LA-UR- 01-6762

c.1

LA-UR-

Approved for public release; distribution is unlimited.

Title:

The Effects of Numerical Methods on the Statistical Comparison between Experiments and Simulations of Shocked Gas Cylinders

Author(s):

William J. Rider, CCS-2
James R. Kamm, CCS-2
Cindy A. Zoldi, X-2
Christopher P. Tomkins, P-22
Katherine P. Prestridge, DX-3
Paul M. Rightley, DX-3
Robert F. Benjamin, DX-3

Submitted to:

Second International Conference on
Computational Fluid Dynamics,
University of Sydney, Australia
15-19 July 2002

Los Alamos
NATIONAL LABORATORY

Form 836 (8/00)

The Effects of Numerical Methods on the Statistical Comparison between Experiments and Simulations of Shocked Gas Cylinders

W. Rider, J. Kamm*, C. Zoldi, C. Tomkins, P. Rightley, K. Prestridge, R. Benjamin
Los Alamos National Laboratory, MS D413, Los Alamos, NM 87545 USA
Email: kammj@lanl.gov

Keywords: Shockwaves, Fluid Instability

Introduction

Validation of numerical simulations, i.e., the quantitative comparison of calculated results with experimental data, is an essential practice in computational fluid dynamics. These comparisons are particularly difficult in the field of shock-accelerated fluid mixing, which can be dominated by irregular structures induced by flow instabilities. Such flows exhibit non-deterministic behavior, which eliminates any direct way to establish correspondence between experimental data and numerical simulation.

We examine the detailed structures of mixing experiments and their simulation for Richtmyer-Meshkov (RM) experiments of Prestridge et al. [1], Tomkins et al. [2], and Jacobs [3]. Numerical simulations of these experiments will be performed with several different high-resolution shock capturing schemes, including a variety of finite volume Godunov methods. We compare the experimental data for configurations of one and two diffuse cylinders of SF_6 in air with numerical results using several multiscale metrics: fractal analysis, continuous wavelet transforms, and generalized correlations; these measures complement traditional metrics such as PDFs, mix fractions, and integral mixing widths.

Approach

The shock tube experiments consist of a heavy gas (SF_6) that is introduced into a light gas (air) by a configurable nozzle and is impulsively accelerated by a planar Mach 1.2 shock wave; these experiments are described in detail by Rightley et al. [4]. In previous work [5,6], we examined the shock-driven evolution of a varicose-profile, thin gas layer (a gas "curtain"); the present work examines shock interactions with one or two gas cylinders. The fluid mixing in these experiments is driven by the deposition of baroclinic vorticity at the interface between the two fluids, producing the RM instability. Multi-exposure flow visualization is obtained with laser-sheet illumination and particle image velocimetry (PIV), providing experimental images of the fluid volume fraction and velocity field.

The computations are initialized with either analytic approximations of the initial condition or with the first (unshocked) experimental image, which is suitably denoised and interpolated onto the computational grid. The numerical method used in the present simulations is an unsplit (both spatial and temporal) direct Eulerian Godunov method with an adaptive quadratic two-shock Riemann solver; we shall also examine results of an operator-split Godunov method implemented in a Lagrange-remap fashion with a linearized two-shock Riemann solver. These two numerical approaches, together PPM, WENO, and discontinuous Galerkin methods, were used on previous gas curtain simulations [5,6] and suggested sensitive dependence of the computed solution on details of the numerical method.

Preliminary Results

We show in Fig.1 a comparison of the volume fraction at comparable post-shock times for an experiment of Jacobs (JE), a result of Prestridge and Tomkins (PTE), and a numerical simulation (NS). JE was at a slightly lower Mach number (M=1.095) and slightly ealier nondimensional time than the other configurations. Qualitative comparison suggests reasonable agreement of the JE and NS, while the image of PTE exhibits greater small-scale structure, suggestive of the onset of instability. Figure 2 contains preliminary results for the quantitative analysis of these images: plots of the local fractal dimension (left) and continuous wavelet energy (right) for the configurations of Fig. 1 are inconclusive. The local fractal dimension indicates quantitative agreement at the small scales between JE andNS; that agreement degrades at larger scales, however, with both experiments differing qualitatively and quantitatively from the calculation. The wavelet energy is qualitatively similar for both JE and NS, while the PTE results are qualitatively dissimilar from both JE and NS. Detailed analysis of such simulations, with various numerical methods as well as systematic mesh refinement, and at other stages of flow development, will be undertaken to elucidate these issues and determine the superior methodology for simulating the gas cylinder configurations.

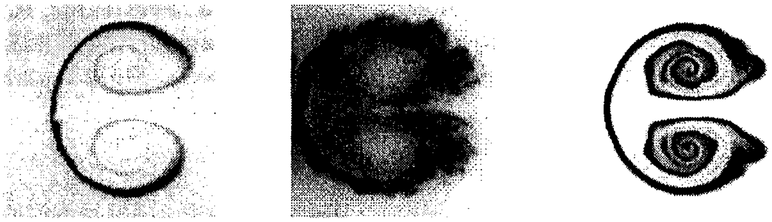

Figure 1. Single gas cylinder configuration at comparable post-shock times: Jacobs' experiment (left), Prestridge/Tomkins' experiment (center), and high-resolution-method simulation (right).

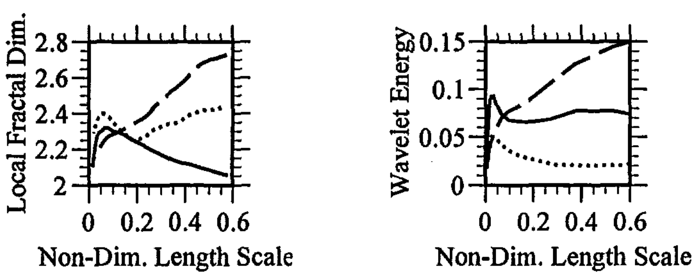

Figure 2. Local fractal dimension (left) and continuous wavelet transform energy (right) for Jacobs' experiment (dotted), Prestridge/Tomkins' experiment (dashed), and simulation (solid).

Conclusions

We have performed simulations of single gas cylinder RM experiments, approximated by the Euler equations and discretized with a high-resolution finite volume method. Comparison of the largest scale structures shows reasonable qualitative agreement. Examination of the spatial statistics, using fractal analysis and continuous wavelet transforms, suggests slightly better comparison between the experiment of Jacobs and the simulation, while the experiment of Prestridge differs significantly. Based on these preliminary results, we shall study several experimental images of both single and double gas cylinder experiments together with various aspects of different integration techniques to better understand the discrepancies between experiments and simulations of shock-accelerated mixing of diffuse gas cylinders.

References

1. K. Prestridge, C. A. Zoldi, P. Voribieff, P. M. Rightley, R. Benjamin, *Experiments and simulations of instabilities in a shock-accelerated gas cylinder*, Los Alamos National Laboratory report LA-UR-00-3973 (2000).
2. C. Tomkins, K. Prestridge, P. M. Rightley, P. Vorobieff, R. Benjamin, *Flow morphologies of two shock-accelerated, unstable gas cylinders*, manuscript in preparation.
3. Jacobs, J. The dynamics of shock accelerated light and heavy gas cylinders, *Phys. Fluids A* 5 (9), pp. 2239–2247 (1993).
4. Rightley, P.M., Vorobieff, P., Martin, R. and Benjamin, R.F., Experimental Observations of the Mixing Transition in a Shock-accelerated Gas Curtain, *Phys. Fluids* 11, pp. 186–200 (1999).
5. W. J. Rider, J. R. Kamm, C. Zoldi, *How do numerical methods effect the statistical details of Richtmyer-Meshkov instabilities?* in *Proceedings of the 23rd International Symposium on Shock Waves, Fort Worth, TX* (2001).
6. W. J. Rider, J. R. Kamm, P. M. Rightley, K. Prestridge, R. Benjamin, P. Vorobieff, *Direct statistical comparison of hydrodynamic mixing experiments and simulations*, in Y. Villacampa Esteve, G. M. Carlomagno, C. A. Brebbia, eds, *Computational Methods and Experimental Measurements X*, WIT Press, Southampton (2001), pp. 199-208.