Investigation of the Richtmyer-Meshkov instability

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Riccardo Bonazza, Mark Anderson and Jason Oakley

Department of Engineering Physics
University of Wisconsin - Madison

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1 Introduction

The present research program is centered on the experimental and numerical study of the hydrodynamics of shock-accelerated spherical density inhomogeneities. These flows are part of a broader category of shock-induced mixing flows that play a critical role in the implosion of D-T pellets in laser-driven ICF experiments.

The value of our work is both in the physics that can be learned from our experiments and calculations and in the validation that comes from comparing the experiments with the numerical results.

2 Accomplishments

The main accomplishments for 2008, are extensive experimental campaigns studying the effects of incident and reflected shocks on gas inhomogeneities. The series dealt with re-shocked gas bubbles and singly- and re-shocked 2-D interfaces, respectively. All the experiments are carried out in the vertical, square shock tube facility used in all our previous investigations (Wisconsin Shock Tube Laboratory - WiSTL).

In the re-shocked bubble case, Ar and SF_6 bubbles (with Atwood numbers of 0.18 and 0.68, respectively) were studied using incident shock waves of Mach number 1.33-2.31. The bubble gas is seeded with smoke and a cross section of the the shocked and re-shocked bubble is imaged by planar Mie scattering, by illuminating the flow with a laser sheet. For the first time, high-speed imaging experiments were performed at rates of up to 10,000 fps. This new approach allows us to study the time evolution of the bubble's macroscopic geometrical properties in a single experiment and from those to infer other fundamental properties of the flow, *e.g.* the circulation, and compare those with prediction from analytical models and numerical simulations. Examples of post-reshock images for an argon bubble accelerated by a $M = 2.00$ shock wave are shown in Fig. 1.

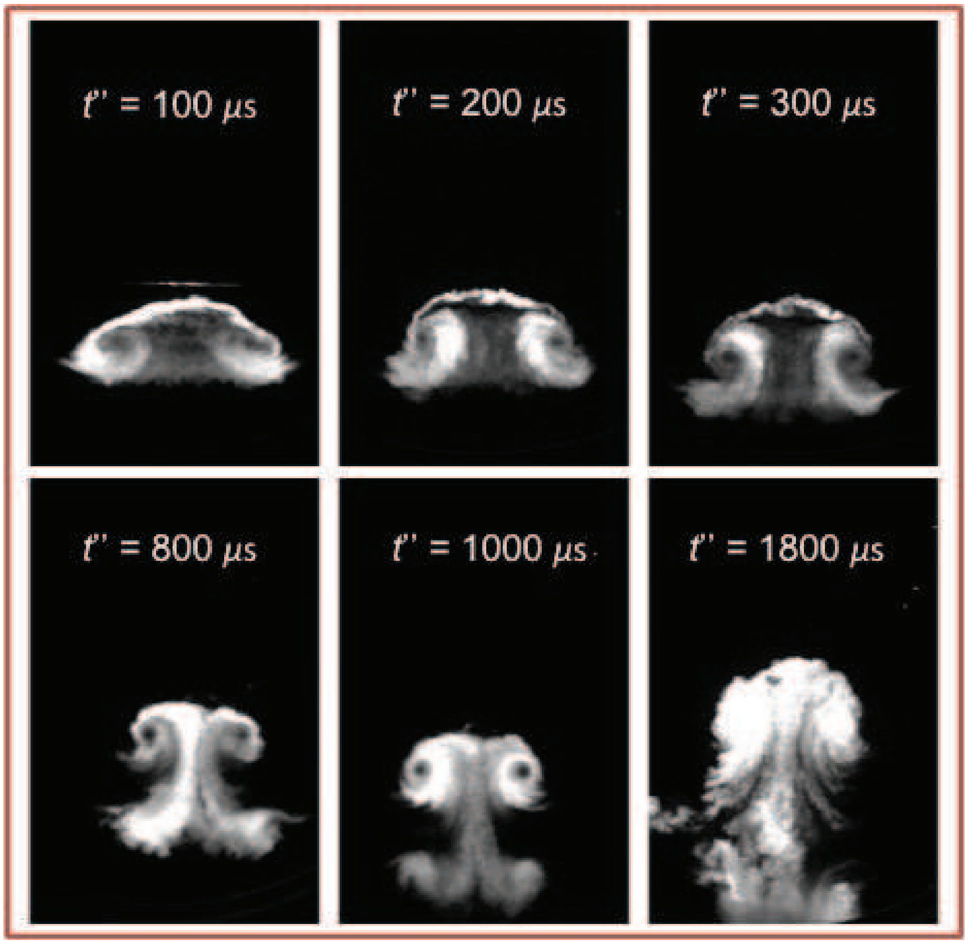


Figure 1: Planar Mie scattering images of an Ar bubble accelerated by a $M = 2.00$ shock wave. Times are from the moment of interaction with the reflected shock.

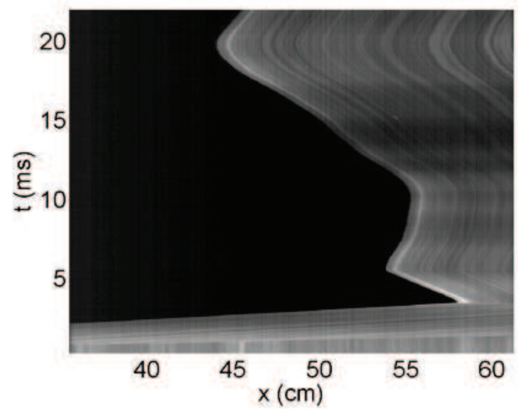
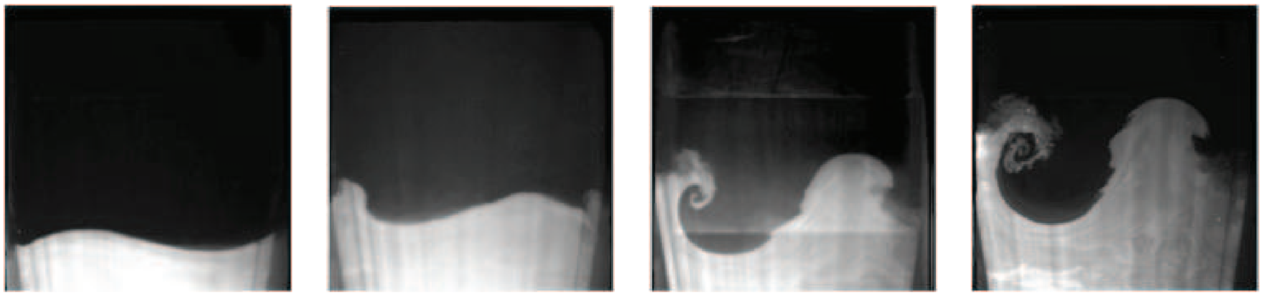


Figure 2: Experimental $x - t$ diagram for a nominally flat (He+Ar)/Ar interface accelerated by a $M = 1.32$ shock wave.

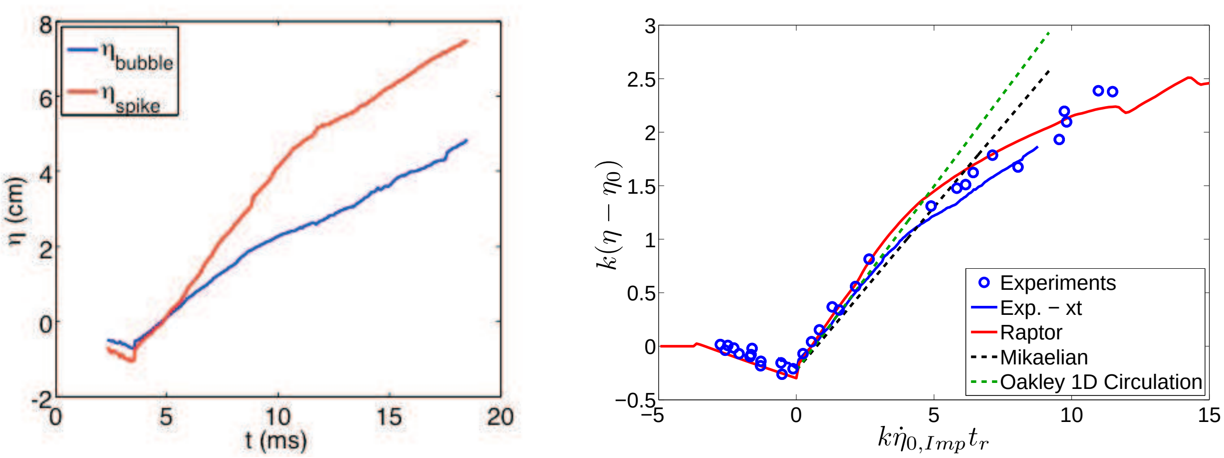
A very large campaign was carried out to study two-dimensional, near single-mode sinusoidal interfaces accelerated by a single shock covering one of largest parameter spaces to date: an Atwood number range of 0.29-095 and a Mach number range of 1.3-2.86. Dimensionless scaling laws were inferred from the experiments and compared with existing models. The results were presented at the 11th International Workshop on the Physics of Compressible Turbulent Mixing, the traditional venue of the Rayleigh-Taylor and RIchtmyer-Meshkov community. A journal article is being prepared to summarize the results. It was with this work that Mr. Brad Motl completed his Ph.D. requirements and earned his degree in August 2008.

A new campaign is currently underway to study the effect of re-shock on these 2-D, sinusoidal interfaces. Experiments have already been carried out on an (Ar+He)/Ar interface ($A = 0.29$) at $M = 1.31$. In the course of this latter study, a new technique has been developed and implemented to experimentally determine the $x - t$ diagram for a shocked interface and to measure the velocity of the bubble and spike tips, continuously over a long period time during a single experiment. This is achieved by shining a laser beam upwards from the bottom of the shock tube, seeding the test gas with smoke, and imaging a narrow and tall field of view within the test section with a high-speed digital camera. The boundary between bright and dark regions in the image corresponds to the interface. From brightness variations (consequent to changes in the density of the test gas and seed), one can also deduce the passage of reverberating shocks and rarefaction waves and thus reconstruct an entire $x - t$ diagram. The position of an initially flat interface as a function of time is extracted from its experimental $x - t$ diagram and is used as the reference to determine the amplitude and growth of the bubble and spike. Numerical simulations using the *Raptor* code on a LLNL supercomputer were also performed and compared very favorably to our experimental results. These are first-of-kind results that will benefit the whole Richtmyer-Meshkov community. Examples of an experimental $x - t$ diagram, an image sequence, a bubble and spike time history, and of the comparison of our experimental results with a theoretical model by Mikaelian are shown in Figs. 2, 3, 4(a) and 4(b), respectively.



(a) (b) (c) (d)

Figure 3: Laboratory experiments on a re-shocked (He+Ar)/Ar, 2-D, sinusoidal interface. $A' = 0.29$ (value after incident shock), M=1.32. Planar Mie scattering. Times from interaction with re-shock: (a) $t = -0.06$ ms; (b) $t = 2.72$ ms; (c) $t = 6.59$ ms; (d) $t = 9.68$ ms.



(a) (b)

Figure 4: (a) Bubble and spike amplitudes measured with respect to the position of a nominally flat interface (from $x - t$ diagram of Fig. 2); (b) Comparison of total amplitude from experimental measurements, analytical predictions and numerical simulations.

3 Publications and presentations

Journal articles

Niederhaus J., Greenough J., Oakley J., Bonazza R., "Vorticity evolution in two- and three-dimensional simulations for shockbubble interactions" *Phys. Scr.* **T132**, 014019, 2008

Ranjan D., Niederhaus J., Oakley J., Anderson M., Greenough J., Bonazza R., "Experimental and numerical investigation of shock-induced distortion of a spherical gas inhomogeneity", *Phys. Scr.* **T132**, 014020, 2008

D. Ranjan, J. Niederhaus, J. Oakley, M. Anderson, R. Bonazza, and J. Greenough, "Shock-bubble interactions: features of divergent refraction geometry observed in experiments and simulations", *Phys. Fluids* **20**, 036101, 2008

Niederhaus J., Greenough J., Oakley J., Ranjan D., Anderson M., "Bonazza R., A computational parameter study for the three-dimensional shock-bubble interaction", *JFM* **594**, 85-124, 2008

Conferences

11th International Workshop on the Physics of Compressible Turbulent Mixing, Santa Fe, NM, July 13-18, 2008

Motl B., Weber C., Oakley J., Anderson M., Bonazza R., "Experimental Richtmyer-Meshkov parameter study"

61th Annual Meeting of the Division of Fluid Dynamics of the American Physical Society, San Antonio, TX 11/ 23-25/2008

Haehn N., Weber C., Oakley J., Anderson M., Bonazza R. "Experimental investigation of a twice-shocked spherical gas inhomogeneity"

Chris Weber C., Haehn N., Oakley J., Anderson M., Bonazza R., Richtmyer-Meshkov Experiments on a Reshocked, Low Atwood Number Interface

4 Personnel

Faculty and staff involved in and supported by the program include:

Prof. Riccardo Bonazza, Department of Engineering Physics; supported for 0.55 months

Dr. Jason Oakley, Assistant Scientist, Dept. Engineering Physics; supported for 3.24 months

Mr. Paul Brooks, Instrumentation Specialist, Dept. Engineering Physics; supported for 4.8 months

Graduate students supported by and fully involved in the program in the past year include:

Mr. Brad Motl (USA; pursuing a PH.D. degree); supported for 6 months

Mr. Nick Haehn (USA; pursuing a Ph.D. degree); supported for 2.65 months

Mr. Jeremy White (USA; pursuing a Ph.D. degree); supported for 6 months

Three **undergraduate students** were also involved in and supported by the program at various levels and for different lengths of time.