Richtmyer–Meshkov instabilities in stratified fluids. *Phys.Rev.A*, **31**(1):410–419, 1985.

[6] K. O. Mikaelian. Turbulent mixing generated by Rayleigh–Taylor and Richtmyer–Meshkov instability. *Physica.D*, **36**:343–357, 1989.

[7] R. D. Richtmyer. Taylor instability in shock-acceleration of compressible fluids. *Comm.Pure.Appl.Math.*, **13**:297–319, 1960.

[8] B. Thornber, D. Drikakis, D. L. Youngs, and R. J. R. Williams. The influence of initial conditions on turbulent mixing due to Richtmyer–Meshkov instability. *Journal of Fluid Mechanics*, **654**:99–139, 2010.

[9] B. Thornber, A. Mosedale, D. Drikakis, D. L. Youngs, and R. J. R. Williams. An improved reconstruction method for compressible flows with low mach number features. *J.Comp.Physics*, **227**:4873–4894, 2008.

[10] M. Vetter and B. Sturtevant. Experiments on the Richtmyer–Meshkov instability of an air/sf$_6$ interface. *Shock Waves*, **4**(5):247–252, 1995.

[11] D. L. Youngs. Numerical simulation of turbulent mixing by Rayleigh–Taylor instability. *Physica.D*, **12**:32–44, 1984.