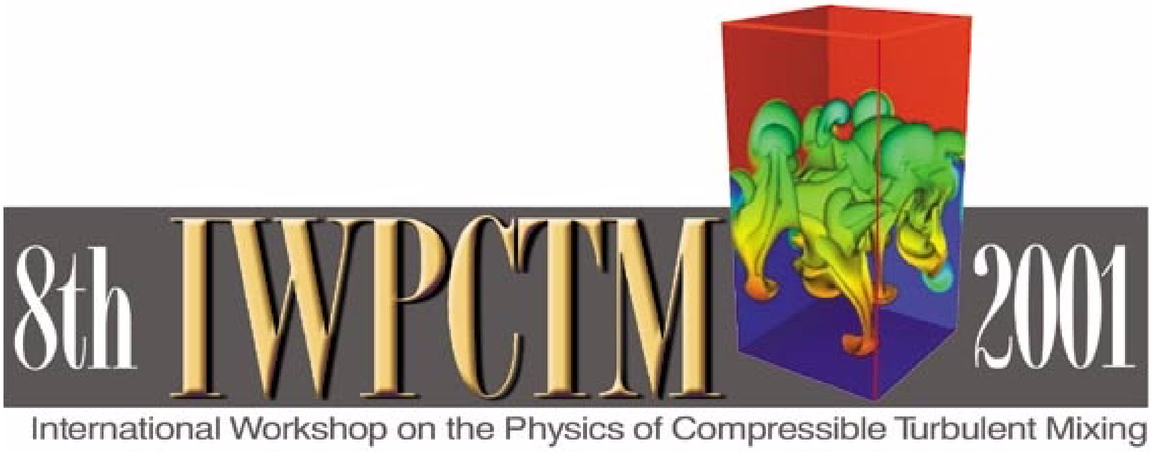
UCRL-ID-146350

CALIFORNIA INSTITUTE OF TECHNOLOGY
1891



December 9-14, 2001
Pasadena, California, USA

ABSTRACTS

Oleg Schilling, Chairman

DISCLAIMER

This document was prepared as an account of work sponsored by an agency of the United States Government. Neither the United States Government nor the University of California nor any of their employees, makes any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness, or usefulness of any information, apparatus, product, or process disclosed, or represents that its use would not infringe privately owned rights. Reference herein to any specific commercial product, process, or service by trade name, trademark, manufacturer, or otherwise, does not necessarily constitute or imply its endorsement, recommendation, or favoring by the United States Government or the University of California. The views and opinions of authors expressed herein do not necessarily state or reflect those of the United States Government or the University of California, and shall not be used for advertising or product endorsement purposes.

This work was performed under the auspices of the U. S. Department of Energy by the University of California, Lawrence Livermore National Laboratory under Contract No. W-7405-Eng-48.

This report has been reproduced
directly from the best available copy.

Available to DOE and DOE contractors from the
Office of Scientific and Technical Information
P.O. Box 62, Oak Ridge, TN 37831
Prices available from (423) 576-8401
http://apollo.osti.gov/bridge/

Available to the public from the
National Technical Information Service
U.S. Department of Commerce
5285 Port Royal Rd.,
Springfield, VA 22161
http://www.ntis.gov/

OR

Lawrence Livermore National Laboratory
Technical Information Department’s Digital Library
http://www.llnl.gov/tid/Library.html

8th International Workshop on the Physics of Compressible Turbulent Mixing,
Pasadena, CA (2001)

Local Organizing Committee

G. Dimonte, Lawrence Livermore National Laboratory, Livermore, CA, USA
B. Goodwin, Lawrence Livermore National Laboratory, Livermore, CA, USA
D. Meiron, California Institute of Technology, Pasadena, CA, USA
T. McAbee, Lawrence Livermore National Laboratory, Livermore, CA, USA
T. Peyser, Lawrence Livermore National Laboratory, Livermore, CA, USA
B. Remington, Lawrence Livermore National Laboratory, Livermore, CA, USA
O. Schilling (Chairman), Lawrence Livermore National Laboratory, Livermore, CA, USA
C. Verdon, Lawrence Livermore National Laboratory, Livermore, CA, USA

International Scientific Committee

G. Ben-Dor, Ben-Gurion University of the Negev, Beer-Sheeva, IL
D. Besnard, Commissariat à l'Energie Atomique, FR
A. Buckingham, Lawrence Livermore National Laboratory, Livermore, CA, USA
T. Clark, Los Alamos National Laboratory, Los Alamos, NM, USA
S. Dalziel, University of Cambridge, Cambridge, UK
D. Galmiche, Commissariat à l'Energie Atomique, FR
S. Gauthier, Commissariat à l'Energie Atomique, FR
J. Glimm, State University of New York at Stony Brook, NY, USA
B. Goodwin, Lawrence Livermore National Laboratory, Livermore, CA, USA
N. Hoffman, Los Alamos National Laboratory, Los Alamos, NM, USA
L. Houas, IUSTI Universite de Provence, Marseille, FR
J. Jacobs, University of Arizona, Tuscon, AZ, USA
Yu. Kucherenko, Russian Federal Nuclear Center-VNIITF, Snezhinsk, RU
P. Linden, University of California at San Diego, San Diego, CA, USA
D. Meiron, California Institute of Technology, Pasadena, CA, USA
E. Meshkov, Russian Federal Nuclear Center-VNIIEF, Sarov, RU
V. Neuvazhaev, Russian Federal Nuclear Center-VNIITF, Snezhinsk, RU
T. Peyser, Lawrence Livermore National Laboratory, Livermore, CA, USA
J. Redondo, Universitat Politecnica de Catalunya, Barcelona, SP
B. Remington, Lawrence Livermore National Laboratory, Livermore, CA, USA
V. Rozanov, P. N. Lebedev Physical Institute, Moscow, RU
O. Schilling, Lawrence Livermore National Laboratory, Livermore, CA, USA
D. Sharp, Los Alamos National Laboratory, Los Alamos, NM, USA
D. Shvarts, Nuclear Research Center, Beer-Sheeva, IL
E. Son, Moscow Physical and Technical Institute, Moscow, RU
H. Takabe, ILE, Osaka University, Osaka, JP
K. Takayama, Tohoku University, Sendai, JP
D. Youngs, Atomic Weapons Establishment, Aldermaston, UK
S. Zaytsev, ENIN, Moscow, RU

8th IWPCTM 2001

International Workshop on the Physics of Compressible Turbulent Mixing

General Information

The workshop is hosted by the Lawrence Livermore National Laboratory and is held at the California Institute of Technology.

Schedule (Oral and poster presentations will be at the California Institute of Technology):

Day	Date	Time	Activity
Sunday	December 9, 2001	5:00 PM – 9:00 PM	Registration – Pasadena Hilton
Sunday	December 9, 2001	6:00 PM – 9:00 PM	Reception – Pasadena Hilton
Monday	December 10, 2001	8:15 AM – 4:15 PM	Opening Remarks/Oral Presentations
Monday	December 10, 2001	4:15 PM – 6:00 PM	Poster Presentations
Tuesday	December 11, 2001	8:15 AM – 4:15 PM	Announcements/Oral Presentations
Tuesday	December 11, 2001	4:15 PM – 6:00 PM	Experimental Discussion/ Computational and Theoretical Poster Presentations
Wednesday	December 12, 2001	8:15 AM – 4:15 PM	Announcements /Oral Presentations
Wednesday	December 12, 2001	4:15 PM – 6:00 PM	Computational Discussion/Experimental and Theoretical Poster Presentations
Wednesday	December 12, 2001	6:00 PM – 9:00 PM	Banquet – Pasadena Hilton
Thursday	December 13, 2001	8:15 AM – 4:15 PM	Announcements /Oral Presentations
Thursday	December 13, 2001	4:15 PM – 6:00 PM	Theoretical Discussion/Computational and Experimental Poster Presentations
Friday	December 14, 2001	8:15 AM – 12:00 PM	Announcements/Oral Presentations/Summary Remarks/Closing Remarks

8th IWPCTM 2001
International Workshop on the Physics of Compressible Turbulent Mixing

Invited Guest Speakers:

Dr. Edward I. Moses, National Ignition Facility (NIF) Project Manager at the Lawrence Livermore National Laboratory, will be the guest speaker at the Reception on Sunday evening, December 9. Z. Nagin Cox, Mission Operations Engineer for the Mars Sample Return Mission at the NASA Jet Propulsion Laboratory, will be the guest speaker at the Banquet on Wednesday evening, December 12.

Message Line:

A phone will be located in the lobby of the Beckman Institute Auditorium for messages: the telephone number is (626) 395-5035.

Shuttles:

The Pasadena Hilton will provide shuttles to and from the hotel and Caltech in the morning and afternoon (parking on or near campus is extremely limited).

Pasadena Convention Center:

The Pasadena Convention Center will have representatives available for scheduling tourist activities. Representatives will be available on Sunday during the Registration and Tuesday through Thursday from 4:00 PM – 8:00 PM in the Pasadena Hilton Hotel lobby.

Administrative Staff:

C. Cantlin, Lawrence Livermore National Laboratory, Livermore, CA, USA
S. Davis, Lawrence Livermore National Laboratory, Livermore, CA, USA
K. Evans, Lawrence Livermore National Laboratory, Livermore, CA, USA

Table of Contents

REVIEW TALKS

A Review on RT and RM Instability and TM Experiments

J.-F. Haas[1] and S. G. Zaytsev[2]
[1]*Commissariat à l'Energie Atomique, Bruyères-le-Châtel, France*
[2]*Krzhizhanovsky Power Engineering Institute, Moscow, Russia*

We analyse the state of the art for experiments on Rayleigh-Taylor, Richtmyer-Meshkov instabilities (RTI, RMI) and the resulting (possibly compressible) turbulent mixing (TM). There is a very wide spectrum of state of matter (in addition to acceleration history and magnitude) ranging from « ordinary » gas or liquid dynamics experiments, through intermediate complexity detonation-driven setups often involving materials with strength, all the way to large laser driven experiments for the study of high energy density plasmas. Experiments are needed for a better understanding of fundamental mechanisms (e.g. nonlinear regime of the RTI and RMI, complex natural phenomena (supernovae explosions) and future applications (inertial confinement fusion). We consider first the field of « simple » gas dynamics RMI and TM experiments performed in ordinary shock tubes. It was suggested at the experimental roundtable of the 7th IWPCTM that the experiment type could be presented on a map with an horizontal axis for a compressibility parameter (such as the incident shock Mach number) and a vertical axis for the instability strength (e.g., according to the linear RMI formula, the product of Atwood number, perturbation wave number and initial amplitude). A second map was proposed, with a horizontal axis tentatively called « usefulness to theory » and a vertical one labelled « complexity of diagnostics ». The classical visualization by refractive effects (shadowgraph, schlieren, Mach-Zehnder or differential interferometry) is useful for geometrical observations of the mixing zones and instability patterns, but of limited quantitative value in TM. The modern laser sheet method provides a 2D map of the density or concentration field (via Mie or Rayleigh scattering or fluorescence). Flash X-rays absorption by Xe, infrared emission or infrared CO_2 laser absorption by shock heated CO_2 allow density measurements within binary mixing zones containing these gases. Laser Doppler Velocimetry (giving the velocity history at a given position) and Particle Image Velocimetry (giving a velocity map at a given time) have recently been introduced. The Hot Wire Anemometer provides the time evolution at a fixed position of the Nusselt number, which depends on velocity, concentration and temperature. The initial gas separation is best membrane-less for RMI and with microfilm for fine scale TM. Often, a good experiment for theory benefits from an imaginative conception while advanced diagnostics are useful for a quantitative comparison with numerical simulation and TM modelling. Among the cold hydrodynamics RTI experiments, some based on gravitational mixing of liquids (molecularly miscible or not, with or without surface tension) increasingly benefit from modern diagnostics. The experiments on gases in modified shock- or combustion tubes allow the investigation of compressibility and acceleration nonsteadiness, but with usually less precise diagnostics. There is a variety of gas detonation or combustion experiments in which the effect of cylindrical geometries are tested. Effects of initial interfacial perturbations and material strength can be investigated with jellies. Solid explosive drivers are needed for the measurement of such RT/RM processes in metals. Among recent high energy laser driven plasma experiments, the high quality visualizations in some very high Mach number experiments are fascinating. Our challenge is to insure that simpler and cheaper gas or liquid dynamics experiments will remain useful with the advent of the next generation of ICF lasers.

PACS Nos.: 42.79, 47.20, 47.27, 47.40, 52.57

The Experimental Study of Excitation and Development of the Hydrodynamic Instability in the Mixing Zone Separating Gases of Different Densities at their Accelerated Motion

S. G. Zaytsev
Krzhizhanovsky Power Engineering Institute, Moscow, Russia

The properties of the mixing zone between gases of different densities during accelerated and decelerated motion caused by compression waves have been analyzed. The design of the experimental set-up for study of the mentioned processes has been described.

The wave diagrams of possible regimes of flows and basic parameters such as velocity u, acceleration g, density ρ, pressure p, and temperature T have been under consideration.

The properties of excitation and development of the Rayleigh-Taylor instability (RTI) at the stages of accelerated and decelerated motion of the mixing zone have been described.
The characteristics of the mixing zone at the stage of "stratification" caused by interaction with a reflected compression wave - non-shocked deceleration - have been defined. The mixing zone volume decreases in this case.

The generation of shocks during evolution of compression waves and their interaction with the mixing zone results in growth of the mixing volume caused by excitation of the Richtmyer-Meshkov instability (RMI).

The amount of the substance involved into mixing during accelerated motion of the mixing zone separating gases of different densities has been defined. The problem of influence of the working media compressibility on process of the mixing has been discussed.

Review of Numerical Simulation of Mixing due to Rayleigh-Taylor and Richtmyer-Meshkov Instabilities

D. L. Youngs
Atomic Weapons Establishment, Aldermaston, United Kingdom

Since the late 1960s numerical simulation has been very successfully used to gain insight into the non-linear growth of Rayleigh-Taylor (RT) and Richtmyer-Meshkov (RM) instabilities. The first calculations were for single-mode growth in 2D. Then in the 1980s, 2D multimode simulations became feasible. 3D simulations of fully-developed turbulent mixing in simple situations have been performed during the past few years. There are many examples where numerical simulation has been used to study the affect of additional physical processes, such as ablation stabilisation or material strength, on instability growth. The progress made is reviewed and instances where numerical simulation has enhanced our understanding are highlighted. The main emphasis of this review will be on RT and RM instability. However, some reference will be made to simulations of turbulent shear flow and homogeneous turbulence, especially where ideas from these areas are relevant to RT/RM studies.

The numerical methods used will be discussed. RT and RM problems involve discontinuities, contact surfaces or shocks. TVD schemes have proved popular and number of researchers have used interface tracking techniques. For 3D LES (Large Eddy Simulation) dissipation at high-wavenumbers is needed. Many researchers, especially those who work on turbulent shear flow, favour the use of an explicit sub-grid model to represent this effect. The TVD methods have high-wavenumber dissipation inherent in the numerical scheme and when applied to turbulence simulations are referred to as MILES schemes (Monotone Implicit LES). There have been a number of examples of the application of MILES to RT and RM turbulent mixing and also some examples of 3D DNS (Direct Numerical Simulation) in which the effects of viscosity and diffusivity are resolved.

The future role of numerical simulation will be discussed. 2D simulation will continue to be useful for understanding complex experiments or the effect of additional physics, where 3D simulation is impractical. However, with the advent of very powerful supercomputers, 3D simulation (LES or DNS) will become increasingly useful and will give a detailed understanding of turbulent mixing in simplified situations. It is likely that RANS (Reynolds-AveragedNavier-Stokes) models will contine to be essential for modelling the most complex real applications. However, 3D simulation can make an important contribution here as well. In addition to experimental data, the results of 3D simulations should be used to validate the RANS models in simplified situations.

Modeling Late-Time Nonlinear Evolution of Hydrodynamic Instabilities and their Role in Inertial Confinement Fusion

D. Shvarts
Ben-Gurion University, Beer Sheeva, Israel and Nuclear Research Center, Negev, Israel

Abstract not available at time of printing.

EXPERIMENTAL ABSTRACTS

Abstract No. E2

Experimental Investigations of the Heavy and Light Media Separation in the Rayleigh-Taylor Turbulence Zone at Different Atwood Numbers

Yu. A. Kucherenko, S. I. Balabin, R. I. Ardashova, A. P. Pylaev, O. E. Kozelkov, and V. D. Murzakov
Russian Federal Nuclear Center – VNIITF, Snezhinsk, Russia

In the paper the experimental results with respect to the nondimensional rate of separation in the Rayleigh-Taylor turbulence zone are presented. In the experiments two different density liquids separated by a plane contact boundary were accelerated so that in the first phase of acceleration the Rayleigh-Taylor instability evolved and the definite zone of the turbulent mixing formed. At the second phase the sign of acceleration was jumpwise changed into the opposite one. As a result, the system of two different density liquids became stable. At these instants of time, in the turbulent mixing zone the separation processes of the heavy and light liquids evolved.

For three values of Atwood numbers the experiments were performed. for each of Atwood numbers the nondimensional rate of separation was determined.

Abstract No. E3

Experimental Investigation into Influence of Stabilizing Properties of Transitional Layers Upon the Turbulent Mixing Evolution

Yu. A. Kucherenko, S. I. Balabin, R. I. Ardashova, O. E. Kozelkov, A. V. Dulov, and I. A. Romanov
Russian Federal Nuclear Center – VNIITF, Snezhinsk, Russia

It is presented the results of the experimental investigation of the transitional layers width influence upon the evolution of turbulent mixing caused by the Rayleigh-Taylor instability. In experiments, mutual soluble liquids with density relation been equal to two were used. A transitional layer having continuous distribution of density arises in the region of liquids contact because of molecular diffusion. In experiments, it has been determined the dependence of the turbulent mixing evolution delay on both the initial perturbation region size and the characteristic width of the transitional layer.

Abstract No. E4

Improvements to Convergent Cylindrical Plasma Mix Experiments Using Laser Direct Drive

C. W. Barnes[1], S. H. Batha[1], A. M. Dunne[2], N. E. Lanier[1], G. R. Magelssen[1],
T. J. Murphy[1], K. W. Parker[2], S. Rothman[2], J. M. Scott[1], and D. Youngs[2]
[1]*Los Alamos National Laboratory, Los Alamos, NM*
[2]*Atomic Weapons Establishment, Aldermaston, United Kingdom*

Experiments studying mix in a compressible, convergent, miscible, plasma system are being conducted on the OMEGA Laser at the Laboratory for Laser Energetics at the University of Rochester.[1,2] Thin-walled polystyrene cylinders 2.25-mm long and 0.86 mm inner diameter with foam inside are directly illuminated with 351-nm wavelength light from 50 laser beams in a 1-ns square laser pulse. The turbulence driven by the Richtmyer-Meshkov instability by shock passage across a density discontinuity mixes marker material that is radiographically opaque. Initial work using a high-density, high-opacity marker layer of gold between the plastic ablator and foam clearly demonstrated significant measurable mix width[2]. However, the high opacity of the gold prevented determination of a density profile in the mix region, and it was also overly sensitive to hydrodynamic effects at the end of the marker layer. Use of lower opacity marker material will be described and its impact on end effects and the measurements of mix density profile described.

---

[1] C. W. Barnes *et al., Rev . Sci. Instrum.* **70** (1999) 471.

[2] C. W. Barnes *et al.,* submitted to *Physical Review Letters* (2001).

Abstract No. E5

Mixing Between Two Compressing Cylinders

S. H. Batha[1], K. W. Parker[2], C. W. Barnes[1], A. M. Dunne[2],
N. E. Lanier[1], G. R. Magelssen[1], T. J. Murphy[1], S. Rothman[2],
J. M. Scott[1], and D. Youngs[2]
[1]*Los Alamos National Laboratory, Los Alamos, NM*
[2]*Atomic Weapons Establishment, Aldermaston, United Kingdom*

Foam-filled cylinders have been imploded by the OMEGA laser at the University of Rochester. A marker layer of heavier material is placed between the foam and the outside ablator. The marker layer is hydrodynamically unstable when a strong shock passes through both these interfaces and the marker layer material mixes into the foam and the ablator. These experiments thus measure mix in the compressible, convergent, miscible, strong-shock regime.

These experiments are being extended by placing a solid cylinder at the center of the foam, forming a set of concentric cylinders separated by foam. The initial shock converges on the central cylinder and then rebounds and expands. The shock is predicted to create even more mixing of the marker layer as it traverses the previously mixed region. We present experimental measurements of this configuration.

Abstract No. E6

Development of a Method for Studying the Interaction Between Shock Wave and a Flame Front

M. Bliznetsov[1], V. Dudin[1], S. Gerasimov[1], L. Houas[3], G. Jourdan[3], A. Logvinov[1,2],
E. Meshkov[1,2], and Yu. Vlasov[1,2]
[1]*Russian Federal Nuclear Center - VNIIEF, Sarov, Russia*
[2]*SarPTI, Sarov, Russia*
[3]*IUSTI/CNRS, Université de Provence, Marseille, France*

Tomsk University has carried out research into explosive method for extinguishing the wild fires (A.M.Grishin, Kovalev Yu.M., 1994, Grishin, 1994, Grishin et al., 2000). This method has been experimentally checked but it is not currently used in practice. According to Grishin's hypothesis (A.M.Grishin, Kovalev Yu.M., 1994, Grishin, 1994), the explosive method for extinguishing the wild fires is based on "blowing out" the flame by a shock. There exists another idea (Meshkov, 1999) according to which this extinguishing is due to development of hydrodynamic instabilities. Experimental study of this method in natural conditions is rather complex, dangerous, and expensive. Hence, modeling this method in laboratory conditions is of interest. We report on results of an experimental study of developing such a method for interaction between shock and flame.

References

Grishin A.M., Babaev V.M., Gruzin A.D., Zverev V.G., Abaltusov V.E., Mamontov G.Ya. (1985). Meaning of extinguishing wild fires A.D. 1136811 USSR. Published 30.01.85. Bul.4

Grishin A.M., Kovalev Yu.M. (1989). Experimental and theoretical study of the interaction between explosion and crown fire. FGV, 6, pp. 72-79

Grishin A.M., Zima V.P., Mashovich A.Ya., Samoilov V.I. (2000). Experimental study of the interaction between a shock induced by point charges, and crowns. Proceedings of international conference "Common problems on mechanics and ecology", Tomsk University, pp.83-85

Meshkov E.E. (2000). Turbulent mixing associated with hydrodynamic instabilities in modern practical problems. Proceedings of international conference "Common problems on mechanics and ecology", Tomsk University, pp.156-158.

Abstract No. E7

The Influence of Scaling for Periodical Perturbations on Development of Turbulent Mixing on a Gas-Liquid Interface

M. Bliznetsov, E. Meshkov, N. Nevmerzhitsky, A. Nikulin, E. Sen'kovsky, and E. Sotskov
Russian Federal Nuclear Center – VNIIEF, Sarov, Russia

We report on results of experimental study of the influence of scaling for 3D periodical perturbations on dynamics of turbulent mixing on a gas-liquid interface, associated with R-T instability. The liquid was modeled with layers of a low-strength (= 0.01 MPa) water-solved gelatin jellies driven in a squared (40x40-mm) channel with helium compressed to 13 atm. The perturbations imposed on unstable surface had quadrilateral pyramidal structures with a height equal to the perturbation wavelength (=(0=0.25; 1; 2, 2.86 mm. The experimental results obtained in tests without imposed perturbations of a given shape are also presented. The acceleration of layers was of 3x10^{4}m/s^2. The obtained results show:

- When the perturbations are not originally given or when they have (=(0=0.25 on unstable surface, the turbulent mixing develops with an initial delay, and then it grows linearly as (l=dhl/d(2S)=0.12(0.025, where (l- intensity for penetration of light substance into heavy, hl- depth of the gas- into- jelly penetration, S - layer displacement,

- For (=(0=0.25; 1; 2, 2.86, the R-T instability grows simultaneously with the layer movement, and turbulent mixing has linear regime for light-into-heavy penetration (l=0.1(0.14. (l increases from 0.13 to 0.42 with growing the perturbation amplitude; hence, for the given range of initial periodical perturbations their amplitudes influence weakly on the rate of the light-into-heavy penetration, but sufficiently on the heavy-into-light.

Abstract No. E8

Compressible Vortex Rings

M. Brouillette and C. Hébert
Université de Sherbrooke, Quebec, Canada

We present the results of an experimental study aimed at characterising compressible and viscous effects on the generation and propagation of vortex rings. The overall aim of this study is to characterise basic vortical structures in the context of compressible turbulence, but these findings also have applications in the study of shock-vortex interaction, for example. In the context of the Richtmyer-Meshkov instability, these rings can be viewed as rapidly mushrooming spikes at moderate Atwood numbers.

The vortices are produced by the diffraction of a shock wave from the open end of the driven section of a specially-built shock tube. By varying the pressure ratio across the driver and driven sections we could control the strength of the incident shock wave. Also, by altering the length of the driver, we could modify the ejection velocity history, also known as the ejection velocity program, at the orifice end of the tube. Finally, by changing the diameter of the end orifice, we could change the size, i.e., Reynolds number, of the vortex ring. Our instrumentation comprised fast-response piezoelectric pressure transducers and flow visualisation was achieved with shadow and schlieren photography along with holographic interferometry.

A major difference between incompressible and compressible vortex ring formation is in the maximum circulation attained in the ring. Previous studies have found that the vorticity saturation threshold of incompressible vortex rings was not a strong function of the ejection velocity program; we found that this was not the case for compressible vortex rings. In the present study, we found that a higher normalised circulation was possible, for a given incident shock wave, with a continuous jet at the exit of the tube than with a rapidly attenuated jet.

The appearance of a shock wave within the recirculating region of the vortex ring is also strongly dependant on the amount of vorticity deposited within the ring. In fact, the onset of appearance of this shock wave and other shock and vortical features around the main vortex ring can now be related to vorticity deposition through the ejection velocity program.

Although the vortex formation mechanism of the present study is inherently compressible and non-linear, the propagation of these vortex rings is similar to that of incompressible rings reported in numerous previous studies. The principal compressibility effect is in the structure of the vortex core, which appears to exhibit a Reynolds number dependence.

Because of the wide range of viscous and convective scales present in this problem, experiments such as these can also pose an interesting challenge to direct numerical simulation in the context of compressible turbulence.

Abstract No. E9

Design of Flyer-Plate-Driven Compressible Turbulent Mix Experiments

R. P. Drake
University of Michigan, Ann Arbor, MI

In this work we consider the optimization of experiments that use flyer plates to study compressible turbulent mixing. There are now at least two types of flyer plates that can be used for such purposes. The recent advent of high-velocity (>20 km/s), solid state flyers on the Z machine at Sandia National Laboratories, along with the pending activation of x-ray backlighting, will make possible very clean experiments. In addition, any large laser can shock and accelerate a slab of material, producing a "plasma flyer" that can deliver energy and momentum to a desired target. If the laser is large enough (~ 1 kJ), then the plasma flyer can have sufficient lateral size to permit studies of mixing. Here we consider the problem of designing of an optimized experiment.

This poster will discuss the optimization of a flyer-driven experiment for either Rayleigh Taylor (RT) or Richtmyer Meshkov (RM) experiments. In RT experiments, one wants to decelerate an interface immediately after it is shocked (with minimum coasting time), and to move the interface as far as possible. In RM experiments, one wants to cause the interface to coast steadily after it is shocked, for the longest possible time. This poster will present an analysis and analytic relations that can guide the achievement of these goals, and hydrodynamic simulations showing what one can do using flyer plates on Z.

Abstract No. E10

Compressible Hydrodynamics on the Omega Laser, Motivated by Astrophysics

R. P. Drake[1], P. Keiter[1], K. E. Korreck[1], K. Dannenberg[1], H. A. Robey[2], T. Perry[2],
J. O. Kane[2], B. A. Remington[2], R. J. Wallace[2], O. A. Hurricane[2], D. D. Ryutov[2],
J. Knauer[3], R. Teyssier[4], A. Calder[5], R. Rosner[5], B. Fryxell[5], D. Arnett[6], Y. Zhang[7],
J. Glimm[7], N. Turner[8], J. Stone[8], R. McCray[9], J. Grove[10]

[1]*University of Michigan, Ann Arbor, MI*
[2]*Lawrence Livermore National Laboratory, Livermore, CA*
[3]*Laboratory for Laser Energetics, University of Rochester, Rochester, NY*
[4]*Commissariat à l'Energie Atomique, Saclay, France*
[5]*University of Chicago, Chicago, IL*
[6]*University of Arizona, Tuscon, AZ*
[7]*State University New York Stony Brook, Stony Brook, NY*
[8]*University of Maryland, College Park, MD*
[9]*University of Colorado, Boulder, CO*
[10]*Los Alamos National Laboratory, Los Alamos, NM*

Compressible turbulent mixing is an inherent feature in supernovae, supernova remnants, and related systems. Our scientific team collaborates to produce, in the laboratory, hydrodynamic mechanisms that are important for the evolution of such systems. These experiments are designed to be well scaled from astrophysical systems to the laboratory. This talk will provide an overview of this work and will highlight our most recent results. Our work is motivated by the specific fact that high-resolution 2D and 3D numerical simulations have proven unable to reproduce certain aspects of observations of supernova SN 1987A, and by the general need to provide experimental tests of modeling of hydrodynamic systems. The experiments take place on the Omega Laser at the Laboratory for Laser Energetics, University of Rochester. We have explored the coupling between unstable interfaces, instability growth in a diverging system, the comparison of 2D and 3D systems, the comparison of single mode and multimode systems, and the production and diagnosis of a radiative-precursor shock. In each of these cases, the experiment begins by using the laser to drive a strong shock into a target material. This produces a hydrodynamic initial state that can be modeled by any astrophysical or laboratory hydrodynamics code. The shock subsequently interacts with other structures in the target, which we design in order to explore a specific physical issue. In each case, we then compare the results of the experiments with those of computer simulations. The US DOE and NASA supported this work.

This work was performed under the auspices of the U.S. Department of Energy by the University of California Lawrence Livermore National Laboratory under contract No. W-7405-Eng-48.

Abstract No. E11

Growth of Perturbations on Metals Interface at Oblique Collission with Supersonic Velocity of Contact Point Motion

O. B. Drennov, A. L. Mikhaylov, P. N. Nizovtsev, and V. A. Raevskii
Russian Federal Nuclear Center – VNIIEF, Sarov, Russia

By now the subsonic mode of collision is studied in detail. In the supersonic mode, when shock waves arrive to the contact point, jet formation is impossible. It is assumed that perturbations growth at metals interface is also impossible. It is obtained in our experiments that perturbations are formed in the mode of supersonic jetless oblique collision at the metals interface. Analytical consideration of the problem determined existence of the critical value of Mach number characterizing transition from the stability area to the instable area. Numerical calculations with use of the two-dimensional Lagrange technique showed presence of an area with large gradient of velocity and high intensity of strains near the contact point. It results in fulfillment of the conditions for growth of Kelvin-Helmholtz instability. Comparison of calculated and experimental values of amplitude of occurred perturbations showed a rather good agreement between them.

Abstract No. E12

An Experimental Study of the Effect of Shock Proximity on the Richtmyer-Meshkov Instability at High Mach Number

S. G. Glendinning, D. G. Braun , M. J. Edwards, W. W. Hsing, B. F. Lasinski,
H. Louis, J. Moreno, T. A. Peyser, B. A. Remington, H. F. Robey, E. J. Turano,
C. P. Verdon, and Y. Zhou
Lawrence Livermore National Laboratory, Livermore, CA

The effect of shock proximity on the non-linear evolution of Richtmyer-Meshkov instability of a sinusoidal perturbation at high Mach number was examined on experiments at the Omega laser at the Laboratory for Laser Energetics, University of Rochester. We will present results from experiments using a laser drive of about $3X10^{13}$ W/cm^2 and targets made with polycarbonate as a pusher and carbon foam (ρ=0.1 g/cc) as a payload. This provided an incident shock of Mach number ~10, a nearly constant interface velocity for 10 ns, and a transmitted shock to interface velocity ratio of about 1.22. Wavelengths studied varied between 50 µm and 150 µm. Different amplitudes were chosen to allow linear growth, nonlinear growth, or proximate-shock growth to dominate.

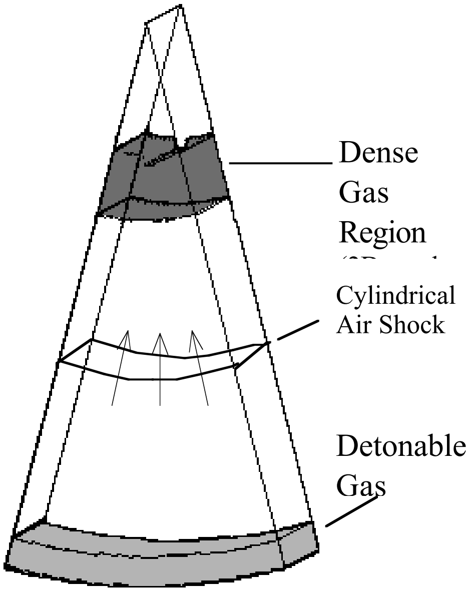
This work was performed under the auspices of the U.S. Department of Energy by the University of California Lawrence Livermore National Laboratory under contract No. W-7405-Eng-48.

Abstract No. E13

Mix Experiments using a Two Dimensional Convergent Shock Tube

D. A. Holder, C. Barton, and A. V. Smith
Atomic Weapons Establishment, Aldermaston, United Kingdom

This paper reports on the first Richtmyer Meshkov instability mix experiments using the improved version of the AWE detonation driven Convergent Shock Tube (CST). Results from an early prototype presented at the 7th IWPCTM demonstrated concept feasibility, but also the need for refinement of the multi-point ignition process that critically controlled cylindricity of the generated shock. This paper includes a brief description of the modifications undertaken to achieve the required performance; also images recording the origin of the detonation wave formation and combination process. The CST facility has been created to allow an extension of earlier RMI studies using a conventional linear shock tube at low Mach number to two-dimensional studies at Mach number 2 – 3.



The current configuration is as shown, with height (internal) 1.02m: depth 50mm: apex angle 30^0. Detonation of an oxy-acetylene gas mixture by 30 sparkplugs drives a cylindrically converging shock of order 10 bar into a dense gas region, bounded by cylindrically curved microfilm membranes, supported by fine wire meshes. Maximum compression of the dense gas during its motion into the apex region is ~40 for sulphur hexafluoride, or optionally, ~20 for xenon.

Visualisation is currently by shadowgraphy using a pulsed copper vapour laser and drum camera. This provides a timed sequence of images of the mixing development over the dense gas region. Results from basic experiments with two unperturbed interfaces will be presented, with comparisons to TURMOIL3D code calculations.

Additionally results will be shown from the first experiments to feature a perturbation superimposed on one interface. These will serve as a forerunner to the proposed investigations in 2D geometry of a series of perturbation profiles previously investigated using the AWE linear shock tube [1]. The results will be used to validate 2D turbulent mix models.

Proposals will also be included for incorporating improved diagnostic techniques including the laser sheet technique with ICCD camera recording to facilitate image analysis and derivation of quantitative data.

PACS No.: 47.20.Ma

Abstract No. E14

Rayleigh-Taylor Instability at a Tilted Interface in Incompressible Laboratory Experiments and Compressible Numerical Simulations

J. M. Holford[1], S. B. Dalziel[1], and D. Youngs[2]
[1]*Cambridge University, Cambridge, United Kingdom*
[2]*Atomic Weapons Establishment, Aldermaston, United Kingdom*

An important feature of Rayleigh-Taylor (RT) instability is the significant amount of molecular mixing that occurs, due to the small scales that are created. Molecular mixing is important both as a control on the rate of reaction between chemically active species, and because it creates a sink for available energy by allowing the background potential energy of the flow to increase. RT instability is the most efficient known mixing process, and laboratory measurements show that, over the whole flow evolution, up to 40% of the initial available energy increases the potential energy of the background stratification, while the balance is lost to viscous dissipation.

Regions of locally unstable stratification are frequently created in perturbed stratified flows, for example in breaking gravity waves and shear-driven billows. However, in these naturally occurring statically unstable regions, the initial conditions are far from the idealised classical RT instability. In this study, we investigate the mixing that occurs in RT instability at an interface that is initially tilted at an angle to the horizontal, introducing a competition between the local overturning of RT instability and a large-scale overturning within the whole domain.

RT instability is initialised in a water tank in the laboratory by withdrawing a barrier separating dense salt water above from fresh water below. Measurements of both the density distribution and in-plane velocity field are made in a vertical slice through the centre of the tank. For the first time, measurements of the instantaneous efficiency of mixing are made. The instantaneous efficiency at early times can be higher than the cumulative efficiency, with the rate of increase of potential energy of the background stratification reaching 50% of the rate of decrease of available energy. The reduction in the cumulative mixing efficiency as the angle of the initial interface increases is quantified.

The experiments have been modelled numerically using the compressible code TURMOIL3D. The initial conditions are carefully chosen to model the incompressible experiments as closely as possible. Analyses of energy and concentration fluctuation spectra are used to understand the mixing and dissipation processes. The combination of experimental and computational modelling is shown to be useful both as a validation of the numerical methods and as a tool for understanding the basic dynamics of the flow.

Abstract No. E15

Study of Diverging and Converging Spherical Shock Waves Induced by Micro Explosives and their Interaction with Product Gases

S. H. R. Hosseini and K. Takayama
Tohoku University, Sendai, Japan

The paper reports an experimental study of production and propagation of spherical shock waves. In order to quantitatively observe spherical shock waves and the flow field behind them, an aspheric spherical transparent test section was designed and constructed. This 150 mm inner-diameter aspheric lens shaped test section permits the collimated visualization laser beam to traverse the test section parallel and emerge parallel. Spherical diverging shock waves were produced at the center of the spherical test section. In order to generate shock waves, irradiation of a pulsed Nd:YAG laser beam on micro silver azide pellets were used. The weight of silver azide pellets ranged from 5 to 20 mg, with their corresponding energy of 9 to 36 J. Pressure histories at different points over the test section were measured to validate production of uniform shock waves. After reflection of spherical shock wave from the test section, a converging spherical shock wave was produced and its interaction with the interface of explosive product gas was studied. Double exposure holographic interferometry and time resolved high speed photography were used for flow visualization. The whole sequence of diverging and converging spherical shock waves propagation and their interaction with product gases were observed.

PACS No.: 47.40.Nm

Abstract No. E16

Interaction of Converging Shock Waves With Cylindrical Heavy Gas Interfaces in an Eccentric Arrangement

S. H. R. Hosseini and K. Takayama
Tohoku University, Sendai, Japan

Paper reports a study on interaction of converging and diverging cylindrical shock waves in air with non-uniform gaseous media and resulting Richtmyer-Meshkov instability. An annular vertical co-axial diaphragmless shock tube was used to produce converging cylindrical shock waves. Cylindrical soap bubbles filled with SF_6 heavy gas were placed out of the geometrical center of shock tube's test section. As a result of asymmetry between converging cylindrical shock waves and cylindrical interfaces, a complex wave motion and interaction was produced. Pressure histories at different radii were measured during the converging and diverging shock wave propagation in the test section after interaction. A strong secondary shock wave focusing in the SF_6 test gas with a high peak overpressure was observed. Double exposure holographic interferometry was used for flow visualization. The time evolution of turbulent mixing zone between the air/ SF_6 light/heavy gases and interfacial deformations were quantitatively studied. After the secondary shock wave focusing in the SF_6 a relatively strong jet, which was penetrating to the air in the direction of geometrical center, was produced.

PACS No.: 47.40.Nm

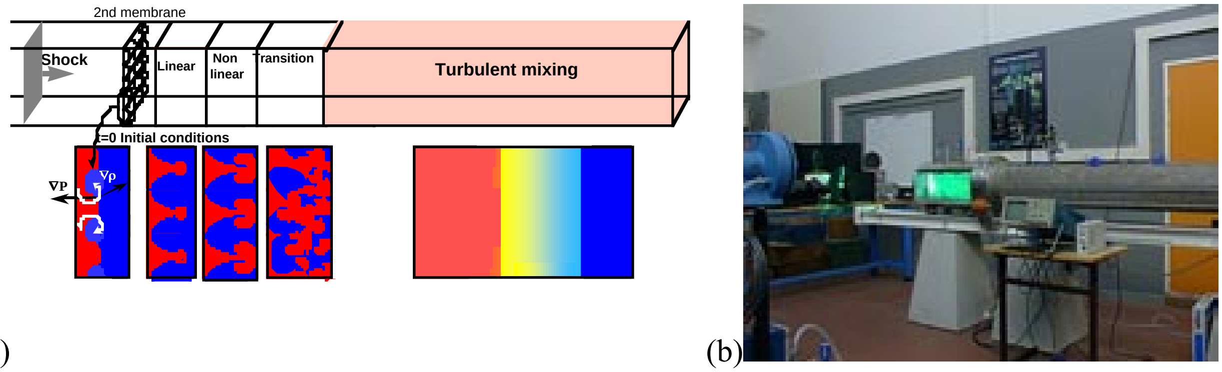
Abstract No. E17

From Linear to Turbulent Stages of the Richtmyer-Meshkov Instability Development in a Large Cross Section Shock Tube

L. Houas[1], G. Jourdan[1], L. Schwaederlé[1], and E. E. Meshkov[2]
[1]*IUSTI, CNRS, Université de Provence, Technopôle de Château-Gombert,*
Marseille, France
[2]*Russian Federal Nuclear Center – VNIIEF, Sarov, Russia*

The aim of the present investigation is to contribute to the understanding of the turbulence transition phases by the help of the development of the Richtmyer-Meshkov instability (RMI). In this way, we have built a new shock tube which allows to follow a Richtmyer-Meshkov instability induced mixing from its beginning to the fully turbulent developed stage with both control and knowledge of the initial conditions. Up today, all experiments developed to study the RMI have been focussed on the observation of the growth of the initial perturbations in the linear and the non-linear regimes and not far, or the investigation of the turbulent phase without knowing the real initial conditions, i.e. when the shock wave interacts with the thin membrane which initially separates the two fluids of different densities. Thus, the new shock tube has first a large square cross section (20 cm by 20 cm) in order to prevent from wall effects. Furthermore a suitable experimental chamber permits to observe and control the initial perturbations we impose to the thin material interface which initially separates the two gases expected to mix together after the incident shock wave accelerates their common interface. The total length of the shock tube is of 7 m, the experimental chamber is 50 cm total length and its field of view starts from 4 cm before the initial position of the interface to 46 cm after. To follow the development of the initial perturbations and the mixing of the two gases, we have carried out a Mie scattering laser sheet technique. A 50 Khz Oxford copper vapor laser beam is transformed as a laser sheet before crossing the experimental chamber in its length direction. This ultra rapid laser is coupled with a 321 Cordin model high speed camera, which together allow to record, during the same run, about 100 plane frames of the experiment spaced by 100 to 20 µs depending on the laser frequency (from 10 to 50 Khz). The maximum recorded image rates is of about 50,000 pictures per second. Moreover, a suitable rotating mirror device accurately coupled and synchronized with the laser-camera system, permits to translate, during the same run, the laser sheet from the center axis of the experimental chamber to its walls in order to obtain a 3D visualization of the phenomenon. The gas initially present in the experimental chamber is seeded with water vapor particles. The test gases are air/He, air/Ar and air/Kr in order to investigate the cases where the shock wave passes from a heavy to a light gas and vice-versa. The initial pressure is 1 atm. and the shock wave Mach number in air is of 1.3. The principle of the experiment and a view of the experimental set up are shown on Figure 1. We are now running the first experiments and we hope to present in the full paper the first results illustrating, during the same run, the development of the different

stages of the instability, the transient phases as well as some information on the fully turbulent regime.



(a) (b)

Fig. 1: Principle of the experiment (a) and view of the new large cross section shock tube of IUSTI coupled with a Copper vapor Mie scattering laser sheet technique (b).

Abstract No. E18

PLIF Flow Visualization of a Shock-Accelerated Air/SF_6 Interface

J. W. Jacobs and V. V. Krivets
University of Arizona, Tucson, AZ

A vertical shock tube is used to study the Richtmyer-Meshkov instability of a membraneless Air/SF_6 interface. The two gases enter the shock tube at opposite ends of the driven section and are allowed to exit through slots in the shock tube wall to produce a flat, slightly diffuse interface in the test section. A sinusoidal perturbation is then given to the interface by oscillating the shock tube in the lateral direction to produce standing waves. Planar laser induced fluorescence (PLIF) is used to visualize the flow by seeding the air with acetone vapor and illuminating it with a sheet of light produced by a pulsed Nd:YAG laser. The resulting fluorescent signal is then recorded using a cooled CCD camera. Images obtained from these experiments show very clearly the development of the instability far into the nonlinear regime in which the interface is contorted into pronounced mushroom structures. New results using $M = 1.3$ shock waves will be presented which clearly show the transition to turbulence in this flow at late times. The transition process begins with the development of Kelvin-Helmholtz instability on the vortex spirals. After formation, the initially coherent Kelvin-Helmholtz pattern very quickly decays into turbulence. Eventually the turbulence, which is initially confined to the vortex cores, begins to erode the remainder of the mushroom structures. Experiments will also be presented that study the effects of reshock on different stages of the instability. In these experiments a false wall is used to vary the distance between the initial interface location and the end wall in order to control the arrival time of the reflected shock wave.

Abstract No. E19

Laser-Based High Pressure, High Strain-Rate Solid-State Experiments

D. H. Kalantar[1], J. Belak[1], J. D. Colvin[1], M. Kumar[1], K. T. Lorenz[1], K. O. Mikaelian[1],
S. Pollaine[1], B. A. Remington[1], S. V. Weber[1], L. G. Wiley[1], A. M. Allen[2],
A. Loveridge-Smith[2], J. S. Wark[2], and M. A. Meyers[3]
[1]*Lawrence Livermore National Laboratory, Livermore, CA*
[2]*Oxford University, Oxford, United Kingdom*
[3]*University of California at San Diego, San Diego, CA*

We have performed a high pressure solid state instability growth experiment using an x-ray ablative drive on the Nova laser [1]. In this experiment, an Al foil is shock compressed to a peak pressure of 1.8 Mbar with a sequence of shocks. A preimposed sinusoidal modulation grows by the Rayleigh-Taylor instability. At early time, the growth is nearly fluid-like, but it is suppressed at late time. The growth of the instability provides information about the strength of the metal at high pressure [2, 3]. In order to model this experiment, we invoke softening by shear bands and recovery of strength following dissipation of the heat associated with the localized shear bands.

In order to develop a lattice level understanding of response of these samples at high pressure, we perform dynamic x-ray diffraction of shocked materials to verify the state of the material under compression. In these experiments, we record x-rays diffracted from orthogonal lattice planes of shock compressed single crystal Cu. The shift of the Bragg diffraction from these orthogonal planes confirms that the lattice undergoes a 3D compression. By comparison, Si is observed to respond with uniaxial compression. [4]

We are also developing shocked sample recovery techniques to characterize the residual deformation microstructure. This residual structure is studied by optical and electron microscopy techniques.

Results of the RT, diffraction, and recovery experiments will be discussed.

---

[1] D. H. Kalantar, B. A. Remington, J. D. Colvin, *et al*, Phys. Plasmas **7**, 1999 (2000).
[2] J. F. Barnes, P. J. Blewett, R. G> McQueen, *et al*, J. Appl. Phys. **45**, 727 (1974).
[3] A. I. Lebedev, P. N. Nizovtsev, V. A. Raevskii, V. P. Solov'ev, Phys. Dokl. **41**, 328 (1996).
[4] A. Loveridge-Smith, A. Allen, J. Belak, *et al*, Phys. Rev. Letters **86**, 2349 (2001).

This work was performed under the auspices of the U.S. Department of Energy by the University of California Lawrence Livermore National Laboratory under contract No. W-7405-Eng-48.

Abstract No. E20

RFNC-VNIITF Multifunctional Shock Tube to Investigate the Evolution of Instabilities in Nonstationary Gas Dynamic Flows

Yu. A. Kucherenko, O. E. Shestachenko, S. I. Balabin, and A. P. Pylaev
Russian Federal Nuclear Center – VNIITF, Snezhinsk, Russia

In the paper, at the shock tube operation in three modes, the parameters of the flows in the RFNC-VNIITF were given.

In the first mode, in the shock tube the stationary shock waves are formed. This makes it possible to investigate the evolution of the Richtmyer-Meshkov instability and turbulence.

In the second mode, in the shock tube a nonstationary shock wave is formed that makes it possible to carry out the investigation of the behaviour of the contact boundaries between different density gases when there are conditions for the evolution of the Rayleigh-Taylor and Richtmyer-Meshkov instabilities.

In the third mode, in the shock tube a compression wave is formed. This makes it possible to investigate the evolution of the Rayleigh-Taylor instability and turbulence.

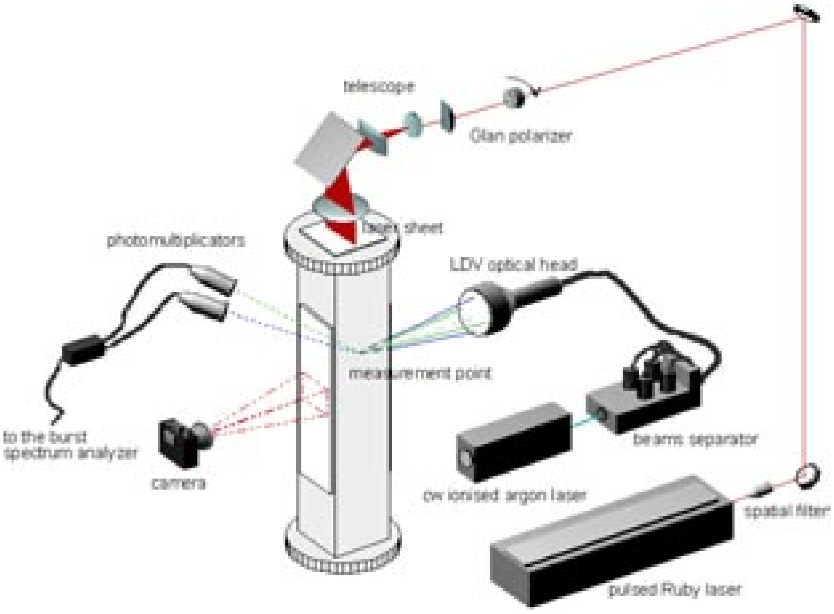
Abstract No. E21

Planar Laser Sheet Visualization and Laser Doppler Velocity Measurements in Shock-Induced Turbulent Mixing Zones

A. Lassis, P. Montlaurent, C. Rayer, and J.-F. Haas
Commissariat à l'Energie Atomique, Bruyères-le-Châtel, France

We plan to present measurements on gaseous turbulent mixing arising from the Richtmyer-Meshkov instability (RMI) in a vertical shock tube of driver (below) and driven (above) sections lengths 1 m and 4-5 m respectively and of square internal cross section throughout (13 cm by 13 cm). In its present configuration, the maximum driver pressure is 8 bar and the driven section is initially at local atmospheric pressure (1 bar), thus the shock tube is limited to Mach numbers of about 1.5 maximum. The main diaphragm is made of two plastic layers (kapton) with conducting wires between them. In a typical low Mach number experiment, the initial pressure of air in the driver is set at 3 bar, and a Mach 1.2 shock is driven in the test section air at a controlled time by Joule heating the wires and locally melting (and weakening) the kapton.

We will characterize the mixing arising when the shock wave (propagating upwards in the z direction) accelerates a planar horizontal contact surface made of a thin (0.5 μm) nitrocellulose membrane laid against a thin stainless steel wire mesh (wire diameter and spacing 1010 and 80 μm). The purpose of the film-mesh combination is to force the small scales (1 by 1 mm in the x and y directions) of the RMI, thus insuring an early transition to turbulence of a thin planar mixing zone after shock passage. The gas pairs of initial interest are SF6-air and air-SF6. As it was several years ago, our primary goal is to provide an experimental data base (density structure and turbulent kinetic energy) for verification and validation of turbulent mixing models (1) imbedded in one- or two-dimensional hydrodynamic codes. The same laser-doppler velocimeter will be used (Dantec two component system) for the measurement of the kinematic parameters of the mixing zone. Compared to the earlier effort performed in a shorter (3.8m) and narrower shock tube (cross section 8 by 8 cm), we expect to improve the quality of the flow because the wall



effects will be much less disruptive. We are also preparing a planar visualization system using a short pulse ruby laser to produce a light sheet (thickness 0.5 to 1 mm) entering the shock tube from the top end-plate. Thus we hope to measure the local structure of the mixing zone without the optical signature from wall-located mixing which perturbed our earlier visualizations in the smaller tube (2).

References :

1. D. Souffland et al., Measurements and Simulations of the Turbulent Energy Levels in Mixing Zones Generated in Shock Tubes. pp. 486-491 in the proceedings of the 6th IWPCTM, Marseilles, June 1997, Jourdan and Houas eds.
2. I. Galametz at al., Visualization of shocked mixing zones using differential interferometry and X-rays. pp. 178-184 in the proceedings of the 5th IWPCTM, Stony Brook, July 1995, Young, Glimm and Boston eds., World Scientific.

Abstract No. E22

Hydrodynamic Instabilities at a Shock Accelerated Bubble Gas-Gas Interface

G. Layes[1], G. Jourdan[1], P. Roualdes[2], and L. Houas[1]
[1]*IUSTI, CNRS, Université de Provence, Technopôle de Château-Gombert,*
Marseille, France
[2]*Centre d'Etudes de Gramat, Gramat, France*

The aim of the present work is to investigate the interaction of a plane shock wave with one gas bubble within another gas of different density in order to better understand the Richtmyer-Meshkov instability process in spherical geometry. These experiments are performed in the new 500 mm circular cross section shock tube installation of IUSTI (donation of DGA Gramat). It is a 12 m total length shock-tube with a 2 m high pressure chamber long and an experimental chamber total field of view of 475 mm long by 320 mm high. The shock tube is coupled with a Schlieren high speed camera system and PCB piezoelectric transducers are flush mounted on the shock tube side walls for both recording the pressure evolutions and triggering the acquisition device.

Spherical volumes of gas (He, Ar or Kr) with density, and sound speed, differing from that of the surrounding atmosphere (air) are accelerated by a relatively weak shock wave. The incident shock wave Mach number in air is around about 1.2. From successive Schlieren pictures (up to 30 000 frames per second), we hope to investigate the hydrodynamic interface instability and the bubble distortion. Finally, we plan to generate several neighboring bubbles in the experimental chamber in order to study the bubble coupling during their acceleration.

Abstract No. E23

Experimental and Numerical Study of Shock Wave–Bubble Interaction

K. Levy[1,2], O. Sadot[1,2], D. Oron[1,2], Y. Srebro[2], Y. Elbaz[2], A. Yosef-Hai[1,2],
G. Ben-Dor[3], and D. Shvarts[1,2]
[1]*Ben-Gurion University, Beer-Sheva, Israel*
[2]*Nuclear Research Center - Negev, Israel*

This work presents a study of the interaction of a shock wave with a spherical bubble, which results in the formation of vortex rings and a jet. Similar studies which presents various stages of the interaction evolution were published in [1-5].

In the present work two configurations were studied in which a spherical bubble of SF6 (Heavy bubble) or He (light bubble) was imbedded in the shock tube at ambient conditions. The evolution of the flow due to the interaction of the shock wave with the bubble was followed experimentally and numerical. The results reveal that in the first case a jet is formed due to a converge shock wave towards the bubble center, which formed high-pressure region on the bubble axis that forced the heavy fluid forward. In the second case a vortex ring is formed around the bubble creating a region of high pressure in the heavy gas forcing the heavy fluid forward and forming a jet. A good agreement was found comparing the results of the experiments to those of the simulations.

References

1. Quirk et al., J. Fluid Mechanics, 318, pp. 129 (1996).
2. Picone et al., J. Fluid Mechanics, 189, pp. 23 (1988).
3. Yang, et al., J. Fluid Mechanics, 258, pp.217 (1994).
4. Haas et al., J. Fluid Mechanics, 181, pp. 41 (1987).
5. Smith et al. in the proceeding of the MIX 91 workshop.

Abstract No. E24

Laser-Driven Near Isentropic Compression of an Aluminum Flyer Plate

K. T. Lorenz, D. Kalantar, J. Edwards, J. D. Colvin, and B. Remington
Lawrence Livermore National Laboratory, Livermore, CA

A new design for producing a ramped pressure wave for the study of material response in solid media under nearly isentropic compression conditions will be discussed. A plasma source, initiated from laser heating of a low-density carbon foam, unloads across a vacuum gap onto an Al target to provide a ramped, shockless, pressure load. Experiments using HE to create shockless drives have previously been demonstrated by Barnes, *et al.* [1] and Levedev, *et al.* [2,3]. This type pressure drive is coupled to targets having modulated surfaces for the study of material response and strength. The current design configuration of our near isentropic drive will provide peak pressures and strain rates on order of 0.4Mbar and $10^6 - 10^7 \text{sec}^{-1}$, respectively. Initial experiments using VISAR, x-ray radiography and thin Al foils will examine both the planarity and the time-dependent nature of the pressure loading in the target. Recent experimental results and as well as experimental simulations scaled to the laser drive conditions will be presented.

[1] J.F. Barnes, P.J. Blewett, R.G. McQueen, K.A. Meyer and D. Venable*, J. Appl. Phys.* **45**, 727 (1974).

[2] A.I. Lebedev, P.N. Nizovtsev, V.A. Rayevsky, in the *Proceedings of the 4th International Workshop on the Physics of Compressible Turbulent Mixing*, 29 March – 1 April, Cambridge, England (Cambridge University Press, Cambridge, 1993), p. 81.

[3] A.I. Lebedev, P.N. Nizovtsev, V.A. Raevskii and V.P. Solov'ev,*Dokl. Akad. Nauk.* **349** (MAIK Nauka / Interperiodica Publishing, Moscow July 1996), pp. 332-4. Translation: *Phys. Dokl.* **41**, 328 (1996).

This work was performed under the auspices of the U.S. Department of Energy by the University of California Lawrence Livermore National Laboratory under contract No. W-7405-Eng-48.

Abstract No. E26

Single-Mode Incompressible Richtmyer-Meshkov Instability Experiments

C. E. Niederhaus[1] and J. W. Jacobs[2]
[1]*NASA Glenn, Cleveland, OH*
[2]*University of Arizona, Tucson, AZ*

The Richtmyer-Meshkov instability of a moderate Atwood number, miscible, two-liquid system is experimentally investigated. The instability is generated by dropping a fluid container onto a coil spring, producing a nearly impulsive acceleration followed by a period of freefall. The initial density interface has a well-defined, 2-D, single-mode sinusoidal perturbation generated by laterally oscillating the fluid container. The perturbation quickly inverts and then grows in amplitude after undergoing the impulsive acceleration. Planar laser-induced fluorescence is used for flow visualization, providing clear views of the fluids far into the nonlinear regime. Disturbance amplitudes are measured and compared to theoretical predictions in the linear, weakly nonlinear, and nonlinear regimes. The effects of Reynolds number (based on circulation) on the vortex core evolution and overall growth rate of the interface are also investigated. In addition, an instability in the vortex cores is observed and criteria established for its occurrence.

Abstract No. E27

Experimental Study of a Strongly-Shocked Gas Interface with Visualized Initial Conditions

J. G. Oakley, M. H. Anderson, and R. Bonazza
University of Wisconsin at Madison, Madison, WI

The Richtmyer-Meshkov (RM) instability is studied for a strongly shocked gas-gas interface in the nonlinear regime. The impulsive acceleration of the interface by a shock wave imparts a velocity to the interface and baroclinic vorticity ($\nabla\rho \times \nabla p$) causes the amplitude of a single mode perturbation to grow. Experiments for studying the compressible, turbulent mixing of a gas-gas interface are conducted in a shock tube. The shock tube is oriented vertically (9.3 m high), has a large square cross-section (25.4 cm), is modular (for studying interfaces of different ages) and has a structural capacity of 20 MPa [1]. The driven and test section gases are initially separated with a thin copper plate that has been formed with a sinusoidal perturbation along its length. The sine wave plate has three wavelengths of λ=38.1 mm and an amplitude, a_0=3.2 mm which forms an initial condition in the linear to nonlinear transition with a wavelength amplitude product of ka_0=0.52. The sine wave plate is retracted from the shock tube forming a membraneless, single-mode perturbation between the driven and test gases. Using a heavy-above-light gas configuration, the Rayleigh-Taylor (RT) instability develops and the perturbation amplitudes grow in time forming the initial condition for the RM experiment. A continuous wave laser is used in the interface section to illuminate the interface, and the RT instability is imaged using a 256x256 pixel array, 8-bit CCD camera framing at 100 fps. The test gas is seeded with smoke particles (~0.5 μm) and Mie scattering is used to visualize the interface the two interface gases. After acceleration by the planar shock wave, the interface travels down the shock tube and is imaged in the test section using a pulsed YAG laser and 1024x1024 pixel array, 16-bit CCD camera. One post-shock image is obtained per experiment. The experimental images are processed to determine the initial and post-shocked perturbation amplitudes. The experimental results are compared with linear and nonlinear RM theories. The gas pair combination CO_2-air is studied in the strongly shocked regime, M=2.90.

[1] Anderson, M.H., B.P. Puranik, J.G. Oakley, P.W. Brooks and R. Bonazza, "Shock tube Investigation of Hydrodynamic Issues Related to Inertial Confinement Fusion," *Shock Waves*, **10**(5), pp. 377-387, 2000.

Abstract No. E28

Experimental Investigations of the Self-Similar Mixing Mode of Different Density Gases in the Earth's Gravitational Field

Yu. A. Kucherenko, O. E. Shestachenko, Yu. A. Piskunov,
E. V. Sviridov, V. M. Medvedev, and A. I. Baishev
Russian Federal Nuclear Center – VNIITF, Snezhinsk, Russia

At the installation OSA the experiments on the investigation of the self-similar mixing mode of different density gases in the Earth's gravitational field were performed. When so doing the heavy gas was placed over the light one. By means of the specter-diaphragm the gases were separated. At some instant of time the specter-diaphragm was quickly ruptured into small-scale fragments under the action of the external force. At the formed contact boundary of two different density gases the Rayleigh-Taylor instability and the unstationary zone of turbulent mixing were evolved.

For three values of Atwood numbers the experiments were carried out. In the experiments the trajectories of the mixing fronts in the light and heavy gases were registered. The mixing asymmetry coefficient and the constant alpha specifying the nondimensional mixing rate were determined.

Abstract No. E29

Modeling Laser Material Strength Experiments

S. Pollaine[1], D. Kalantar[1], B. Remington[1], J. Belak[1], J. D. Colvin[1],
J. Edwards[1], R. Minich[1], K. O. Mikaelian[1], K. T. Lorenz[1], S. V. Weber[1], L. G. Wiley[1],
D. Paisley[2], A. Hauer[2], J. S. Wark[3], A. Loveridge[3], A. M. Allen[3], T. R. Boehly[4], and
M. A. Meyers[5]
[1]*Lawrence Livermore National Laboratory, Livermore, CA*
[2]*Los Alamos National Laboratory, Los Alamos, NM*
[3]*Oxford University, Oxford, United Kingdom*
[4]*Laboratory for Laser Energetics, University of Rochester, Rochester, NY*
[5]*University of California at San Diego, San Diego, CA*

We have done many experiments on the Omega and Janus lasers to measure material strength and other properties of Al, Si and Cu at high pressures (100 kb – 1 Mb) and strain rates (1.e5 – 1.e8). These experiments are diagnosed by VISAR (velocity measurement), x-ray diffraction and material recovery. We simulate these experiments with the Steinberg-Guinanconstitutive model that includes shear strength, yield and melting temperature as a function of pressure and temperature.

This work was performed under the auspices of the U.S. Department of Energy by the University of California Lawrence Livermore National Laboratory under contract No. W-7405-Eng-48.

Abstract No. E30

Experiments and Simulations of Instabilities in a Shock-Accelerated Gas Cylinder

K. Prestridge[1], C. A. Zoldi[1,2], P. Vorobieff[3], P. M. Rightley, and R. F. Benjamin[1]
[1]*Los Alamos National Laboratory, Los Alamos, NM*
[2]*State University New York, Stony Brook, Stony Brook, NY*
[3]*University of New Mexico, Albuquerque, NM*

The interaction of a planar (M=1.2) shock with a heavy-gas SF6, round cylinder surrounded by air produces strong vorticity, driven by the shock wave's pressure gradient interacting with density gradients at the air/SF6 interface. The growth of the cylinder is measured using six images of the density profiles of each experimental event, unlike earlier studies, which captured only one image per event. The velocity field is measured at one time using Particle Image Velocimetry (PIV). We also present two-dimensional computational simulations, using the RAGE code, which utilize the actual initial conditions measured in the experiment. The simulation has the same spatial resolution as the experimental diagnostics, and for the first time, the width of the computational domain has been matched to that of the experiment, allowing us to consider sidewall effects. Experimental images show an instability growth rate somewhat higher than the results of the RAGE simulation. Velocity fields measured experimentally qualitatively agree with simulations, but the quantitative difference in velocity magnitudes is substantial.

Abstract No. E31

Experimental Study into Rayleigh-Taylor Turbulent Mixing Zone Heterogeneous Structure

Yu. A. Kucherenko, A. P. Pylaev, V. D. Murzakov, A. V. Belomestnih, V. N. Popov, and A. A. Tyaktev
Russian Federal Nuclear Center – VNIITF, Snezhinsk, Russia

The heterogeneous structure study has been performed by means of a “light-sheet” technique at the SOM gas-dynamic accelerator. The investigated system consisted of three layers of different density liquids. For leading out the information from the mixing zone inner region illuminated by the “light-sheet”, visualizing particles were seeded into one of the liquids. The visualizing particles, which got into the “light-sheet”, diffused light, and at the same time photo images of the liquid fragments, contained the visualizing particles, were formed by a light-sensitive receiver. For the error reduction refractive indexes of all the three liquids were equalized. A special test has been conducted for determining of measurements inaccuracy. Experiments have been performed for two values of acceleration of artificial field of gravity. Distributions of liquid fragments sizes are showed in the form of bar charts for different moments of time.

Abstract No. E32

Measurements of Turbulence Correlations in Low Atwood Number Rayleigh-Taylor Mixing

P. Ramaprabhu and M. J. Andrews
Texas A & M University, College Station, TX

Simultaneous measurement of velocity and density fields in a statistically-steady, low Atwood number ($\sim 10^{-3}$), Rayleigh-Taylor experiment have been made. The experiment allows long data collection times and thus extensive spectral characterization. The method used is referred to as Particle Image Velocimetry-Scalar (PIV-S), and is a variant of the PIV technique. The PIV-S method uses different concentrations of particles to mark fluids of different densities. Tracking the motion of individual particles yields velocity measurements, while local particle concentrationsgives density measurements. Two-dimensional fields of $<\rho'^2>$, $<u'^2>$, $<v'^2>$, $<u'v'>$, $<\rho'u'>$, and $<\rho'v'>$ correlations, with associated power spectra will be presented. The density measurements compare well with corresponding temperature data from thermocouple experiments.

Abstract No. E34

Experimental Study of the Interaction of a Strong Shock with a Spherical Density Inhomogeneity

H. F. Robey[1], T. S. Perry[1], R. I. Klein[1, 2], J. A. Greenough[1], J. O. Kane[1], and T. R. Boehly[3]
[1]*Lawrence Livermore National Laboratory, Livermore, CA*
[2]*University California at Berkeley, Department of Astronomy, Berkeley, CA*
[3]*Laboratory for Laser Energetics, University of Rochester, Rochester, NY*

Laser-driven experiments conducted on the Omega Laser are described which probe the interaction of a very strong shock with a spherical density inhomogeneity. The interaction is viewed simultaneously from two orthogonal directions. This enables visualization of both the initial distortion of the sphere into a double vortex ring structure as well as the onset of an azimuthal instability that ultimately results in the three-dimensional breakup of the ring. The experimental results are compared with three-dimensional numerical simulations using an adaptive mesh refinement technique. The agreement between experiment and simulation is shown to be quite good. The experimental results completely define the three-dimensional topology of the flow, and the three-dimensional breakup is shown to be in remarkable agreement with the incompressible theory of Widnall et al.

This work was performed under the auspices of the U.S. Department of Energy by the University of California Lawrence Livermore National Laboratory under contract No. W-7405-Eng-48.

Abstract No. E35

Turbulent Transition in a High Reynolds Number, Rayleigh-Taylor Unstable Plasma Flow

H. F. Robey[1], Y. K. Zhou[1], A. C. Buckingham[1],
P. Keiter[2], B. A. Remington[1], and R. P. Drake[2]
[1]*Lawrence Livermore National Laboratory, Livermore, CA*
[2]*University of Michigan, Ann Arbor, MI*

A high Reynolds number, Rayleigh-Taylor unstable plasma flow driven by laser radiation is described. Given enough time at these experimental conditions, the interfacial mixing layer will eventually transition to turbulence. The experiments are limited, however, in the very short time duration of the available flow. The Reynolds number characterizing the mixing layer is determined from the experimentally measured length and velocity scales together with the plasma kinematic viscosity determined from a corresponding 1D numerical simulation. From these, the Reynolds number is determined to be sufficiently large ($Re > 10^5$) to support a turbulent flow. An estimate of the developing Taylor and Kolmogorov dissipation scales, however, shows that the temporal duration of the flow is insufficient to allow for the appearance of a turbulent inertial subrange. A methodology is described for estimating the time required for the development of a fully turbulent flow at these conditions.

This work was performed under the auspices of the U.S. Department of Energy by the University of California Lawrence Livermore National Laboratory under contract No. W-7405-Eng-48.

Abstract No. E36

Effects of High Initial Amplitudes and High Mach numbers on the Evolution of the RM instability: II. Experimental Study

O. Sadot[1,2], A. Yosef-Hai[2], A. Rikanati[1,2], D. Oron[1], G. Ben-Dor[2], and D. Shvarts[1,2]
[1]*Nuclear Research Center Negev, Israel*
[2]*Ben-Gurion University, Beer-Sheva, Israel*

Recent theoretical work [Rikanati et. al. this conference] suggested that the reduction in the RM instability initial growth rate observed in recent experiments [1, 2] is mainly a result of high initial amplitudes used in those experiments, rather then high Mach number effects.

In the present work, effects of high initial amplitudes and high Mach number are studied experimentally. Results from a shock tube apparatus at low Mach number (M=1.2) with high initial amplitudes shows velocity reduction similar to the theoretical predictions. Preliminary experiments studying the RM instability at high Mach numbers were done, using a newly constructed shuck tube, to confirm the velocity reduction due to effects of high Mach numbers.

References

1) Aleshin *et. al.*, in Proceedings of the Sixth International Workshop on the Physics of Compressible Turbulent Mixing edited by G. Jourdan & L. Houas, Marsielle France 1997. Page 1.

2) Dimonte G., Frerking C.E., Schnider M. and Remington B., Phys. of Plasmas **12**, 304 (1996).

Abstract No. E37

Measurements within a Richtmyer-Meshkov Mixing Zone using a Triple Hot Wire Probe Technique

L. Schwaederlé[1], G. Jourdan[1], L. Houas[1], and J.-F. Haas[2]
[1]*IUSTI, CNRS, Université de Provence, Technopôle de Château-Gombert, Marseille, France*
[2]*Commissariat à l'Energie Atomique, Bruyères-le-Châtel, France*

A triple probe constant temperature hot wire anemometer (CTHWA) investigation is undertaken in a shock tube to characterize the turbulent mixing zone induced by the Richtmyer-Meshkov instability (RMI) when the shock wave propagates through the interface between two gases of different densities. The first gas is air and the second is He (lighter), Ar (moderately heavier) and Kr (much heavier). The experiments are conducted in a 8.5cm square cross section shock tube of which test section is represented on Fig. 1. The two gases are separated by a thin (0.4µm) nitrocellulose film resting on an orthogonal grid made of 9_9 wires (180µm diameter, 8.5mm spacing) which is accelerated by a Mach number 1.25 shock wave in air at atmospheric pressure. Fig 2. summarizes the principle and the aim of the present investigation.

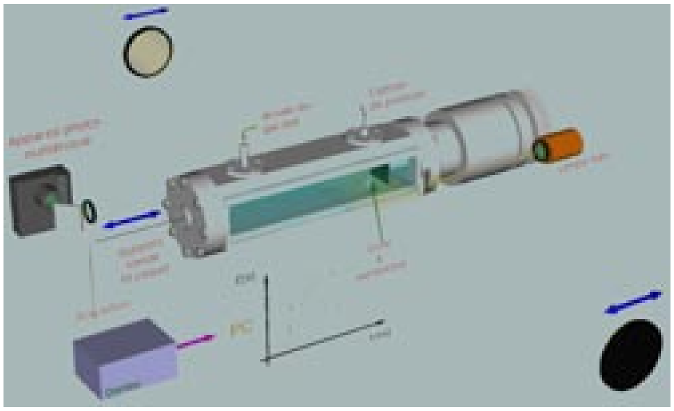


Fig 1. Experimental set-up

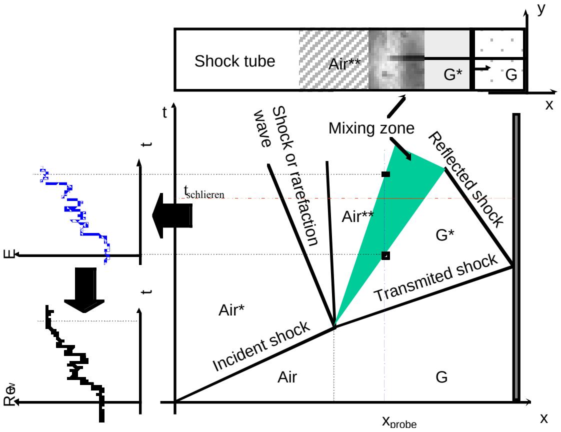


Fig 2. Principle of the investigation

The CTHWA output voltage is a function of local Reynolds number, heat conductivity and temperature with empirical constants. With the simplifying assumption of linear profiles for both temperature (with a jump less than 30K in all cases) and heat conductivity across the mixing zone, and using the Rankine-Hugoniot calculations in pure and premixed gases, the determination of the constants, given by a suitable calibration procedure with varying concentrations (by steps of 10%), provides the evolution of the Reynolds number within the mixing zone. An example of both (a) raw hot-wire signal and (b) deduced Reynolds number evolution in air/Ar mixing zone are represented in Fig 3.

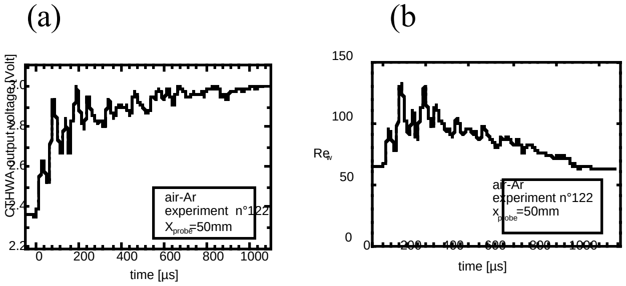


Fig. 3. Typical hot-wire signal and local Reynolds number evolution

In order to obtain separately the mixing density, temperature and velocity we positioned three HWA probes (5 µm in diameter and 1.25 mm in length), inserted from the end plate along the shock tube axis and working at different temperatures. We intend to present the local Reynolds number evolution across the mixing zone, the estimates of density, velocity and temperatures with statistical results based on identical shock tube experiments, and carry this study at different positions both axially and laterally.

Abstract No. E38

Experimental Study into Evolution of Gravitational Turbulent Mixing of Gases at the Multifunctional Shock Tube

Yu. A. Kucherenko, O. E. Shestachenko, Yu. A. Piskunov, E. V. Sviridov,
V. M. Medvedev, and A. I. Baishev
Russian Federal Nuclear Center – VNIITF, Snezhinsk, Russia

At initial moment of time investigated different density gases are placed inside the multifunctional shock tube and separated with the “Spectre-diaphragm”. Next the “Spectre-diaphragm” is destroyed into small-scale fragments by an external force. The gaseous interface is accelerated by a compression wave formed in the shock tube. At that, the Rayleigh-Taylor instability arises at the contact boundary of different density gases, and a non-stationary zone of gravitational turbulent mixing forms. According to the experimental results, the dependence of the turbulent mixing zone width on the interface displacement has been built, and the non-dimensional rate of mixing alpha has been obtained.

Abstract No. E39

Shock Tube Experiments on Richtmyer-Meshkov Instability Across a Chevron Profiled Interface

A. V. Smith, D. A. Holder, C. J. Barton, A. P. Morris, and D. L. Youngs
Atomic Weapons Establishment, Aldermaston, United Kingdom

This paper reports on the latest experiment in the series of Richtmyer-Meshkov instability (RMI) shock tube experiments. They feature a dense gas / air interface in the form of a chevron of central obtuse angle 157º and full test cell height. The interest in an inclined interface of this angle was initiated at the 5th IWPCTM [1].

The experiments were conducted at shock Mach number 1.26 (70kPa overpressure), using the 200 x 100 mm shock tube with a three zone test cell arrangement of air / dense gas / air. The dense gas is optionally sulphur hexafluoride (SF_6) or xenon (Xe) which provide Atwood numbers of 0.67 and 0.64 respectively. Gas separation was by means of microfilm membranes, supported by fine wire meshes. Visualisation of the gas mixing was by laser sheet illumination of the seeded dense gas using a copper vapour laser pulsing at 12.5kHz. Mie scattered light was recorded using a 35mm rotating drum camera to capture a sequence of 50 images per experiment; or alternatively a single image from an ICCD camera.

Sample laser sheet images are compared to those from corresponding 3-D hydrocode calculations. Quantitative analysis will be of the form of derived relative intensity data from line-outs through experimental images and their code equivalents. Comparisons will reveal substantial agreement on major features.

A video will also be available showing a full sequence of images from one experiment with corresponding computed code images.

1. Bashurov et al. Experimental and Numerical Evolution Studies for 2-D Perturbations of the Interface Accelerated by Shock Waves. 5th IWPCTM

PACS No.: 47.20.Ma

Abstract No. E40

The Evolution and Interaction of Two Shock-Accelerated Unstable Gas Cylinders

C. Tomkins, K. Prestridge, P. Rightley, C. Zoldi, and R. Benjamin
Los Alamos National Laboratory, Los Alamos, NM

The interaction of two Richtmyer–Meshkov-unstable gas cylinders is investigated experimentally. The dense-gas cylinders are initially configured with separation S in the spanwise direction ($S = 1.1$ to 2.0 times the diameter, center-to-center), and subject to acceleration by a planar shockwave. The evolution of the resulting flow structures is captured downstream by flow visualization and PIV.

In the single-cylinder case (Prestridge *et al.*), the flow structure is dominated by two spanwise-separated vortices. In the double-cylinder configuration, the innermost vortices interact (e.g., Figure 1). The nature and degree of the interaction—and hence the morphology of the resulting flow structures—is observed to be highly sensitive to the initial cylinder spacing. The effects of the interaction on both the initial baroclinic vorticity production, and the subsequent evolution of this deposited vorticity, are investigated.

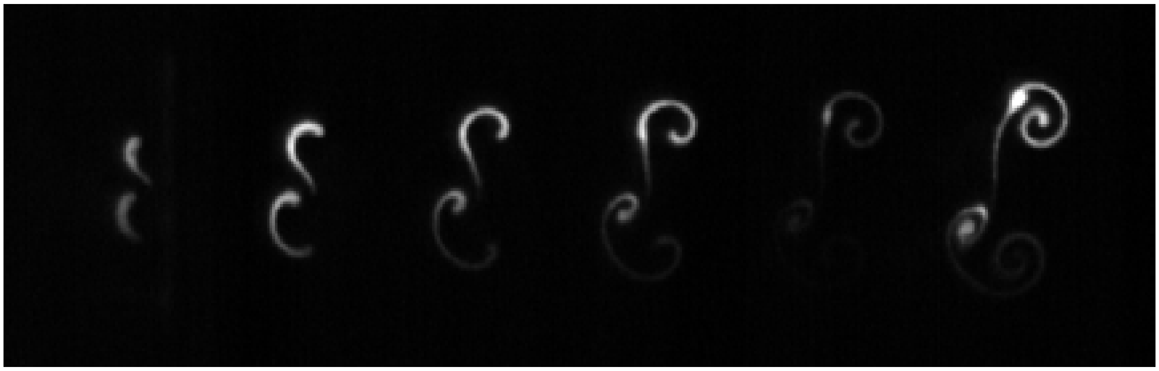


Figure 1. Flow visualization example of interaction between adjacent shock-accelerated gas cylinders.

References

K. Prestridge, *et al.*, “Experiments and Simulations of Instabilities in a Shock-Accelerated Gas Cylinder”, submitted to *Phys. Fluids*.

PACS No.: 47.20Ma

Abstract No. E41

Doubly-Shocked Richtmyer-Meshkov Instability Experiments at Nova

D. J. Ward, K. S. Budil, T. A. Peyser, B. A. Remington,
P. L. Miller, R. J. Wallace, H. Louis, and A. Demiris
Lawrence Livermore National Laboratory, Livermore, CA

Hydrodynamic instabilities are present in many physical systems, ranging from very small inertial confinement fusion capsules to supernovae. A great deal of effort, computational, theoretical and experimental, has been focused on the evolution of buoyancy-driven (Rayleigh-Taylor), shear-driven (Kelvin-Helmholz) and shock-driven (Richtmyer-Meshkov) instabilities. For astrophysics the interaction of shock waves with molecular clouds in the interstellar medium is a common occurrence and a problem that has been studied extensively. A slightly more complex problem is the interaction of multiple shock waves with such a cloud, in either a co- or counter-propagating geometry. This is the system that we chose to address with these experiments.

We will present the results of a series of experiments that investigated hydrodynamic instabilities in doubly shocked systems. A half-hohlraum driver was used to launch a shock into a miniature shock tube that then crossed a rippled interface, causing the ripples at the interface to grow via the Richtmyer-Meshkov instability. A second, counterpropagating shock was launched from the opposite end of the shock tube by a second half-hohlraum driver that impacted the developing mix region at some later time. This unique geometry allowed independent control of the relative timing of the two shocks and their relative strength. However, for ease of experimental implementation we have chosen to begin with the case of two roughly equal strength, counter-propagating shock waves. The evolution of the mixing region was observed via radiography.

The quality of the data obtained in this experiment was greatly improved over prior experiments by the use of a layered ablator, constructed by using two density matched plastic materials, only one of which was radiographically opaque to the backlighter X rays. The opaque material was confined to the central 100 microns along the line-of-sight, thus virtually eliminating the complications due to shock curvature in that direction. The initial perturbation was a 100 μm wavelength ripple with an initial amplitude of 1 μm.

The experimental results show good agreement with two-dimensional radiation-hydrodynamics code simulations. We will also discuss comparisons to existing analytic models for the evolution of the RM instability.

This work was performed under the auspices of the U.S. Department of Energy by the University of California Lawrence Livermore National Laboratory under contract No. W-7405-Eng-48.

Abstract No. E42

The Interaction of Supernova Blast Waves with Interstellar Clouds: Experiments on the OMEGA Laser

R. I. Klein[1,2], H. Robey[1], T. Perry[1], and J. Greenough[1]
[1]*Lawrence Livermore National Laboratory, Livermore, CA*
[2]*University of California at Berkeley, Berkeley, CA*

The interaction of strong shock waves, such as those generated by the explosion of supernovae with interstellar clouds, is a problem of fundamental importance in understanding the evolution and the dynamics of the interstellar medium (ISM) as it is disrupted by shockwaves.. The physics of this essential interaction is critical to understanding the evolution f the ISM, the mixing of interstellar clouds with the ISM and the viability of this mechanism for triggered star formation. We present the results of a series of new OMEGA laser experiments investigating the evolution of a high density sphere embedded in a low density medium after the interaction of a strong shock wave, emulating the supernova shock-cloud interaction. The interaction is viewed from two orthogonal directions using face-on and side-on x-ray radiography enabling visualization of the both the initial distortion of the sphere into a vortex ring as well as the onset of a powerful azimuthal 3D instability that ultimately results in the three-dimensional breakup of the ring. These studies augment the previous studies of Klein et al. (2000, 2001) on the NOVA laser by enabling the full three-dimensional topology of the interaction to be understood. We compare the experimental results for the vortex ring with the incompressible theory of Widnall et al. 1974 and we discuss high resolution 3D numerical simulations that recover all of the essential features of the interaction including Richtmyer-Meshkov, Rayleigh-Taylor and Kelvin-Helmholtz instabilities. We discuss implications for mixing in the ISM.

This work was performed under the auspices of the U.S. Department of Energy by the University of California Lawrence Livermore National Laboratory under contract No. W-7405-Eng-48.

Abstract No. E43

Evolution of the Mixing Zone of Different Densities Gases Being Interaction to Compression Waves

S. G. Zaytsev[1], V. V. Krivets[1], I. M. Mazilin[1], S. N. Titov[1], E. I. Chebotareva[1],
V. V. Nikishin[2], V. F. Tishkin[2], S. Bouquet[3], and J.-F. Haas[3]
[1]*Krzhizhanovsky Power Engineering Institute, Moscow, Russia*
[2]*Institute of Mathematical Modeling, Moscow, Russia*
[3]*Commissariat à l'Energie Atomique, Bruyères-le-Châtel, France*

The experimental and numerical study of the mixing zone evolution between a combustible mixture (hydrogen-oxygen, molecular weight is 18.5) and argon was carried out during accelerated, and then decelerated motion. The accelerated motion was formed by compression waves generated by a flame front in a combustible mixture. The magnitude of acceleration was about 10^4 acceleration of gravity. In experiments the density distribution and shape of the mixing zone in the test-section were observed.

One-dimensional (1D) and two-dimensional (2D) models of process were used in numerical calculations.

The analysis of numerical and experimental results has shown:

1. The one-dimensional model satisfactorily describes a trajectory of the mixing zone motion and density distribution outside the mixing zone during accelerated, and then decelerated motion.
2. The shape of perturbations in the mixing zone generated as a result of the Rayleigh-Taylor instability evolution at the stage of accelerated motion is satisfactorily described by two-dimensional model.
3. At the stage of deceleration two qualitatively different ways of the mixing zone evolution are observed:
4. At deceleration caused by the reflected shock, the decrease of the perturbation amplitude is observed – **non-shocked deceleration.**
5. In the given design of experiments, there are waves, which observed sometimes inside the incident compression wave. They form reflected shock waves with the Mach number just slightly exceeding M=1. The interaction of these extremely weak shocks with the mixing zone resulted in the perturbation amplitude growth inside the mixing zone – **shock-induced deceleration**.

Abstract No. E44

Studies of Rayleigh-Taylor Instability in Aluminum Under Shock-Wave and Shock Less Loading

A. Lebedev, P. Nizovtcev, and V. Raevsky
Russian Federal Nuclear Center – VNIIEF, Sarov, Russia

The paper present results of experimental studies of Rayleigh-Taylor instability growth in aluminum alloys AMg-6 and 6061-T6 subjected to shock-wave and shock less loading up pressures of 45Gpa. Fast growth of perturbations was recorded at the initial stage of acceleration in experiments with shock-wave loading. This testifies to short-time reduction of strength of tested material. To explain this phenomenon, the authors suggest a relaxation model of aluminum strength, taking into account heterogeneous character of deformation at shock wave front. Results of micro structural analysis of samples subjected to shock less and shock-wave loading are presented.

The study was performed at financial support under Agreement 512964 between Lawrence Livermore National Laboratory University of California and All-Russia Research Institute of Experimental Physics

Abstract No. E45

Ablative Rayleigh-Taylor Instability at Short Wavelengths

H. Azechi[1], T. Sakaiya[1], M. Nakai[1], H. Shiraga[1], K. Shigemori[1], N. Miyanaga[1],
M. Nishikino[1], S. Fujioka[1], Y. Tamari[1], H. Nagatomo[1], H. Takabe[1], and A. Sunahara[2]
[1]*Osaka University, Osaka, Japan*
[2]*University of Rochester, Rochester, NY*

The Rayleigh-Taylor (RT) instability in inertial confinement fusion (ICF) targets and in some astrophysical objects has an essential difference from the classical RT instability: material ablation. Since the ablation removes the RT perturbation away from the unstable surface, the RT growth is expected to be substantially reduced from its classical growth. Accordingly the RT instability at short wavelengths provides a critical test of various theories. To date, few experiment has addressed the short wavelength RT instability because of the wavelength of interest is around or even below the diagnostic spatial resolution. We will report in this Workshop the short wavelength RT instability growth rates which are measured for the first time by utilizing the newly innovated moiré interferometry. The measured growth rates are reasonably well reproduced by the simulation that solves the Fokker-Plank equation for non-local heat transport.

Abstract No. E46

A Vortex Model for Studying the Effect of Shock Proximity on Richtmyer-Meshkov Instability at High Mach Number

H. F. Robey and S. G. Glendinning
Lawrence Livermore National Laboratory, Livermore, CA

The effect of shock proximity on the non-linear evolution of Richtmyer-Meshkov instability of a sinusoidal perturbation at high Mach number is investigated analytically using a vortex model. The presence of the time-dependent shock boundary condition is incorporated using a system of image vortices of opposite sign located at the shock-to-interface distance ahead of the shock. For certain conditions, the perturbation growth rate is predicted by the linear theory to exceed the velocity of the transmitted shock relative to the mean interface. The effect of the image vortices is to initially suppress the growth of the perturbation while the shock remains close to the unstable interface. Later in time as the shock separates from the interface, the growth rate rebounds to a value slightly greater than would have occurred in the absence of the proximity effect. The model is compared with data from recent high Mach number RM experiments conducted on the Omega Laser and is shown to provide very reasonable agreement.

This work was performed under the auspices of the U.S. Department of Energy by the University of California Lawrence Livermore National Laboratory under contract No. W-7405-Eng-48.

COMPUTATIONAL ABSTRACTS

Abstract No. C1

Modes' Interaction on Nonlinear Stage of Richtmyer-Meshkov Instability Evolution

V. I. Anisimov and A. V. Polionov
Russian Federal Nuclear Center – VNIITF, Snezhinsk, Russia

Universal dependence, permitting to describe linear and non-linear stages of Richtmyer-Meshkov instability evolution for single mode for the wide range of Mach and Atwood numbers was obtained earlier. In the present paper we are making an attempt to describe modes' interaction. For each single mode its own turbulent viscosity is determined. During modes interaction it is supposed that evolution of each mode damps because of total viscosity all modes being in the presence. The obtained results are compared with direct numerical simulation by MACH code.

Abstract No. C2

Application of Kε-Model for the Description of an Atmospheric Surface Layer

M. G. Anuchin, V. E. Neuvazhayev, and I. E. Parshukov
Russian Federal Nuclear Center – VNIITF, Snezhinsk, Russia

The problem on determination of non-dimensional characteristics of turbulent flow in atmospheric surface layer is considered within kε-model. Kε-equations and their singular points are investigated. The mathematical program for calculations of characteristics of turbulent flow in surface atmospheric layer is developed. From the set of integral curves those curves are chosen which correspond to the solution of formulated task and ensure the satisfactory experiments description. Here the basic model constants are chosen according to the conventional criteria. At the same it is shown that the parameter responding to convection source term of an ε-equation should be chosen depending on stability conditions. The best agreement with experimental results is reached if for steady stratification and for unstable stratification. By a numerical choice of value and factor of turbulent diffusion the quite satisfactory description of experimental observations known as analytical interpolar dependencies is received.

Abstract No. C4

Computational Modeling of Low-Mach-Number High-Atwood-Number Turbulent Mixing

Wm. T. Ashurst and A. R. Kerstein
Sandia National Laboratories, Livermore, CA

A prerequisite for physical understanding of compressible turbulent mixing is clarification of low-Ma high-At turbulent mixing mechanisms. Remarkably, uncertainty persists concerning the interpretation of the fundamental experiments in this regime, such as the seminal mixing-layer study by Brown and Roshko [1] and subsequent GALCIT experiments. It is difficult to perform numerical simulations directly comparable to the pertinent experiments, and theoretical progress has been limited. The present study provides an integrated picture of low-Ma high-At turbulent mixing using a new computational model for stochastic simulation of variable-density turbulent mixing. Comparison of model results to various published and unpublished experimental and numerical results clarifies the physical mechanisms underlying the diverse results and demonstrates novel predictive capabilities. A planned extension of the model to compressible flow is outlined.

G. L. Brown and A. Roshko, *J. Fluid Mech.* 64, 775 (1974).

PACS Nos.: 47.27.Eq, 47.27.Nz, 47.27.Jv

Abstract No. C8

Spectral and High-Order Compact Methods for Shock-Induced Mixing

A. W. Cook, W. H. Cabot, and J. A. Greenough
Lawrence Livermore National Laboratory, Livermore, CA

A methodology, based on high-order compact and spectral schemes, is described for computing multicomponent turbulent flows at any Mach number. Filters are employed to stabilize the numerical integration and high-order artificial transport coefficients are introduced to control Gibbs oscillations. The equations and numerical scheme are formulated such that, under grid refinement, the method approaches a DNS. The method is evaluated for flows in 1, 2, and 3 dimensions, including comparisons with lower-order schemes. The dissipative character of the filter and artificial terms appears to be of little consequence for strongly forced flows which evolve over short periods of time; however, the dissipation is more noticeable for unforced flows which evolve over long periods of time.

PACS Nos.: 02.70.Hm, 47.20.Ma

This work was performed under the auspices of the U.S. Department of Energy by the University of California Lawrence Livermore National Laboratory under contract No. W-7405-Eng-48.

Abstract No. C9

Numerical Simulation of Mode Coupling in Laser-Driven Rayleigh-Taylor Instability Experiments

R. M. Darlington and K. S. Budil
Lawrence Livermore National Laboratory, Livermore, CA

This study addresses the simulation of multimode laser-driven Rayleigh-Taylor instability experiments. The linear and transition stages of the instability will be examined, with particular study of the mode coupling between short and long wavelengths. The experiments, conducted at the Nova laser facility at LLNL, consisted of ablatively-accelerated planar composite foils mounted onto the side of a gold hohlraum. A modulation was machined at the interface between a brominated plastic ablator layer (40 um thick) and a titanium payload (15 um thick) and its growth was diagnosed by measuring the changing optical depth modulation via face-on radiography. In this work we will focus on the evolution of a superposition of a 20 and a 4 um mode and contrast this to the evolution of a 20 um single mode perturbation. The shape and growth rate of the resulting instability will be examined, as well as the effect of numerical methods on the simulation. Similar simulations will also be used to examine the evolution of this perturbation in a more idealized situation where the target layers will be much thicker in order to mitigate thin foil effects, and the laser drive can be sustained for much longer durations. This will allow us to investigate the experimental conditions required to follow the instability further toward the turbulent regime.

This work was performed under the auspices of the U.S. Department of Energy by the University of California Lawrence Livermore National Laboratory under contract No. W-7405-Eng-48.

Abstract No. C10

A Comparison of High-Resolution 3D Numerical Simulations Of Turbulent Rayleigh-Taylor (RT) Instability: Alpha-Group Collaboration

G. Dimonte[1], A. Dimits[1], S. Weber[1], D. L. Youngs[2], A. C. Calder[3], B. Fryxell[3], J. Biello[3],
L. Dursi[3], P. MacNeice[4], K. Olson[4], P. Ricker[3], R. Rosner[3], F. Timmes[3], H. Tufo[3], Y.-N. Young[3],
M. Zingale[3], M. J. Andrews[5], P. Ramaprabhu[5], S. Wunsch[6], C. Garasi[6], and A. Robinson[6]
[1]*Lawrence Livermore National Laboratory, Livermore, CA*
[2]*Atomic Weapons Establishment, Aldermaston, United Kingdom*
[3]*University of Chicago, Chicago, IL*
[4]*NASA Goddard Space Flight Center, Greenbelt, MD*
[5]*Texas A & M University, College Station, TX*
[6]*Sandia National Laboratories, Livermore, CA*

The RT instability is investigated by comparing high resolution (256 x 256 x 512 zones) simulations using various (5-7) numerical techniques with identical initial conditions. The fluids have a density ratio $\rho_2/\rho_1 = 3$ and an ideal gas specific heat ratio of $\gamma = 5/3$. The hydrostatic equilibrium is adiabatic with a pressure $\sim 2\pi\ (\rho_1+\rho_2)gL$ (g = acceleration, L = box width) at the interface to keep the velocities sub-sonic (Mach < 0.2). The initial perturbations have an RMS amplitude $h_o/L \sim 3 \times 10^{-4}$ with mode numbers randomly distributed in a cylindrical shell $32 \leq n \leq 64$. This paper compares the self-similar growth $\sim gt^2$ of the mixing zone and internal scales, the atomic mixing, and the energy budget from the different codes and with available experiments.

This work was performed under the auspices of the U.S. Department of Energy by the University of California Lawrence Livermore National Laboratory under contract No. W-7405-Eng-48.

Abstract No. C11

Numerical Methods for Determination of Mix

S. Dutta[1], E. George[1], J. Glimm[1,3], J. Grove[2], X. Li[1],
A. Marchese[1], D. H. Sharp[2], Z. Xu[1], and Y. Zhang[1]
[1]*State University of New York at Stony Brook, Stony Brook, NY*
[2]*Los Alamos National Laboratory, Los Alamos, NM*
[3]*Brookhaven National Laboratory, Brookhaven, NY*

We present numerical studies of the growth of a 3D mixing layer due to Rayleigh-Taylor (RT) or Richtmyer-Meshkov(RM) instabilities. Simulations based on the Front Tracking code FronTier give a mixing rate alpha for the bubble growth in planar RT mixing within the range determined by experiments of Youngs-Reed, Smeeton-Youngs and Dimonte et. al. Identical simulation problems, solved with a TVD capturing code, give an alpha below this range of experiment. We present an analysis (based on theory and on diagnostics from the two simulations) to indicate that the difference between simulations is primarily due to diffusion of mass across the fluid interface in the TVD (capturing) simulation.

Axisymmetric 3D spherical RM mixing studies show dependence of the mixing rate on the azimuthal angle, especially after reshock. Statistical mix quantities (volume fraction, etc.) are recorded and compared with mix model equations of the authors and co-workers.

PACS Nos.: 47.20Bp, 47.52+j

Abstract No. C12

Rayleigh-Taylor Instability in Compressible Fluids

Y. Elbaz[1,2], A. Rikanati[1,2], D. Oron[3], and D. Shvarts[1,2]
[1]*Nuclear Research Center Negev, Israel*
[2]*Ben Gurion University, Beer-Sheva, Israel*
[3]*Weizmann Institue of Science, Rehovot, Israel*

The behavior of the single mode and multimode Rayleigh-Taylor (RT) instability in compressible fluids is studied using full two-dimensional numerical simulations and analytical theoretical models. Due to the finite mass of the heavier fluid above the bubble, resulting from the initial density distribution, the perturbation growth causes a state of pressure non-equilibrium on the heavier fluid, leading to a bulk acceleration of the heavier fluid as in the case of RT instability in a finite layer of an incompressible fluid. Also, the finite sound speed of the heavier fluid causes an effective mass accumulation in time, therefore changing the pressure gradient on the interface with time.

Analyzing the instability dynamics in a frame of reference moving with the accelerated physical system shows a small effect of compressibility on the instability dynamics. In this frame of reference the simulation results coincide with the known incompressible results - a constant velocity in the single mode case and $\alpha\sim0.04$-0.06 in the multimode case. However, due to the bulk acceleration of the heavier fluid, in the laboratory frame of reference the bubble velocity continuously increases in the single mode case, and in the multimode case an $\alpha g t^2$ growth rate is obtained, with α continuously increasing as well.

Abstract No. C13

One-Dimensional Simulation of the Effects of Unstable Mix on Neutron and Charged-Particle Yield from Laser-Driven Implosion Experiments

R. Epstein, J. A. Delettrez, V. Yu. Glebov, V. N. Goncharov, P. W. McKenty,
P. B. Radha, S. Skupsky, V. A. Smalyuk, and C. Stoeckl
Laboratory for Laser Energetics, University of Rochester, Rochester, NY

The effects of Rayleigh–Taylor flow in laser-driven implosion experiments are simulated in one dimension by the hydrodynamics code *LILAC*. Mix is modeled as a diffusive transport process affecting material constituents, thermal energy, and turbulent mix-motion energy within a mix region whose boundaries are derived from a saturable, linear, multimode model of the Rayleigh–Taylor instability. The growth rates and the coupling between perturbations of different unstable interfaces are obtained analytically in terms of the one-dimensional fluid profiles. The initial perturbations are due to beam-energy imbalance, hydrodynamic imprint of short-scale laser nonuniformity, and target surface roughness. The effects of fuel–pusher mix on neutron production and secondary particle yields are characterized and compared with data from implosion experiments. The limitations of one-dimensional mix as an approximation to the multidimensional distortion of the fuel–pusher interface will be considered.

Abstract No. C14

3D Computation for Surface Perturbation Evolution of Plasma Cloud During its Expansion in Magnetic Field

E. S. Gavrilova, E. V. Gubkov, V. A. Zhmailo, and Yu. V. Yanilkin
Russian Federal Nuclear Center – VNIIEF, Sarov, Russia

Previously, ref. [1] considered the 2D problem of initially spherical plasma cloud expansion in the axial magnetic field. In particular, it was noted that the plasma surface was unstable to evolution of perturbations (of "chute" type).

This paper solves the above problem with taking into account the growth of the perturbations. The computation is performed with 3D code TREK [2]. Two methods to solve the problem are discussed:

- it is assumed that outside the cloud there is plasma of quite low density as well which magnetic field is "frozen into", in this case appropriate MHD equations are used to compute magnetic field variations;
- it is assumed that outside the cloud there is vacuum, in this case quasi-stationary approximation [1] is used to compute the magnetic field.

Two initial perturbation types are given: one mode and random. The computed data for the linear stage of the one mode perturbation growth is compared to the analytical data.

The results of the problem computation with random perturbations are averaged (over azimuth). Thus obtained plasma density and magnetic field profiles, in particular, dependence of the transition zone width in the profiles on the problem parameters are considered. Applicability of this plasma model is discussed.

1. Bakhrakh S.M., Gubkov E.V., Zhmailo V.A., Terekhin V.A. "Plasma cloud expansion in homogeneous magnetic field". PMTF, 1974, No. 4, pp. 146-150.

2. Yanilkin Yu.V., Tarasov V.I., Stadnik A.L., Bazhenov S.V., Bashurov V.V., Belyaev S.P., Bondarenko Yu.A., Bykova E.A., Gavrilova E.S., Gorev V.V., Dibirov O.A., Ivanova G.G., Kovalev N.P., Korol'kova T.V., Pevnaya P.I., Sofronov V.N., Toropova T.A., Shanin A.A. Program System TREK for Numerical Simulation of 3D Multi-component Medium Flows. Proceedings of workshop "New Models and Numerical Codes for Shock Wave Processes in Condensed Media", Oxford, 1997, pp 413-422, 1997.

Abstract No. C15

The Richtmyer-Meshkov Instability in Cylindrical Geometry: Experiments and Simulation

M. J. Graham[1], K. S. Budil[1], J. Grove[2], and B. A. Remington[1]
[1]*Lawrence Livermore National Laboratory, Livermore, CA*
[2]*Los Alamos National Laboratory, Los Alamos, NM*

Hydrodynamic instabilities are fundamentally important to a wide range of fields, including astrophysics, inertial confinement fusion (ICF), and inertial fusion energy (IFE). The most common of these instabilities is the Rayleigh-Taylor (RT), or buoyancy-driven instability, is caused when a material of higher density is accelerated by a material of lower density. The Richtmyer-Meshkov (RM), or shock-driven instability is produced when an incident shock wave impulsively accelerates a material interface causing small disturbances to grow.

The RT interface is unstable only when the external force acts from the heavy material to the lighter material, whereas the RM instability is present whether the incident shock travels from light to heavy or vice versa. The majority of the theoretical, computational and experimental work has been successfully performed for the RM instability in planar geometry. In most physical applications the RM instability occurs in a curved geometry, either cylindrical or spherical. This curved geometry complicates the system considerably. For example, the unperturbed system does not have an analytical solution, while the unperturbed system in plane geometry does. The occurrence of re-acceleration or re-shock of the material interface caused by the waves reflecting back from the origin is unavoidable in curved geometry.

The Nova Laser was used to test critical ingredients of our understanding of the fundamental properties of the RM instability in the strong-shock, high-compression regime. A shock was launched into a copper hemicylinder with a thin plastic ablator layer by focusing 6 KPP-smoothed, 1 ns square laser beams at 3ω onto the interior of the target. A single-mode sinusoidal perturbation was machined onto the outer surface of the copper, which was embedded in a thick layer of plastic. The expanding interface was diagnosed by side-on radiography and radiographs were recorded at several times.

We will show numerical simulations of this experiment using two difference codes: FronTier and CALE. In the FronTier method a lower dimensional grid is fitted to and moves dynamically with discontinuities in the flow. CALE is a continuous adaptive Lagrangian Eulerian method.

PACS Nos.: 52.35.Tc, 47.11+j

Abstract No. C16

Code to Code Comparisons for the Problem of Shock Acceleration of a Diffuse Dense Gaseous Cylinder

J. A. Greenough[1], W. J. Rider[2], C. A. Zoldi[2], and J. R. Kamm[2]
[1]*Lawrence Livermore National Laboratory, Livermore, CA*
[2]*Los Alamos National Laboratory, Los Alamos, NM*

The current computational study is motivated by large-scale (and small-scale) discrepancies between ongoing calculations and experiments of a shock wave accelerating a diffuse cylinder of SF_6 ("Experiments and simulations of instabilities in a shock accelerated cylinder," K. Prestridge, C. A. Zoldi, P. Vorobieff, P.M. Rightley, and R. F. Benjamin, Los Alamos Report LAUR –00-3973). Three different Eulerian based codes, Rage (LANL), Cuervo (LANL) and Raptor (LLNL), are applied to an idealized two-dimensional version of the experiment. The model problem consists of a Gaussian shaped SF_6 inhomogeneity in air that is accelerated by a M=1.2 shock wave. The initial diffuse cylinder evolves into a quasi-vortex dipole at intermediate times until finally becoming unstable at late times. The integral (large) scale features, which include the length and width of the evolving structure, will be measured from the calculations and compared. The sub-integral scale, small-scale vortical features in the central roll-up, will also be examined quantitatively and compared at intermediate times. An assessment of the degree of convergence of the simulations as well as factors accounting for computed differences will be discussed.

This work was performed under the auspices of the U.S. Department of Energy by the University of California Lawrence Livermore National Laboratory under contract No. W-7405-Eng-48.

Abstract No. C17

Implementation of a Turbulent Mix Model in a 2D ALE Code

B. Grieves
Atomic Weapons Establishment, Aldermaston, United Kingdom

The addition of a turbulent mix model to a two dimensional finite element ALE hydrocode, CORVUS, is discussed. Use is made of the existing mixed-cell data structure to facilitate the inclusion of the model.

This first stage of the model is based on the multiphase flow equations, and is a simplified form of the model implemented by Youngs (See paper at this workshop) in a 2D Eulerian Code. This is applicable to simple Rayleigh-Taylor and Richtmyer-Meshkov instabilities, and some results are presented.

A simple buoyancy-drag model is used to calculate the early stages of the instability growth at interface nodes, and this is used to initialise the turbulent mix model calculation.

Abstract No. C18

Error Estimation for Strong Shock Hydrodynamics

J. W. Grove
Los Alamos National Laboratory, Los Alamos, NM

The quantification of uncertainty is a fundamental problem in mathematical modeling. Sources of uncertainty include incomplete physical models, poorly defined initial conditions, and the effect of numerical methods. Traditional numerical analysis is extremely limited in accessing the accuracy of a computation, especially in highly nonlinear regimes. Predictive calculations require a more detailed assessment of solution error, including a quantitative model for the probability distribution of the error in a simulation.

This talk will describe a prototype methodology, developed in collaboration with researchers at the University at Stony Brook, for studying uncertainty in a computational model. We apply this methodology to a simple strong shock refraction test problem. Assuming known probability distributions for a set of initialization and flow parameters, we perform a statistical study of the generation and propagation of solution error. Error is computed by comparing fine and coarse grid computations for different mesh sizes, and numerical methods. We obtain a space-time field of probability distributions for a variety of state variables, and seek stochastic models for the generation and propagation of solution error as a function of flow state and numerical method.

PACS Nos.: 07.05.Tp, 47.11.+j, 47.40.-x

Abstract No. C19

A Semi-Empirical Model for Turbulent Diffusion of Magnetic Field to Accelerated Plasma

E. V. Gubkov, V. A. Zhmailo, and Yu. V. Yanilkin
Russian Federal Nuclear Center – VNIIEF, Sarov, Russia

A nonlinear phase of instability development at the accelerated plasma/magnetic field interface is studied. The paper considers the case with short wavelength and incidental initial perturbations. A semi-empirical model which structure is similar to that of the hydrodynamic model from /1/ is proposed to describe perturbations of such a kind.

Two problems are solved using the proposed model: a one-dimensional problem of a converging cylindrical liner with axial magnetic field in cavity (ultra-high magnetic field generator "MK-1" /2/); a two-dimensional problem of a plasma cloud expansion in external magnetic field /3-5/.

By comparing computation results with the corresponding experimental data, some constants introduced to the model are determined, as well as frames of its applicability are specified.

1. Yanilkin Yu.V., Nikiforov V.V., Zharova G.V. A Two-Equation Model and a Method for Turbulent Mixing Computations in 2D Compressible Flows. – VANT, Ser.:MMPhP, 1994, Iss.4.
2. Sakharov A.D., LudaevR.Z., Smirnov E.N., Plyushcheyev Yu.I., Pavlovskii A.I., et al. DAN SSSR, 1965, V.196, No.1, pp.65-68.
3. Bakhrakh S.M., Gubkov E.V., Zhmailo V.A., Terekhin V.A. Expansion of a Plasma Cloud in Uniform Magnetic Field. – PMTPh, 1974, No.4, pp.146-150.
4. Zakharov Yu.P., Orishich A.T., Ponomarenko A.G. "Plasma Physics" Journal, 1986, V.12, p.674.
5. Pisarczuk T., Kasprczuk A., Karpinski L., et al. Application of Interferometric Methods to Investigation of Laser-Produced Plasma in Strong External Magnetic Field. –In "Advances in laser interaction with matter and inertial fusion", Madrid, 1996.

Abstract No. C20

Localization and Spreading of Interfaces (Contact Discontinuities) in PPM and WENO Simulations of the Inviscid Compressible Euler Equations

S. Gupta, N. J. Zabusky, R. Samtaney, and Y. Gulak
Rutgers, StateUniversity of New Jersey, Piscataway, NJ

The physical or numerically- "motion" of interfaces or contact discontinuities (CD) between two fluids of different density or temperature governs the mixing of species, particularly during the late time ("asymptotic ") epochs.

Using the methods of Vorozhtzov and Yanenko, [1] we show that for the equation $\frac{f\rho}{ft} + u_0 \frac{f\rho}{fx} = 0$, the continuum limit yields $\frac{f\rho}{ft} + u_0 \frac{f\rho}{fx} = (-1)^{r+1} \mu(h, \tau, u_0, p_0) \frac{f^{r+1}\rho}{fx^{r+1}}$ (A) where r is the order of the scheme (r = 1 for 1st order schemes, such as Lax, etc.), h is the grid size and τ is the time-step of the integration. For r = 1 and 2, the exact solution of (A) with a discontinuous initial density function ,$(\rho = \rho_1, x < x_0; \rho = \rho_2, x > x_0)$, is $\rho(x,t) = (\rho_1 + r\rho_2)/(r+1) + (\rho_2 - \rho_1) F(\xi(x,t))$, (B), where $\xi(x,t) = (x - x_0 - u_0 t)/(c_r \mu t)^{1/(r+1)}$ and **F** is the solution of an ODE arising in a self-similar study. In our numerical PPM [3] solutions, we find accurate agreement with the constant term in (B), i.e. the center of a spreading interface depends on r. This explains the lack of convergence in attempting to localize the CD previously [2]. However, the numerical spreading, $\xi_{PPM}(x,t)$, produced by PPM artificially steepens the density over two grid intervals if $\rho_2 > \rho_1$ and spreads it according to a power law if $\rho_2 < \rho_1$. This asymmetry will prove troublesome for reshock and reacceleration problems at late time epochs. We also comment on higher-order algorithms [4] and the effects of vorticity on the interface in 2D.

[1] E. V. Vorozhtzov and N. N. Yanenko, 1990. Methods for the Localization of Singularities in Numerical Solutions of Gas Dynamics Problems, Springer.
[2] R. Samtaney and N. J. Zabusky, 2001. High gradient compressible flows: Visualization, feature extraction and quantification, In *Flow Visualization: Techniques and Examples*, Editors T. T. Lim and A. Smits, Imperial College Press.
[3] J.M Blondin *et al* at NCSU.VH-1. A Lagrangian remap code based on PPM.
[4] Ravi Samtaney, Caltech . Higher order WENO code

Abstract No. C22

Update on Instability Modeling for the NIF Ignition Targets

S. W. Haan, T. Dittrich, S. Hatchett, D. Hinkel, M. Marinak, D. Munro, O. Jones,
S. Pollaine, and L. Suter
Lawrence Livermore National Laboratory, Livermore, CA

This talk is a general update on the hydrodynamic instability modeling that we do for ignition targets for the National Ignition Facility. Recent results include design of a polystyrene-ablator target, analysis of Rayleigh-Taylor growth on beryllium targets driven at 250eV at various scales, simulations of the effect of fill tubes on the implosion,, and simulations of 3D asymmetry and its impact. Hydrodynamic instability modeling is done with direct numerical simulations, since the targets are designed to avoid short wavelength instability growth.

PACS Nos.: 52.57.Bc, 52.57.Fg

Abstract No. C23

Pillars of Creation

J. O. Kane[1], D. D. Ryutov[1], B. A. Remington[1], S. G. Glendinning[1], J. Nash[1],
M. Pound[2], and D. Arnett[3]
[1]*Lawrence Livermore National Laboratory, Livermore, CA*
[2]*University of Maryland, College Park, MD*
[3]*University of Arizona, Tuscon, AZ*

The towering ‘Pillars of Creation’ of the Eagle Nebula are a long-standing astrophysical mystery. A new initiative is underway to develop a model for the formation of the Pillars, employing three-dimensional numerical modeling and scaled verification experiments using intense lasers. In the Rayleigh-Taylor instability (RT) model of the Pillars advanced almost fifty years ago by Spitzer and Frieman (Spitzer, L. 1954, ApJ 120, 1, Frieman, E. A. 1954, ApJ 120, 18), radiation from nearby stars photo-evaporates and accelerates the cloud surface, and the Pillars are falling ‘spikes’ of dense gas. Recently, fluid velocities and column densities in the Pillars have been measured (Pound, M. W. 1998, ApJ 493, L113). Preliminary two-dimensional numerical simulations of the RT model have been performed which produce results consistent these observations, assuming compressible fluids and a thin initial cloud. Since the radiation may impact the surface at an angle, a ‘Tilted Radiation’ instability (LLNL report UCRL-JC-138744, May 2000; .D. Ryutov, B.A. Remington, H.F. Robey, R.P. Drake. Phys. Plasmas, 8, 1804 (2001)) can cause the spikes to translate as waves whose tips may ‘break’, producing the small gas ‘bullets’ visible near the Pillars in images taken by the Hubble Space Telescope. In an alternate model for the Pillars, the cometary model, the Pillars consist of gas swept behind dense preexisting nuclei, but it appears difficult to reproduce the observed velocities and densities in numerical models with dense preexisting nuclei as the initial condition. . However, the effect of radiative cooling and magnetic fields remains to be explored. The maturing field of laser astrophysics presents an opportunity for testing models for the Pillars in the laboratory. Theoretical and numerical evaluations of various models, implications for observations, and plans for verification experiments are presented.

This work was performed under the auspices of the U.S. Department of Energy by the University of California Lawrence Livermore National Laboratory under contract No. W-7405-Eng-48.

Abstract No. C25

Application of a Laser Shock Tube for the Study of Supersonic Gas Flows and the Development of Hydrodynamic Instabilities in Layered Media

I. G. Lebo[1] and V. D. Zvorykin[2]
[1]*Tekhnikal University-MIREA, Moscow, Russia*
[2]*P. N. Lebedev Physical Institute of the Russian Academy of Sciences, Moscow, Russia*

The study of the evolution of hydrodynamic instabilities of the interface between two media found in the field of acceleration is a problem of great importance in inertial confinement fusion (ICF), physics of high energy densities, cosmology, and astrophysics. The passage of strong shock waves (with Mach number M>>1) through contact surfaces of two gases or plasma with different densities causes the formation and development of complex vortex structures, which are of interest for present-day nonlinear hydrodynamics and for studying the problem of a change from an ordered state to chaos. Another problem, which is important for the development of modern aerospace engineering and protecting the Earth from collisions with space objects, is the study of supersonic flow past bodies of complex shape at large Mach numbers. Usually, such experiments in gases are carried out at relatively small Mach numbers M=1-4 with help of shock tubes. The pressure amplitudes in shock wave are about 2-10 bar. The design of a miniature laser shock tube for the study of a wide range of hydrodynamic phenomena in liquids at pressures greater than 10 kbar and supersonic flows in gases with large Mach numbers (greater than 10) is discussed in this paper. In the system considered here, the confinement of a laser-produced plasma and the excitation of plane shock waves take place inside a miniature tube, which restricts lateral unloading. The design of such a laser shock tube (LST) is based on the use of the following basic components: a shock tube chamber; a powerful KrF laser [1]; an original laser focusing system; and 2D numerical codes. The technique proposed here for exciting shock waves in gases and compression waves in liquids by KrF laser radiation has some advantages in comparison with the conventional technique used in experiments with shock tubes: 1) large Mach numbers in gas flows (M>20) and pressure pulses greater than 10 kbar in liquids [2]; 2) economy of noble gases and other supplies (laser driven shock tube volume is less in ~ 10^3-10^4 times). This study is supported by RFBR, grant N0101-00023

References.

1. Zvorykin V.D., Lebo I.G. Laser and Particle Beams, 17, 69, 1999
2. Zvorykin V.D., Lebo I.G. Quantum Electronics, 30, 540, 2000

Abstract No. C26

Molecular Dynamic Simulation of Shock and Richtmyer-Meshkov Instability in Cylindrical Geometry

K. Nishihara, V. Zhakhovskii, and M. Abe
Osaka University, Osaka, Japan

Molecular dynamic (MD) approach has been applied to study the converging cylindrical shock waves and the Richtmyer-Meshkov instability in a dense Lennard-Jones fluid. MD method is based on tracking of the atom motion and hence it has fundamental advantages over hydrodynamic methods that assume a shock as a structureless discontinuity and require an equation of state. In addition, hydrodynamic simulation has a limitation in grid resolution, especially, in the cylindrical geometry. It is found that the one million particles is enough to simulate propagation of a cylindrical shock in close detail due to small thickness of shock fronts (a few Angstroms for Argon) in liquid.

We investigate the stability of converging shocks with different perturbation modes and its mixture for different Mach numbers. The converging shock is unstable for low mode number perturbation in large Mach number. It was shown that the amplitude of a shock front ripple increases and the Mach stems are formed. Supersonic jets generated by interaction of reflected shocks in downstream flow are observed. We also study the Richtmyer-Meshkov instability of an interface between two L-J liquids of different densities in the cylindrical geometry. The turbulent mixing is observed when the reflected shock near the center passes again through the unstable interface.

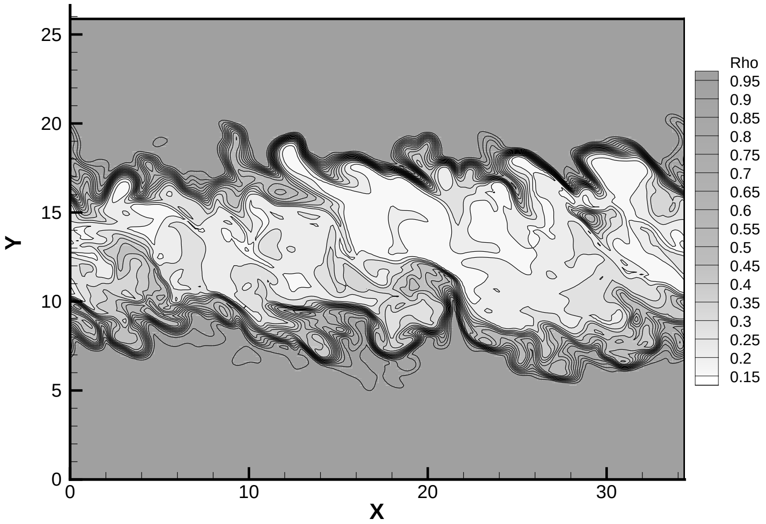
Abstract No. C27

Compressibility Effects in a High-Speed, Reacting Shear Layer: An Investigation Using DNS

C. Pantano and S. Sarkar
University of California at San Diego, La Jolla, CA

In technological applications such as combustion, high-speed propulsion and energetic devices, the variation in thermodynamic variables associated with large heat release interacts with and modifies the underlying turbulent flow. Direct numerical simulations of the reacting shear layer using up to 20 million grid points are performed over a wide range of heat release rates and convective Mach numbers to quantify and understand some of these modifications to the turbulence evolution and structure. Large heat release rates typical of hydrocarbon combustion are considered, and not only the overall growth characteristics but also the turbulence structure is investigated. The single-step irreversible combustion of a diluted methane stream mixing with an air stream is considered. An infinitely fast reaction rate is assumed, that is, the heat release is confined to an infinitely thin region in mixture fraction space located at the stoichiometric value.

A longitudinal snapshot of the density field is shown in Fig. 1. The upper air stream moves to the left while the lower fuel stream moves to the right. The mean location of the flame sheet is displaced to the upper air side. However, the convective stirring of the flame sheet by the turbulent motion spans the entire width of the shear layer so that an instantaneous snapshot such as Fig.1 shows a *wide* central core of hot, low-density fluid separated from the cold, high-density fluid on either side by thin regions with large values of the density gradient. The thickness growth rate of the shear layer is the overall quantity of primary interest. With increasing values of convective Mach number, the growth rate of the nonreacting cases shows the well-known large reduction. What is perhaps less expected is the effect of Mach number on the growth rate of the reacting cases. The growth rate is already quite low at the low-Mach number reacting case and a further increase in the Mach number causes only a relatively small additional reduction. The Reynolds shear stress profiles show that, in the low-speed case, there is a significant reduction of its peak value in the case with the highest heat release. However, at the largest convective Mach number, any additional change in the Reynolds shear stress is relatively small. The width of the profiles of Reynolds shear stress (not shown) as well as other Reynolds stresses scale well with the vorticity thickness but not the momentum thickness. The full paper will present results regarding all Reynolds stress components as well as thermodynamic correlations and cross-correlations


Y
X
0
5
10
15
20
25
0
10
20
30
Rho
0.95
0.9
0.85
0.8
0.75
0.7
0.65
0.6
0.55
0.5
0.45
0.4
0.35
0.3
0.25
0.2
0.15

Abstract No. C28

Computational Modelling of Two-Shell Cylindrical Implosions with Mix

K. W. Parker[1], A. M. Dunne[1], S. Rothman[1], D. Youngs[1], C. W. Barnes[2],
S. H. Batha[2], N. E. Lanier[2], G. R. Magelssen[2], T. J. Murphy[2], and J. M. Scott[2]
[1]*Atomic Weapons Establishment, Aldermaston, United Kingdom*
[2]*Los Alamos National Laboratory, Los Alamos, NM*

Experiments to look at mix in a compressible, convergent geometry have been carried out on the Omega Laser Facility. These employ a radio-graphically opaque marker layer, which is sandwiched between the polystyrene ablator and low-density foam. As the implosion proceeds, a strong shock is launched which causes the marker to become mixed into both the foam and the ablator. More recently, these experiments have introduced a high-density core to the targets, such that a shock is reflected from the core back through the mix layer at late time. Presented here are calculations for these '2-shell' targets. Where possible, comparisons are made to the experimental results.

Abstract No. C29

Dispersal of Mass and Circulation Following Shock-Sphere (axisymmetric) and Shock Cylinder Interactions: Effects Arsing From Shock Cavity Collapse, Vortex Double Layers; Density-Gradient Intensification and Vortex Projectiles

G. Peng, S. Gupta, S. Zhang, and N. J. Zabusky
Rutgers, StateUniversity of New Jersey, Piscataway, NJ

We quantify and scale the dispersal and mixing (transport) of mass and vorticity following a spherical (axisymmetric) shock-bubble interaction. We use planar shocks of Mach =2.5, 5.0 and 10 and a density ratio - bubble/ambient- of 10.0, a parameter domain beyond that explored earlier [1], where new effects arise. We correlate and scale the transports with: the primary circulation layer deposited by the passing incident shock in epoch 1; the collapsing *transmitted shock cavity circulation layer* (TSCCL); and a vortex "double layer" (VDL) on the downstream boundary. The TSCSL is generated at the sharp kink of the collapsing transmitted shock (where numerous shocklets arise, e.g. a "penta-point" shock for M= 2.5) and is responsible for an epoch 1 appearing and upstream-moving Vortex Projectile (VP) (with an associated density enhancement). The VDL arises from two shock wave sources incident on the downstream side of the bubble: from inside, the re-expanding cavity and from outside the incident shock as it passes the rear side of the bubble. These phenomena evolve into a chaotic downstream array of vortex projectiles (VPs) which in axisymmetry are complex-shaped stratified rings of *opposite* polarity. We observe strong circulation generating baroclinic effects during this epoch [2]. In 3D, these VPs will be rapidly unstable and lead to domains of reconnecting vortices and stratified turbulence. The collapse of the shock cavity produces: large short-time enhancements of pressure, density and temperature, which we scale; and subsequent *reverberationeffects* in the bubble interior and exterior, which we quantify. We simulated the 2d axisymmetric Euler equations with the Colella & Woodward (1984) PPM in a Galilean frame translating uniformly with the velocity equal to 20 percent of the post-shock velocity. Our study was made at three resolutions, (z, r): (1){803,123}; (2){1606,246} and {3212,492}. At our high Mach numbers and resolutions fast instabilities arise which yield coherent structures (e.g.[3]) and we comment on their relevance to the new observed phenomena.

---

[1] N.J. Zabusky and S-M. Zeng, J. Fluid Mechanics 362, pp. 327-346, 1998. Shock cavity implosion morphologies and vortical projectile generation in axisymmetric shock-spherical F/S bubble interactions. Also,: N.J. Zabusky, Annual Review Fluid Mechanics 31, pp. 495-536, 1999

[2] S. Zhang and N. J. Zabusky Shock –planar curtain interactions: Strong secondary baroclinic deposition and the emergence of coherent and random vortex projectiles (VPs) and decaying stratified turbulence. 8th IWPCTM: International Workshop on the Physics of Compressible Turbulent Mixing (this volume)

[3] R. Samtaney and D.I. Pullin, Physics of Fluids 8, pp. 2650-2655, 1996

---

*This work was supported mainly by DOE (Grant No. DE-FG0293ER25179.A000) and monitored by Dr. Daniel Hitchcock. Additional support was provided by Rutgers University SROA program

This paper is dedicated to Brad Sturtevant whose experiments inspired important configurations for accelerated flows.

PACS Nos.: 47.40.-x, 47.40.Nm, 52.57.Fg, 47.20 Ma, 47.27.-I, 47.27.Eq, 47.11.+j

Abstract No. C30

Influence of Turbulent Mixing Zone on Growth of Local Perturbation in Environments of Rayleigh-Taylor Instability (Numerical Simulation)

V. A. Raevski, S. N. Sinitsina, and Yu. V. Yanilkin
Russian Federal Nuclear Center – VNIIEF, Sarov, Russia

It is common knowledge that self-similar growth of local perturbation occurs following the law in the case of absence of turbulent mixing zone. The growth constant is about 3 times higher than the constant of growth of self-similar turbulent mixing zone. Basing on two-dimensional numerical computations by Euler technique EGAK, it is revealed that continuous continuum of self-similar solutions occurs, where is function of the relation and, if at the initial time there are local perturbation and the perturbations forming further the turbulent mixing zone.

Abstract No. C31

A Statistical Comparison of Gas Cylinder Experiments with Their Simulation

W. J. Rider, J. R. Kamm, and C. A. Zoldi
Los Alamos National Laboratory, Los Alamos, NM

We present the statistical analysis of the evolution of a diffuse cylinder of SF_6 shocked by a Mach 1.2 shock. The cylinder baroclinically develops a vortical structure and subsequently mixes with the surrounding air. The experimental diagnostics are images of tracer particles in the SF_6 and particle image velocimetry. We examine the nature of the mixing using a variety of tools including image analysis using correlations, wavelets, and fractal dimension. Our efforts follow the path of earlier investigations of a gas curtain geometry. There we found significant departures in behavior between the details of the experimentally measured mixing and that computed with the hydrodynamic codes. These statistics from the experiment are then compared with complementary simulations using several computer codes. In each case, we examine the sensitivity of the results to variations in mesh resolution and numerical algorithms. Figure 1 contains plots showing that both the integral size of the evolving cylinder and the magnitude of the velocity field computed in hydrodynamic codes do not match the experimentally measured results.

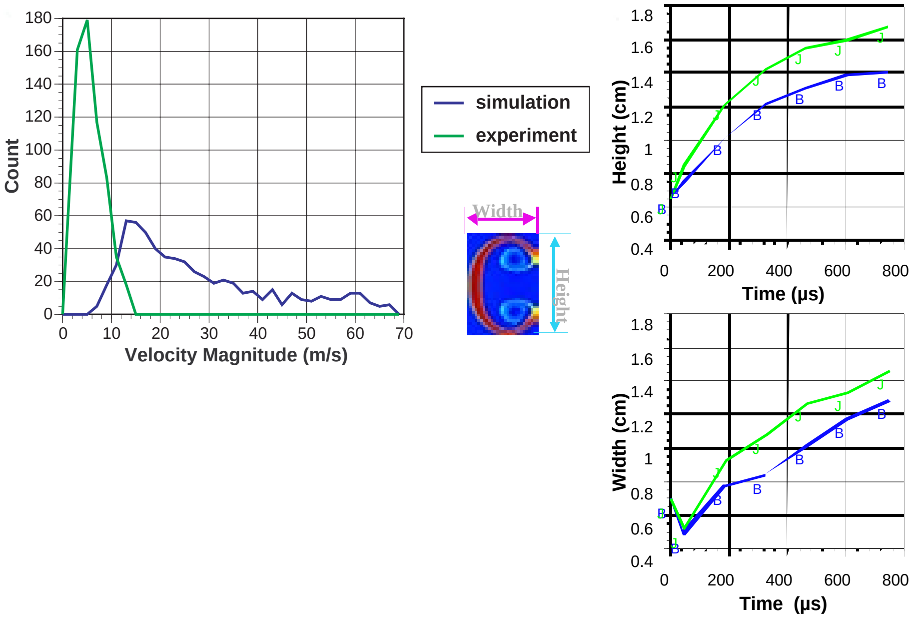


Fig. 1. The plot on the left shows a distribution of the velocity magnitude for the experiment (green) and simulation (blue). The plots on the right show the time evolution of the height and width of the evolving shocked cylinder structure.

Abstract No. C33

Large Eddy Simulation of Strong Shock Richtmyer-Meshkov Instability

R. Samtaney, T. Voelkl, and D. I. Pullin
Graduate Aeronautical Laboratories, California Institute of Technology, Pasadena, CA

In previous studies of isotropic compressible turbulence [1], it was demonstrated that low-order difference schemes are unsuitable for large eddy simulations (LES) of compressible turbulence. In this paper, we present results from formally high-order accurate LES of the Richtmyer-Meshkov (RM) instability. We chose fifth and seventh-order accurate Weighted Essentially Non-Oscillatory (WENO) schemes as the numerical method. These were suitably modified to suppress the so-called carbuncle numerical instability of the shock front. The physical details of the simulations are as follows. The physical domain is a shock-tube of square cross-section. A smooth flat interface with a hyperbolic tangent profile between two gases is initially deformed with a prescribed spectrum giving it multiple harmonic perturbations. This interface is accelerated with a strong (Mach number = 10) shock. The boundary conditions are periodic in the transverse directions, and inflow and reflecting along the length of the shock-tube.

The sub-grid-scale (SGS) model employed in the LES is the stretched vortex (SV) SGS model [2]. This model assumes sub-grid motion to be generated by nearly axisymmetric vortices. The sub-grid heat flux is modeled by advection of a passive scalar taken as the temperature. This model was successfully demonstrated in *a posteriori* comparisons between LES and direct numerical simulations of moderate turbulent Mach number decaying isotropic compressible turbulent simulations in the presence of shocklets [1]. It requires the velocity gradient tensor and the temperature gradient, both of which are calculated with an explicit fourth-order finite difference method.

We will present the evolution of the mixing width as a function of time computed using a level-set approach and a variety of diagnostic procedures, the transverse spectra and evolution of the turbulent kinetic energy (both sub-grid and resolved). In particular, we focus on the effects on these variables due to reshock. Finally, we will endeavor to shed light on the modified wavenumber characteristics of the WENO method and it's suitability for the LES of RM flows.

Acknowledgement: We gratefully acknowledge support of this work by the Academic Strategic Alliances Program of the Accelerated Strategic Computing Initiative (ASCI/ASAP) under subcontract no. B341492 of DOE contract W-7405-ENG-48. Useful discussions with Paul Dimotakis, Tony Leonard, Dan Meiron, and Branko Kosovic are gratefully acknowledged.

References:

[1] Branko Kosovic, Dale I. Pullin, and Ravi Samtaney. *Subgrid-scale modeling for large-eddy simulation of compressible turbulence.* Physics of fluids, sub-judice.

[2] Tobias Voelkl and D.I Pullin. A physical-space version of the stretched-vortex subgrid-stress model for large-eddy simulation. Physics of Fluids, Vol. 12, pp1810-1825

Abstract No. C35

Numerical Investigation of a Laser Induced Turbulent Mixing Zone

P. Seytor and M. Legrand
Commissariat à l'Energie Atomique, Bruyères-le-Châtel, France

We have used high Mach number (M~30) mix instability experiments[1] which have been conducted using Nova laser system to investigate the growth of the Richtmyer-Meshkov instability resulting from a strong shock wave. The initial nonlinear single-mode two dimensionnal pertubation was machined into a brominated plastic ablator (1.22 g/cm^3) adjacent to a low density carbon foam (0.10 g/cm^3). We compared the experimental measurements with LLNL simulations (CALE 1D/2D) and our own numerical simulations (FCI1/FCI2). We found both experiment and simulation to be in good agreement with a k-_ model and also with recent theories for the non linear evolution of instability relevant to an other work presented at this meeting[2].

[1] D.R. Farley, L. M. Logory, S.D. Murray and E. W. Burke PHYS; Plasmas **6**, 4304, (1999).

[2] M. Vandenboomgaerde this meeting 8th IWPCTM 2001.

Abstract No. C36

A Mix-Model For One-Dimensional Simulations of Laser-Driven Implosion Experiments

D. Souffland and F. Renaud
Commissariat à l'Energie Atomique, Bruyères-le-Châtel, France

In laser-driven implosion experiments, hydrodynamic instabilities can growth at interfaces between components as well as at ablation fronts. These processes have various origins and evolve through different ways, but they have in common to favor interpenetration of different fluid components or of fluid regions differing only by their thermodynamic states. The complete study of these intrinsically three-dimensional phenomena, involving a large range of length scales, is still unworkable. We thus need simplified models to assess the impact of variations in the definition of the target, the hohlraum or the laser drive.

The main hypothesis for the present mix-model is that, at the scale of the mesh size, an intimate mixing can simulate the interpenetration region. The description of the model, called hereafter MeDiC, specifies the treatment for the two main cases: density interface instabilities and non-material front instabilities. Diffusive terms are added to model heat and momentum transfers. In the first case, an additional equation for the mass concentration of one component of the mixing is calculate, when, for the second one, the boundaries of the mixing region are imposed. The thickening of the interpenetration zone is, indeed, supposed to be known from experimental data or from post-processing of two-dimensional computations results. This information is used to set the boundary locations, in the non-material front instabilities case, and, in both cases, to calculate the evolution of the diffusion coefficients.

We will discuss examples of mixings due to the Richtmyer-Meshkov instability occurring at the interface between the plastic shell and the fuel, on one hand, and to the ablation front instability occurring at the edge of the hot spot during its formation, on the other hand.

PACS Nos.: 52.57.Fg, 51.20, 42.27.Qb

Abstract No. C37

Modeling Turbulent Mixing in Inertial Confinement Fusion Implosions

Y. Srebro[1,2], D. Kushnir[2,3], Y. Elbaz[1,2], and D. Shvarts[1,2]
[1]*Ben-Gurion University, Beer-Sheva, Israel*
[2]*Nuclear Research Center, Negev, Israel*
[3]*Hebrew University, Jerusalem, Israel*

A series of high uniformity spherical implosion experiments has recently been conducted on the OMEGA laser system in the University of Rochester. In these experiments 3-15atm gas-filled plastic shells of diameter ~1mm were irradiated with 1ns square laser pulses of total energy ~20kJ. Fusion yields were measured experimentally to be 10-40% of one-dimensional numerical simulations' prediction, probably because of core-shell mixing.

Perturbations to these implosions include inner and outer surface roughness, beam-to-beam power imbalance and single-beam laser nonuniformity, which has been reduced to a minimal level using 1THz 2D-SSD.

Two-dimensional numerical simulations, describing the Rayleigh-Taylor growth of multimode perturbations during the deceleration-stage, were performed to determine mix region width. Reductions in the temporal neutron production rate, attained from the simulations assuming various levels of atomic mixing in the mixed region, were compared to experimental results for implosions with different convergence ratios.

Abstract No. C38

Turbulent Mixing Nuclear Burning in Type Ia Supernova Explosion Based on Bubble Statistical Mechanics

H. Takabe[1], S. Yamada[1], K. Kobayashi[1], A. Mizuta[1], and K. Nomoto[2]
[1]*Osaka University, Osaka, Japan*
[2]*University of Tokyo, Tokyo, Japan*

It is well known that Type Ia supernovae explode when the masses of white dwarfs become close to the Chandrasekhar limiting mass. This is the reason why the Type Ia explosion is used as a standard candle in the universe to determine, for example, the Hubble constant and dark energy. The scale of explosion has been well studied with one-dimensional code with some mixing model; however, the physical mechanism has not determined from the first principle, yet. There are many works to understand the physics with large scale computing based on hydrodynamics in two-dimension or mostly three-dimension in these days [1]. It seems, however, that the smaller scale fluctuation appears, the smaller the grid size, and it is still open question how the instability grows and evolves into nonlinear stage and enhance the energy release by nuclear reactions.

In the present report, we would like to model the growth of the Rayleigh-Taylor instability coupled with the Landau-Darrieus instability. In the nonlinear stage, we consider the statistical mechanics of the bubbles following the way developed by Don Shvarts[2] and estimate the increase in the nuclear burning rate due to the increase in the surface area of the burning wave in the form of fractal structure. This model is coupled with the multi-dimensional explosion code to predict the scale of explosion. Such work is expected to be used to identify the physical mechanism of the time evolution of the burning wave, which may change from deflagration wave to detonation wave.

Reference:

[1]W. Hillebrandt and J. Niemeyer, Ann. Rev. Astron. Astrophys. 38, 191-230 (2000)
[2]D. Shvarts et al, Physics of Plasmas 2. 2465 (1995).

Abstract No. C39

Turbulent Diffusion in Solar Type Star

N. Toqué
University of Montreal, Quebec, Canada

The shear layers with the instability of Kelvin-Helmoltz are common topics of the fluids mechanics. They are less common when they are assumed to be in a solar type star to partly explain the anomalies of abundances at the photosphere. Thanks to the rolling-up of the convective zone, the ionized species, which are produced in the radiative core of the star, such as the Lithium, have to migrate to the top of it. However, they are not enough detected at the photophere to validate the standard stellar model. So, it is assumed that at the vicinity of the tachoclyne, the goin-up of the light abundances is blocked by horizontal turbulence in shear layers.

This poster introduces the content of the numerical 2D code and the assumptions made to simplify the modelisation of the physical problem. It shows results which enforce the influence of the turbulence and quantify its effect on the going-up of the ionized species to the photophere of the star.

Abstract No. C40

Recent Computational Simulations of Rayleigh-Taylor Mix Layer Growth With a Multi-Fluid Model

E. Vold
Los Alamos National Laboratory, Los Alamos, NM

Recent results of computational simulations of the Rayleigh-Taylor mix layer are presented and discussed. Our previous work is summarized briefly comparing mix layer growth characteristics observed in different simulation modes including single fluid with initial density discontinuity, two-fluids with interface reconstruction and in a full multi-fluid dynamic approach. Recent comparisons under varying compressibility are presented showing negligible influence of compressibility on the mix layer growth rate. Using spectral analyses, perturbations intentionally introduced in the initial conditions are compared to long wave length perturbations introduced inadvertently in these initial conditions. The influence of these initial conditions on late time growth and growth rate are explored. The compressible multi-fluid model allows each fluid to have its own 'drift velocity' relative to the mass averaged fluid velocity. This can be applied in several ways within the mix layer to represent a real molecular mixing, a turbulent enhanced diffusive mixing, or an individual species 'sub-grid' convective drift flux. Examples of these in the Rayleigh-Taylor mix layer are discussed. Finally, we consider the combination of these factors which best matches the experimental results for mixing layer growth rates in incompressible experiments, and how these results may apply to compressible fluids.

Abstract No. C41

An Efficient and High Resolution Solver for the Two-Dimensional Numerical Simulation of the Richtmyer-Meshkov Instability

S. P. Wang, M. H. Anderson, J. G. Oakley, and R. Bonazza
University of Wisconsin at Madison, Madison, WI

The development of a consistent and fully conservative model and a corresponding efficient and high resolution solver for the numerical simulation of multicomponent or multifluid flows is presented. This theoretical and numerical work was developed to support the Wisconsin shock tube investigation of hydrodynamic issues related to the Richtmyer-Meshkov and Rayleigh-Taylor instabilities.

A consistent and fully conservative treatment of contact discontinuities is proposed for the simulation of compressible multifluid flows. The model is capable of capturing contact discontinuities with significantly reduced numerical uncertainties compared to conventional conservative models. Starting from the concept of total enthalpy conservation for the mixture, a new formulation is defined for the determination of the ratio of the specific heats of the mixture, and a governing equation in conservative form for pressure is obtained subsequently. With continuity equations for the individual components, a governing equation in conservative form for the ratio of specific heats of the mixture is easily derived. These two derived equations, combined with mass balance and momentum balance equations form the full system for the description of multifluid flows.

The conservative governing equations are then solved with an efficient and high resolution Godunov-type solver which is based upon the exact Pike(1993) Riemann solver. To improve the accuracy of the scheme, by preserving monotonicity of the variables at shock waves and contact surfaces, a Monotonic Upstream-Centred Scheme for Conservation Laws (MUSCL) technique for the data reconstruction of fluxes is used. Second order accuracy is achieved by using a piece-wise linear method and a piece-wise spline method is introduced to achieve higher-order accuracy especially useful for capturing contact discontinuities such as the Richtmyer-Meshkov instability (fourth order accuracy has been achieved even for non-uniform mesh sizes).

Several 1-D multifluid flows with both strong and weak shocks are simulated using the model. Comparisons of numerical results obtained by the proposed model, conventional models and exact solutions are made. They show that the proposed model and the methods are accurate, robust and generate oscillation-free solutions near material interfaces. Finally, the proposed model and method are extended to 2-D multifluid flow problems and compared to experimental Richtmyer-Meshkov instability growth measurements conducted in the University of Wisconsin shock tube.

Abstract No. C42

ALE Simulations of Turbulent Rayleigh-Taylor Instability in 2-D and 3-D

S. V. Weber, G. Dimonte, and M. M. Marinak
Lawrence Livermore National Laboratory, Livermore, CA

We have performed simulations of the evolution of the turbulent Rayleigh-Taylor instability with the ALE code HYDRA3, including interface reconstruction. The test problem is that of the “alpha group”, discussed in the presentation of Dimonte *et al.* at this conference. Perfect γ=5/3 gases of densities 1 and 3 are accelerated by constant gravity. The initial interface perturbation is a random spectrum of modes in the range $32 \leq n \leq 64$. We employed meshs of 256 x 512, 512 x 1028, and 1028 x 2048 in two dimensions (2-D) and 128^2 x 512 and 256^2 x 512 in 3-D. The shortest seed modes have only 4 zones/wavelength at the nominal (coarsest) resolution. Consequently, linear growth is suppressed by under-resolution, and is not fully converged even at the highest resolution. However, as the growth transitions toward turbulence, turn-over of the growth rate in the 2-D simulations occurs earlier and at smaller amplitude with higher resolution. Results for mixing layer growth in the self-similar ~ gt^2 regime and sub-structure of the mixing layer will be discussed.

1 M. Marinak *et al*., *Phys. Plasmas* **3**, 2070 (1996).

This work was performed under the auspices of the U.S. Department of Energy by the University of California Lawrence Livermore National Laboratory under contract No. W-7405-Eng-48.

Abstract No. C44

Study of Turbulent Gravitational Mixing at Large Density Differences Using Direct 3D Numerical Simulation

Yu. V. Yanilkin, V. P. Statsenko, S. V. Rebrov, N. I. Selchenkova, O. G. Sin'kova,
A. L. Stadnik and A. Ya. Uchayev
Russian Federal Nuclear Center – VNIIEF, Sarov, Russia

3D hydrocode TREK is used for numerical study of turbulence evolution in the field of gravity at a plane interface between two incompressible fluids (gases) with a large density difference, $3 \leq \rho_2/\rho_1 \leq 40$.

The computations were conducted on a fine computational grid with parallelization on several tens of processors.

The computed data was processed (averaged) in order to obtain moments of hydrodynamic values: diagonal components of Reynolds tensor (turbulent energy), turbulent flows, density profiles and mean-square pulsation. The resultant values are compared to predictions with phenomenological turbulence models and known experimental data.

The dissipation problems in these computations are disscussed.

A one-point function of concentration probability density is constructed using processed results of the direct numerical simulation. The results are compared to computed data obtained elsewhere.

A fractal analysis of turbulent vortex scales is also conducted, which demonstrates that in the turbulent mixing zone the fractal size does not essentially change and is close to the measured value and the value from 3D computations by other investigators.

Abstract No. C46

Development and Validation of a 2D Turbulent Mix Model

D. L. Youngs
Atomic Weapons Establishment, Aldermaston, United Kingdom

A 2D turbulence model based on the equations of multiphase flow with turbulent diffusion effects added, is used to model mixing by Rayleigh-Taylor and Richtmyer-Meshkov instabilities in situations where the mean flow is two dimensional. For simple 1D flows it is relatively easy to check that the turbulence model gives satisfactory mix distributions. However, this is much more difficult to do for the case when the mean flow is two dimensional. In order to validate the 2D turbulence model, results are compared to the tilted-interface Rayleigh-Taylor mixing experiments presented by J.M.Holford at this meeting and the 'chevron' shock tube experiments presented by A.V.Smith at this meeting. Experimental measurements of mix distributions are difficult to make in 2D. Hence 3D Large Eddy Simulation is able to make a very useful contribution. The TURMOIL3D code is used to perform 3D simulations which give a satisfactory match to the experimental results. The mix distributions obtained by averaging the calculational results in the third dimension may then be compared directly with the 2D turbulence model results.

At present 3D LES is often not practical for complex real applications. However, 3D LES for simplified problems does have a very useful role in helping to validate the turbulence models which can be applied to complex problems.

Abstract No. C47

Preliminary Results of DNS and LES Simulations of Self-Similar Variable Acceleration RT-Mixing Flows

D. L. Youngs[1], X. Silvani[2], J. Magnaudet[2], and A. Llor[3]
[1]*Atomic Weapons Establishment, Aldermaston, United Kingdom*
[2]*Institut de Mécanique des Fluides de Toulouse, Toulouse, France*
[3]*Commissariat à l'Energie Atomique, Bruyères-le-Châtel, France*

The importance of self-similar variable acceleration RT flows (SSVARTs) for the design an calibration of turbulent mixing models has been shown in an other presentation to the present workshop.

Because experimental results on SSVARTs are not, and will probably not be available in any close future, we are currently investigating such flows by means of DNS and LES.

This first presentation of our preliminary results will be devoted to discussing the technical issues (compressibility effects, subgrid models, initial conditions, mesh size, Atwood number...) whose influence must be carefully controled due to the lack of experimental data. The behaviour of the observed growth rates and large scale turbulent structures will also be analysed.

Abstract No. C48

Shock–Planar Curtain Interactions: Strong Secondary Baroclinic Deposition and the Emergence of Coherent and Random Vortex Projectiles (*VPs*) and Decaying Stratified Turbulence

S. Zhang and N. J. Zabusky
Rutgers, State University of New Jersey, Piscataway, NJ

We continue our previous investigation [1] of the interaction of a shock with a planar, inclined curtain (s/f/s) to higher Mach numbers, (M=1.5, 2.5 & 5.0), longer times (epochs) and alternate configurations in 2D and 3D (e.g. a fast/slow/fast or (f/s/f)). In all cases, the qualitative features may be explained in terms of opposite-signed vortex layers (deposited by shock waves in epoch 1) that move in opposite directions and collide at one boundary to form a complex *vortex* ***d****ouble* ***l****ayer* (***VDL***) that traverses the shock tube. (This causes early-time ``breakthrough'' [1]). We focus on longer evolution times where, eventually, the transversely moving VDLs collide with the opposite horizontal boundary and evolve into upstream & downstream moving stratified *vortex* ***p****rojectile****s*** (***VPs***) [2]. In 2D, we compare these near-stationary, inhomogeneous coherent structures to the Lamb-Chaplygin vortex of 2D homogeneous flow. We also display and quantify: (1) *strong* non-acoustic circulation generation via baroclinic processes during traversal of the VDL across the shock tube (epoch 2); and (2) evolution and decay (epochs > 2). of a stratified turbulent domain that arises between the two dominant VPs. We compare with images from Sturtevant' s 1985 experiments and comment on the unusual advantages of this configuration as well as the convergence of results under mesh refinement.

---

[1] Yang, X. , N.J. Zabusky, and I-L. Chern. Phys. Fluids A 2(6),892-895, **1990.**
"Breakthrough" via Dipolar-Vortex/Jet Formation in Shock-Accelerated Stratified Layers.
[2] N.J. Zabusky and S-M. Zeng, J. Fluid Mechanics 362, pp. 327-346, **1998**.
Shock cavity implosion morphologies and vortical projectile generation in axisymmetric shock-spherical F/S bubble interactions.

---

*This work was supported mainly by DOE (Grant No. DE-FG0293ER25179.A000) and monitored by Dr. Daniel Hitchcock. Additional support was provided by SROA program and the Jacobs Chair of Applied Physics at Rutgers University

Abstract No. C49

Rapid Turbulization Arising from Vortex Double Layers in Interactions of "Complex" Blast Waves and Cylindrical and Spherical Bubbles

S. Zhang[1], Y.-G. Kang [2], K. Nishihara, N. J. Zabusky[1], and H. Kim[2]
[1]*Institute of Laser Engineering, Osaka, Japan*
[2]*Rutgers, State University of New Jersey, Piscataway, NJ*

[1]We examine the interaction of both cylindrical and spherical bubbles and a *complex* blast wave which consists of an approaching shock/contact discontinuity/shock . Such configurations arise following a supernova explosion, e.g. SN 1987A where a complex blast wave is presently approaching a high density ring ("inner circumstellar"), and may lead to rapid onset of turbulence on the *upstream* part of the bubble[2], not an occurrence at low Mach numbers and density ratios[3]. The mixing in this turbulent domain will affect the electromagnetic radiation processes. Using PPM[4], we examine a parameter domain containing SN 1987A parameters to validate the occurrence of this process which is related to shock reverberations and vortex double layers and their rapid instabilities.

*At Rutgers, this work was supported mainly by DOE (Grant No. DE-FG0293ER25179.A000) and monitored by Dr. Daniel Hitchcock. Additional support was provided by the SROA program and the Jacobs Chair of Applied Physics at Rutgers University.[2]Laser Plasma Laboratory, Dept. of Materials Sci. & Eng., Kwangju Institute of Science and Technology, 1 Oryong-dong, Puk-gu, Kwangju, Korea

---

[1] Y-G Kang, et al , "A novel experiment on the blast wave-sphere interaction using a laser produced plasma" Phys. Rev E , submitted May 2001.

[2] K.J.Borkowski, J.M. Blondin and R. McCray. Astrophys J. **477**, 281-293, 1997

[3] N.J. Zabusky and S-M. Zeng, J. Fluid Mechanics **362**, 327-346, 1998.

[4] M. Blondin et al, Code VH-1 , NCSU. A lagrangian remap code based on PPM.

Abstract No. C50

Simulations of a Shock-Accelerated Gas Cylinder and Comparison with Experimental Images and Velocity Fields

C. A. Zoldi[1,2], K. Prestridge[1], P. M. Rightley[1], and R. F. Benjamin[1]
[1]*Los Alamos National Laboratory, Los Alamos, NM*
[2]*State University New York at Stony Brook, Stony Brook, NY*

The evolution of a cylinder of SF_6 gas accelerated by a Mach 1.2 shock wave is studied both experimentally and computationally. Images of the initial conditions and the time evolution of the cylinder are obtained from the experiment. Velocity measurements are determined at one time using Particle Image Velocimetry. Using an image of the experimental initial conditions, 2D simulations are performed with the adaptive mesh Eulerian code, RAGE. Although qualitative agreement is achieved, significant differences exist in quantitative measurements. The linear dimensions of the cylinder measured over time are approximately 15% smaller in the simulation than in the experiment. In addition, although the directions of the velocity vectors are similar, the peak magnitude of the velocity is a factor of three larger in the simulation. The effect of turbulent mixing, which has not been considered in previous analyses, is examined using the BHR K-S-a-b mix model recently added to the RAGE code.

PACS No.: 47.20.Ma

Abstract No. C51

Turbulent Flow Simulations of Two Fluids Moving with Different Laws of Acceleration

V. I. Kozlov, A. N. Razin, and I. V. Sapozhnikov
Russian Federal Nuclear Center – VNIIEF, Sarov, Russia

With Dimonte tests as an example, turbulent mixing (TM) evolution is discussed that results from Rayleigh-Taylor instability at the interface between two fluids. In these tests, an ampoule with two molecularly immiscible fluids (freon and water) was accelerated while the acceleration law being varied in these tests.

The VIKHR code was used for the numerical simulations of the Dimonte's tests. This VIKHR technique includes V.V. Nikiforov's semiempirical model of turbulent mixing. This model treats various characteristics of a turbulent field, like the kinetic energy of turbulence, the turbulence energy dissipation rate, the average square density fluctuations and the turbulent mass transfer velocity.

The calculations were performed with a sequence of refined grids with different initial TM zone widths for increasing, decreasing, pulse and constant accelerations of the ampoule (the acceleration laws were the same as those given in the paper by Dimonte). TM zone growth laws versus the ampoule's path and the initial TM zone width have been obtained. The numerical results have been shown to be in good agreement with the measured data provided additional constrains have been included in the V.V. Nikiforov's model. These constraints can be interpreted as effective treatment of turbulent motion energy being transferred to the interface energy of the boundary between the fluids that are molecularly immiscible.

References

Dimonte Guy, Schneider Marilyn. Turbulent Rayleigh-Taylor instability experiments with variable acceleration // Physical Review E, 1996, v. 54, p.3740-3743.

Abstract No. C52

The Behaviour of Velocity Variance Resulting from Turbulent Mixing Zone-Shock Interaction

V. I. Kozlov and A. N. Razin
Russian Federal Nuclear Center – VNIIEF, Sarov, Russia

Turbulent mixing (TM) caused by Richtmyer-Meshkov instability at an interface between two gases with different densities is discussed. VIKHR code simulations of shock tube tests by Poggi et al have been performed. The feature of these tests is that the fluid's instantaneous mass velocities were measured by Doppler's laser anemometer.

The VIKHR code includes the 1D version of the semiempirical TM model suggested by V.V. Nikiforov that treats eddies' anisotropy. The VIKHR technique permits to precisely calculate various quantities of a turbulent field, like for instance, the average square variance of different velocity components and the average square density fluctuations, along with the flow's gas-dynamical parameter distributions.

The calculations gave TM zone width and location versus time. The temporal evolution of the average square axial velocity variance was also obtained for several Eulerian points. No special calculation algorithm for turbulence quantities was used at the shock front in these calculations.

On the whole, there is satisfactory agreement with the test data by Poggi et al. Meanwhile, behind the front of the first wave (whose intensity is the highest) reflected from the tube's dead end is approximately two time higher than that measured in the tests. (Note that the same quantity calculated by Souffland et. al. exceeds the observed value by an order of magnitude). These results have shown that the correlations used in the Nikiforov's model to treat shock wave-turbulent field interactions, need to be improved.

References

1. *F. Poggi, M.-H. Thorembey, G. Rodriguez.* Physics of Fluids, v. 10, _ 11, 1998, pp. 2698-2700.
2. *D Souffland, O. Gregoire, S. Gauthier, F. Poggi, J.M. Koenig.* 6th International Workshop on the physics of compressible turbulent mixing (Marseille, France), 1997, pp. 486-491.

Abstract No. C53

An Assessment of Multi-Velocity Versus Single Velocity in a Multi-Component Model of Turbulent Mixing

D. E. Eliason, W. H. Cabot, and Y. Zhou
Lawrence Livermore National Laboratory, Livermore, CA

Turbulent mixing of the fluids in a multi-component system is of interest in situations such as inertial confinement fusion (ICF) and core-collapse supernovae [1]. We report results of a project to include a model of turbulent mixing in a multi-component hydrodynamics and physics model called KULL, which is used for ICF. Because KULL is a complex, multi-dimensional model, we have developed a simplified, one-dimensional version called sKULL to speed-up the development of the turbulent mixing model.

Of primary interest in the development of a turbulent mixing model for a multi-component fluid is the question of whether it is necessary to allow each component of the fluid to retain its own velocity. A recently developed model of turbulent mixing, consisting of an extended buoyancy-drag model and two-equation turbulent transport model [2], treats all components of the fluid as if they had the same velocity. In contrast, multi-velocity turbulent mixing models allow separate velocities for each component of the fluid [3]. However, the necessity to carry separate velocities for each component of the fluid greatly increases the memory requirements and complexity of the computer implementation. We will report results of a comparison between single velocity and multi-velocity turbulent mixing models in sKULL with the intention of answering the question of whether the full multi-velocity treatment is really necessary.

This work was performed under the auspices of the U.S. Department of Energy by the University of California Lawrence Livermore National Laboratory under contract No. W-7405-Eng-48.

[1] Remington, B.A., D. Arnett, R.P. Drake, and H. Takabe, Modeling Astrophysical Phenomena in the Laboratory with Intense Lasers, *Science*, **284**, 1488 (1999).

[2] Zhou, Y., G. Zimmerman, and E.B. Burke, submitted to *Phys. Rev. E.,* (2001).

[3] Youngs, D.L., *Laser & Particle Beams* **12**, 725 (1994).

Abstract No. C54

High Order Numerical Methods for the 2D Richtmyer-Meshkov Instability

W.-S. Don[1], D. Gottlieb[1], L. Jameson[2], and C.-W. Shu[1]
[1]*Brown University, Providence, RI*
[2]*Lawrence Livermore National Laboratory, Livermore, CA*

The primary goal of this presentation is to examine several numerical methodologies with high order accuracy for the investigation of the two dimensional (and eventually three dimensional) Richtmyer-Meshkov instability. The high order schemes employed are the Spectral methods and the high order Weighted Essentially Non-Oscillatory (WENO) finite difference scheme. We will briefly discuss several important aspects of the numerical schemes when applied to the Euler equations. Multi-species full Navier-Stokes equations will be implemented in the near future.

A series of numerical simulations are carried out to investigate the convergence properties of the schemes and long time behavior of the interface evolution. Numerical results from the simulation of shock interaction with a single mode perturbation of interface separating the heavy (Xenon) to light (Argon) gases will be presented with various interface thickness and different Mach numbers. It can be observed that the large and median scale structures such as the spike and bubble, transmitted shock, shocked-interface velocity and shock triple point obtained by the different schemes are basically in excellent agreement with each other and with available experimental data. Also convergence studies had been made. Some minor discrepancies of the finest scale structures along the gaseous interface, as can be expected for numerical simulations of the Euler equations with this sensitive nature, are observed.

This work was performed under the auspices of the U.S. Department of Energy by the University of California Lawrence Livermore National Laboratory under contract No. W-7405-Eng-48.

Abstract No. C55

Mixing Due to the Rayleigh-Taylor Instability

A. M. Dimits
Lawrence Livermore National Laboratory, Livermore, CA

Several aspects of mixing due to the Rayleigh-Taylor (RT) instability are investigated.

Analysis of 3D multimode simulations using the PPM code [D.H. Porter and P.R. Woodward, Astrophys. J. Suppl. 93, 309 (1994), and references therein.] show that there are regions of the parameter space of the initial conditions in which the growth rate is independent of variations in the initial conditions. The simulated growth rates are found to increase as the Navier-Stokes viscosity is increased. It is investigated whether this couterintuitive result is due to the suppression of material mixing at the molecular level for larger viscosities.

Analyses of two RT experiments, one in which water is accelerated by a compressed gas (E.E. Meshkov and N.V. Nevmerzhitsky, Proc. 3rd Int. Workshop. on the Physics of Compressible Turbulent Mixing, 1991) and one in which an interface between gases of different density is decellerated in the post-shock region of a shock in an electromagnetic shock tube (A.M. Vasilenko et al., ibid.), are presented. Direct compressibility effects on the RT growth are shown to be negligible in the former. Various effects of the expansion of the gases in the region of the interface on the RT growth rates are investigated for the latter experiment, both analytically and with 1D simulations. These effects are found to be insufficient to reconcile the growth rates observed in the Vasilenko et al. experiments with some other experimental and simulation results.

This work was performed under the auspices of the U.S. Department of Energy by the University of California Lawrence Livermore National Laboratory under contract No. W-7405-Eng-48.

Abstract No. C56

Transition Stages of Rayleigh-Taylor Instability Between Miscible Fluids

A. W. Cook and P. E. Dimotakis
Lawrence Livermore National Laboratory, Livermore, CA
California Institute of Technology, Pasadena, CA

Direct Numerical Simulations are presented of three-dimensional, Rayleigh-Taylor instability between two incompressible, miscible fluids, with a 3:1 density ratio. Periodic boundary conditions are imposed in the horizontal directions of a rectangular domain, with no-slip top and bottom walls. Solutions are obtained for the Navier-Stokes equations, augmented by a species transport-diffusion equation, with various initial perturbations. Three of the simulations (Cases A, B and C) were performed at a resolution of 256 x 256 x 1024 grid points, and the fourth simulation (Case D) was performed at a resolution of 512 x 512 x 2040 grid points. The A, B and C cases achieved outer-scale Reynolds numbers, based on height and rate of growth of mixing-zone, in excess of 3000; Case D achieved an outer-scale Reynolds number of 5500. Initial diffusive growth is captured in the simulations. The onset of nonlinear growth is as predicted by linear stability theory. Following the diffusive stage, growth rates are found to depend on the initial perturbations through the end of the simulations. Mixing is found to be even more sensitive to initial conditions than growth rates. Taylor microscales and Reynolds numbers are anisotropic throughout the simulations. Improved collapse of many statistics is achieved if the height of the mixing zone, rather than time, is used as the progress variable. Mixing has dynamical consequences for this flow, since it is driven by the action of the imposed acceleration field on local density differences.

This work was performed under the auspices of the U.S. Department of Energy by the University of California Lawrence Livermore National Laboratory under contract No. W-7405-Eng-48.

Abstract No. C57

CALE Simulation of Richtmyer-Meshkov Experiments at High Mach Number

A. Miles[1,2], J. Edwards[2], G. Glendinning[2]
[1]*Lawrence Livermore National Laboratory, Livermore, CA*
[2]*University of Maryland, College Park, MD*

Richtmyer-Meshkov instability experiments, recently conducted on the Omega laser, are simulated via the C-based Arbitrary Lagrangian-Eulerian (CALE) hydrodynamics code in 2D. In the experiments, a high Mach number shock ($M \approx 10$) is incident on a corrugated plastic-foam interface ($ka = 0.92$). The ratio of plastic to foam density is 12:1. After passage of the incident shock, the perturbation amplitude grows in time. Computational grids initially rectangular and conforming to the initial amplitude perturbation are both considered, as are zoning effects. Discrepancies between the experiment and simulation are considered, including the growth rate at early times, the post-shock amplitude, and the shock-interface proximity as the transmitted shock propagates through the foam. A modified input velocity source is presented which results in a time-dependent growth rate that agrees with the experimental observations much better than does the original source, which is produced by a 1D Lasnex simulation. Various EOS models are used, and their predictions compared.

THEORETICAL ABSTRACTS

Abstract No. T1

Nonlinear Evolution of Unstable Fluid Interface

S. I. Abarzhi
State University of New York at Stony Brook, Stony Brook, NY

We study the nonlinear evolution of the fluid interface generated by the Richtmyer-Meshkov instability. For the first time we find the theoretical solutions, which capture the interplay of harmonics in the nonlinear dynamics of 3D and 2D flows. A new type of the evolution of the bubble front in RMI is discovered [1]. It is shown that the nonlinear RM bubbles flatten in time and the shapes of Rayleigh-Taylor and Richtmyer-Meshkov bubbles differ significantly.

To perform the multi-mode analysis for the RM flow, we generalized the method developed in [2] for RTI, and based our approach on symmetry theory. From the conservation aws we derived a dynamical system governing the local dynamics of the nonlinear bubble. To capture the interplay of harmonics in the local dynamics, we extended the functional space, involved all bubbles allowed by symmetry of the flow, and found a family of regular asymptotic solutions. The physically dominant solution in this family, i.e. the fastest stable one, corresponds to a flattened bubble, not to a bubble with finite curvature as in [3].

The theory reveals deficiency of previous theoretical approaches in [3], explains existing experiments, and establishes control parameters to be monitored in experiments.

1.S.I.Abarzhi, Nonlinear evolution of unstable fluid interface, Phys.Rev.Lett. submitted
2.S.I.Abarzhi, PRL89, 1332 (1998)
3.J.Hecht, U.Alon, D.Shvarts, Phys.Fluids 6, 4019 (1994); N.A.Inogamov, Sov.Phys.JETP 80, 890 (1995); K.O.Mikaelian, Phys.Rev.Lett.80, 508 (1998); Q.Zhang, Phys.Rev.Lett. 81,3391 (1998); S.Abarzhi, Phys.Fluids 12, N12 (2000).

Abstract No. T2

Nonlinear Asymptotic Solutions to RT and RM Problems for Fluids With Close Densities

S. I. Abarzhi
State University of New York at Stony Brook, Stony Brook, NY

We consider the interface dynamics in the Rayleigh-Taylor and Richtmyer-Meshkov instabilities for fluids with close densities, the Atwood number $A<1$. We find the analytical solutions to the equations governing the interface dynamics in 3D and 2D (conservation laws, potential approximation), and analyze their regular and singular asymptotic behavior. First we derive a nonlinear solution of the Layzer-type, i.e. single-mode solution [1]. For this solution the normal component of velocity is discontinuous, and the flux of mass through the interface is significant. We resolve this paradox and find a multi-mode nonlinear solution with NO FLUX of MASS through the interface. This solution is the fastest one in the family of asymptotic solutions to the conservation laws [1].

The theory [1] determines parameters to distinguish between the Layzer-type solution and the nonlinear solution with NO FLUX. In RTI the bubble with NO FLUX is in few times narrower than the Layzer-type bubble, while in RMI the bubble with NO FLUX is flattened. The singular asymptotes (spikes) are also analyzed, and the influence of vorticity on the spike motion is evaluated. We conclude that there is a non-trivial dependence on the Atwood number for the parameters of the nonlinear motion (such as velocity of the bubble or spike) in either RTI or RMI cases. The RT/RM mixing process is discussed.

1. S.I.Abarzhi, The dependence of the nonlinear RT/RM motion on the Atwood number, in preparation, 2001.

Abstract No. T3

Turbulent Mixing in RTI as Order-Disorder Process

S. I. Abarzhi
State University of New York at Stony Brook, Stony Brook, NY

The cascades of energy and the dynamics of large-scale coherent structure are fundamental issues in the problem of Rayleigh-Taylor turbulent mixing. The large-scale structure is a periodic array of bubbles and spikes in the plane normal to the direction of gravity. We study dynamics of this structure based on group theory, and analyze transitions associated with the growth of length scale of the flow. In the limiting case of 2D flow, the scale growth occurs as a doubling of the spatial period, in agreement with Sharp and Wheeler model, and a stable observable coherent structure appears under this transition. In contrast, for a 3D flow the growth of length scale leads eventually to anisotropy of the flow in the plane normal to the direction of gravity and no isotropic structure occurs. We see that in RT turbulent mixing a balance between the inverse and direct cascades is required to keep isotropy of the flow. These two processes may lead in a generation of an internal structure with hexagonal symmetry and with close packing in the plane normal to the direction of gravity. The concept of self-similarity in the RT mixing is discussed.

Abstract No. T4

A New Turbulent Two-Fluid RANS Model for KH, RT and RM Mixing Layers

P. Bailly and A. Llor
Commissariat à l'Energie Atomique, Bruyères-le-Châtel, France

Our aim is to develop an accurate turbulent mixing model for combined RT, RM and KH type of instabilities, with arbitrarily variable accelerations.

Following the recent analysis of the RT and RM cases by G. Dimonte, and of the self-similar variable acceleration RT flows (SSVARTs) in an other presentation to the present workshop, we have considered as crucial to capture the following physical aspects by the corresponding model features:

- the directed transport by a two-fluid approach,
- the correct buoyancy force by including mass transfer between the fluids,
- the turbulence diffusion by including most of the standard k-ε features,
- the geometrical aspects by consistent closures of the length scales.

This yielded a two-fluid two-turbulence model whose specific and original features will be discussed. 1D numerical results of this model applied to self-similar flows will be presented.

Abstract No. T5

Super-Exponential Rayleigh-Taylor Flow

R. E. Breidenthal
University of Washington, Seattle, WA

A new class of forced, self-similar turbulence is proposed. In it, the rotation period of the large-scale vortices is forced to decrease by a constant factor at each rotation. This is achieved by imposing an e-folding time scale on the flow that decreases linearly with time. Based on experimental results in analogous flows, super-exponential turbulence may exhibit extraordinarily low entrainment and mixing rates. One application is in inertial-confinement fusion, where super-exponential acceleration may play a useful role in achieving ignition. It is shown that super-exponential flows are the mirror image of unforced turbulence, and both are members of a closely related family of self-similar turbulence.

Abstract No. T7

Theoretical Methods for Determination of Mix

B. Cheng[1], J. Glimm[2,3], and D. H. Sharp[1]
[1]*Los Alamos National Laboratory, Los Alamos, NM*
[2]*State University of New York at Stony Brook, Stony Brook, NY*
[3]*Brookhaven National Laboratory, Brookhaven, NY*

We present a theoretical description of the growth of a planar 3D mixing layer due to Rayleigh-Taylor (RT) or Richtmyer-Meshkov (RM) instabilities. The methods yield agreement with all known experiments. They also possess advantageous theoretical features, such as real characteristic speeds and improved mixed cell EOS.

The first method is a bubble merger model, validated by comparison to experiments of Smeeton and Youngs and of Dimonte et al. The model is based on a renormalization group fixed point calculation, incorporating the self similar behavior of RT instability. The second method is based on the dynamic motion of the RT center of mass; it couples the bubble and spike mixing zone edges, and predicts the RT spike growth as a function of the RT bubble growth. The third method is a drag buoyancy model, with a phenomenological drag coefficient, set to agree with the RT edge motion models above.
This model predicts RM edge motion. The final method is a mix model, i.e. a set of averaged equations, with prediction of the behavior of mixed average flow quantities such as volume fraction, as a function of the mixing zone edges.

PACS Nos.: 47.20Bp, 47.52+j

Abstract No. T8

Modeling Radiation Effects in Mixing Layers

T. Clark and F. Harlow
Los Alamos National Laboratory, Los Alamos, NM

Radiative heat transport and resulting material phase changes can have a pronounced effect on the evolution of Rayleigh-Taylor and Richtmyer-Meshkov mixing layers. For sufficiently high temperature differences across the materials in these layers, the radiation effects may significantly alter the rate of growth of these mixing layers. Direct numerical simulation of these processes is generally not possible for practical circumstances due to the rapid growth of fine-scale structures as well as the inherent stochasticity of the mixing process. Consequently, we are developing a turbulent mix model that incorporates the effects of radiative heat transfer and ablation in a computationally tractable fashion. The model under development describes the ablation of the cold material as a surface phenomenon in which a thin skin of the cold material is ablated by the radiation through a thin skin of the hot material. As a first approximation we have assumed that only two materials are present. Thus after the cold material is ablated it is indistinguishable from the hot material. The goal of the model is to derive a model with sufficient predictive power to determine the mixing layer growth rates, and to distinguish the circumstances under which the ablation process (i.e., "fire-polishing") will overwhelm the tendency towards hydrodynamic mixing intrinsic to these mixing layers. We will discuss both model development and computed results.

PACS Nos.: 47.27.Eq, 47.27.Te, 47.55.Kf, 47.70.Mc

Abstract No. T9

A Model for Instability Growth in Accelerated Solid Metals

J. D. Colvin[1], M. Legrand[2], B. A. Remington[1], G. Schurtz[2], and S. V. Weber[1]
[1]*Lawrence Livermore National Laboratory, Livermore, CA*
[2]*Commissariat à l'Energie Atomique, Bruyères-le-Châtel, France*

We present the derivation of an approximate analytical dispersion relationship for elastic-plastic acceleration-driven instability growth. We have applied this model, where applicable, to perturbation growth measurements made in three separate types of experiments: HE-driven planar Al plates, HE-driven implosions of steel cylinders, and planar Al foils driven indirectly by LLNL's Nova laser. We have also compared the analytical modeling with 2-D simulations. We find that for the moderate strain rates of the HE experiments the simulations and analytical modeling agree with each other and with the data, with an equivalent plastic viscosity consistent with the von Mises criterion. For the high strain rates of the Nova experiments, on the other hand, the viscosity needed in the analytical model to match the data is about one-tenth of what the simulations predict. This initial material weakening, followed by a relaxation to a strengthened state, is consistent with a "relaxation model" in which plastic flow at high strain rate is confined to discrete shear bands. We also derive a characteristic scale for the plastic viscosity and find under what conditions the growth is independent of initial amplitude.

This work was performed under the auspices of the U.S. Department of Energy by the University of California Lawrence Livermore National Laboratory under contract No. W-7405-Eng-48.

Abstract No. T10

Toy Models for the Growth Rate of Rayleigh-Taylor Instability

S. B. Dalziel
Cambridge University, Cambridge, United Kingdom

There remains an on-going debate about one of the most basic characteristics of the instability: the growth-rate coefficient α. In many respects this is surprising, but at the same time it is perhaps inevitable. After undergoing a period of convergence between experiments and numerics for values of this important quantity, some recent studies show a continued decline in the growth rate for some numerical models, at the same time as the models offer overall improvement in the resolution and quality of results. This paper makes use of a range of toy models for Boussinesq Rayleigh-Taylor instability in an effort to understand and reconcile the issues.

The paper begins by returning to the classical Layzer model and reconciles it with the behaviour of other buoyancy-driven flows, before exploring the possible growth rates it predicts for the developing instability. Attention is then turned to a shell model for the instability. Shell models are normally used to help explain the behaviour of turbulence in homogeneous fluids subject to forcing at low wavenumbers. In this study, a very simple model is adapted to take account of buoyancy-driven forcing over the entire range of available scales. The results offer an interesting comparison with Rayleigh-Taylor instability, and offer insight into the behaviour that determines the growth rate α.

Abstract No. T11

A General Buoyancy-Drag Model for the Evolution of the Rayleigh-Taylor and Richtmyer-Meshkov Instabilities

Y. Elbaz[1,2], Y. Srebro[1,2], O. Sadot[2], and D. Shvarts[1,2]
[1]*Ben-Gurion University, Beer-Sheva, Israel*
[2]*Nuclear Research Center - Negev, Israel*

The growth of a single-mode perturbation is described by a buoyancy-drag equation, which describes all instability stages (linear, non-linear and asymptotic) at time-dependant Atwood number and acceleration profile. The evolution of a multi-mode spectrum of perturbations from a short wavelength random noise is described using a single characteristic wavelength. The temporal evolution of this wavelength allows the description of both the linear stage and the late time self-similar behavior.

The model includes additional effects, such as shock compression and spherical convergence. In addition to the mixing zone fronts, the internal density profile of the mixing region has been investigated using a simple diffusion-like model.

Model results are compared to full 2D and 3D numerical simulations and shock-tube experiments of random perturbations, studying the various stages of the evolution.

Abstract No. T12

3D Rayleigh-Taylor and Richtmyer-Meshkov Single-Modes

N. A. Inogamov[1], A. M. Oparin[2], M. Tricottet, and S. Bouquet[3]
[1]*Landau Institute for Theoretical Physics, Moscow, Russia*
[2]*Institute for Computer Aided Design, Moscow, Russia,*
[3]*Commissariat à l'Energie Atomique, Bruyères-le-Châtel, France*

We study 3D topology of Rayleigh-Taylor (RT) and Richtmyer-Meshkov (RM) single-modes. 3D case is much richer than 2D case. For example, in addition to the well-known bubbles and jets, 3D saddles appear. Saddles are points of stagnation - as are the tips of bubbles and jets - and, therefore, they play the same important role. We present a 3D analytic description of the interface as a whole,from bubbles to jets. Hexagonal, square and triangular lattices of bubbles are investigated both analytically and numerically.

Abstract No. T13

Rayleigh-Taylor Instability for Compressible and Incompressible Media

N. A. Inogamov[1,2], M. Tricottet[2], A. M. Oparin[3], and S. Bouquet[2]
[1]*Landau Institute for Theoretical Physics, Moscow, Russia*
[2]*Commissariat à l'Energie Atomique, Bruyères-le-Châtel, France*
[3]*Institute of Computer-Aided Design, Moscow, Russia*

After a brief Reminding of the role played by Rayleigh-Taylor Instabilities in astrophysics (Type II supernovae, supernovae remnants, insterstellar clouds driven by ablation), some developments concerning instability criteria, linear growth for compressible media will be presented.

Then, the 3D structure of non-linear single-mode instability interfaces is investigated, and proves to be much richer than in 2D. Accumulation points are analytically studied, up to high-order development, for arbitrary long times - including asymptotic behaviour.

Finally, some comparisons will be effected to numerical simulations with the predictions concerning this points and some shape factor.

PACS Nos.: 47.20.Ma, 47.40.Nm

Abstract No. T14

Three Dimensional Multi-Mode Rayleigh-Taylor and Richtmyer-Meshkov Instabilities at All Density Ratios

D. Kartoon[1,2], D. Oron[1], L. Arazi[3], A. Rikanati[1,2], U. Alon[4], and D. Shvarts[1,2]
[1]*Nuclear Research Center Negev, Israel*
[2]*Ben-Gurion University, Beer-Sheva, Israel*
[3]*Tel-Aviv University, Tel-Aviv, Israel*
[4]*Weizmann Institute, Rehovot, Israel*

The three dimensional turbulent mixing zone (TMZ) evolution was studied using two approaches. First, an extensive numerical study was made, investigating the growth of a random three dimensional (3D) perturbation under Rayleigh-Taylor and Richtmyer-Meshkov unstable conditions in a wide range of density ratios. Following that, a new 3D statistical model was developed based on the same logic as the 2D statistical model – binary interactions between bubbles growing at a 3D asymptotic rate.

The results for the growth rate of the 3D bubble front attained from the theoretical model show good agreement with both the experimental [1] and the 3D simulation results. The simulation results also agree well with the experimental spike front growth rate. Further approval for the theoretical model was gained by detailed comparison of the bubble size distribution to the numerical simulations, and by comparison to a 3D multi-mode drag-buoyancy model [2].

The good agreement between the theoretical models, the 3D numerical simulations and the experimental results, together with the clear differences between the 2D and the 3D results, suggest that the discrepancies between the experiments and the previously developed models are due to geometrical effects.

[1] G. Dimonte, Phys. Plasmas 6, 2009 (1999).
[2] D. Oron, L. Arazi, D. Kartoon, A. Rikanati, U. Alon, D. Shvarts, Phys. Plasmas 8 (June 2001)

Abstract No. T15

Stability of Diverging Shock Waves

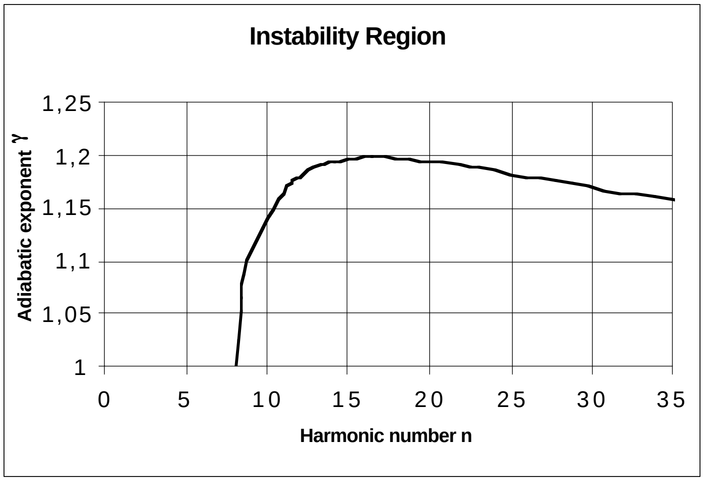
V. M. Ktitorov
Russian Federal Nuclear Center – VNIIEF, Sarov, Russia

For the first time the self-similar approach was successfully applied to the stability problem of diverging shock waves when calculating evolution of small perturbations of self-similar point blast wave. The new sort of Rayleigh-Taylorinstability was found in this case when $\gamma<1.2$ (See instability region on Fig.1 /1/). The results of calculations were later proved in laboratory experiment /2/ as well as in computer simulation /3/.

In this paper we summarize the solutions of stability problems of various types of diverging shock waves (both spherical and cylindrical) which were obtained with the help of the self-similar approach. The following cases are considered:
Point blast wave in non-ideal gas and in the gas which density depends on radius,
Reflected from the center converging shock wave.

We calculate the values of complex exponents of power time dependence of front perturbations in a wide region of values of harmonic number and of gas adiabatic exponent. We also determine the region of instability.

V.M.Ktitorov, Khim.Fizika(Chem.Phys.Issues),V.14,No2-3,p.169,1995
J.Grun et al, Phys.Rev.Let.,V.66,No21,p.2738,1991
V.Ktitorov,V.Meltsas, Proceedings of the 6thIWPCTM,Marseille,1997



Abstract No. T16

Stability of Reflected from the Center Self-Similar Converging Shock Wave

V. M. Ktitorov
Russian Federal Nuclear Center – VNIIEF, Sarov, Russia

The technique first used in /1-3/ for solving the point blast wave stability problem is applied for the one of the self-similar converging shock wave after focusing.

Small (linear) perturbations of the shock wave are expanded into spherical harmonics the components of expansion being presented in the self-similar form. The stability problem is reduced to the solving of the system of the ordinary differential equations, which are to be solved simultaneously with the main spherically symmetric equations of the shock wave.

The eigenvalue problem is formulated. This problem is solved, complex values of power exponent (they describe a time dependence of front perturbations) are calculated as eigenvalues. The eigenvalues are calculated numerically in the general case of arbitrary values of harmonic number n and gas adiabatic exponent γ. The region of instability is defined on the plane n-γ.

V.M.Ktitorov (Russian Atomic Science and Technique Issues, Ser. Theoretical and Applied Physics), No2, p.28, (1984);
D.Ryu and E.T.Vishniac, Astrophys.J. 313, 820 (1987);
V.M.Ktitorov, Khimicheskaya Fizika (Chemical Physics Issues) V.14, No 2-3, p.169, (1995);

Abstract No. T17

Using a Turbulence Transport Approach to Study Shocks Through Polycrystalline Metal

R. R. Linn and F. H. Harlow
Los Alamos National Laboratory, Los Alamos, NM

A polycrystalline metal is composed of close packed crystals in each of which the elastic modulus is non-isotropic to a degree that ranges from slight to extreme (as in delta-phase plutonium where there is a seven to one variation). We have made considerable progress in the development of a stochastic model by which to describe the collective behavior as a strong shock or rarefaction passes through the material. The basic idea is to start with the laws of mass, momentum, and energy conservation, decompose each variable into mean and fluctuating parts, ensemble average the equations, and then derive transport equations and closures for the higher-order moments. The first version has been obtained and tested numerically for a self-similar traveling wave, and results show deficiencies, together with strong clues for their remediation. We have made much progress in developing a second, improved version for which results will be presented during the talk.

Abstract No. T18

Response of Turbulent RANS Models to Self-Similar Variable Acceleration RT-Mixing: An Analytical 0D Analysis

A. Llor
Commissariat à l'Energie Atomique, Bruyères-le-Châtel, France

So far, the validation of RANS models applicable to variable acceleration RT mixing flows (as found in ICF) has mostly been carried out by fitting experimental or numerical data obtained for constant (RT) and impulsive (RM) accelerations. Further checks are also possible on the few available data for variable acceleration, such as in mixing-demixing flows induced by reverting the gravity field. Although this approach is widely applied and accepted, it is unsatisfactory because of the complex relationship between the model features and coefficients and the experimental measurements.

It is shown here that self-similar variable acceleration RT (SSVART) provides an appealing alternative since it extends the usual calibration techniques of turbulent RANS models based on simple self-similar flows. The general model equations in 1D (PDEs) are still too complex for full analytical calculations of SSVART flows, but using reasonable assumptions, simple 0D (ODEs) approximations can be derived and solved analytically.

This approach is applied to an extended k-ε model derived from Andronov's and to Young's two-fluid model. The behaviour of the mixing layer growth rate and integral turbulent scales provides important informations on the accuracy of these models.

Finally, general qualitative arguments will be discussed showing the importance and the difficulty of capturing accurately a broad range of SSVARTs with a single simple model.

Abstract No. T19

Nonlinear Evolution of an Interface in the Richtmyer-Meshkov Instability

C. Matsuoka[1], K. Nishihara[2], and Y. Fukuda[2]
[1]*Ehime University, Ehime, Japan*
[2]*Institute of Laser Engineering, Osaka University, Osaka, Japan*

We have developed an analytical model that describes a fully nonlinear evolution of an interface in the Richtmyer-Meshkov instability. Proper boundary conditions at the interface are derived and the temporal evolution of the interface is investigated as a vortex sheet using them. It is shown that the created vorticity on the interface has a strong inhomogeneity, which causes the stretching and compression of the sheet. We discuss the inhomogeneity in detail, from which we show the interface has a double spiral structure. We also show a good agreement in the analytical solutions of the interface shape with two-dimensional hydrodynamic simulations.
We present the proper kinematic boundary condition, the modified Birkhoff-Rott equation, in order to describe the nonlinear evolution of the interface with the temporal evolution of the circulation, corresponding to the Bernoulli equation, on the interface for an arbitrary Atwood number. The analytical solutions show that the interface is stretched to the tangential direction proportional to time. In the nonlinear stage, the modes in the normal and tangential directions mutually interact to yield to the large deformation of the spike. By introducing the self-similar form of the velocity potential first found by Rott, we can construct a fully nonlinear evolution of the double spiral structure in the spike.

Abstract No. T20

Evolution of Arbitrary Perturbations in the Richtmyer-Meshkov Instability

K. O. Mikaelian
Lawrence Livermore National Laboratory, Livermore, CA

We present analytical and numerical calculations on the evolution of arbitrarily shaped initial perturbations undergoing the Richtmyer-Meshkov instability. In many cases a simple, explicit, analytic formula can be written down for the linear regime. These formulas serve as nontrivial tests of hydrocodes, and we present simulations with the Arbitrary Lagrangian-Eulerian hydrocode CALE that cover the linear as well as the deeply nonlinear regime of the instability. A brief outline and code calculations for possible experiments will also be presented.

PACS No.: 52.35.Py

This work was performed under the auspices of the U.S. Department of Energy by the University of California Lawrence Livermore National Laboratory under contract No. W-7405-Eng-48.

Abstract No. T21

RT Turbulence: Dramatic Dynamics of Interpenetration (Fast Jets, Sharp Decelerations and Accelerations)

A. M. Oparin[1], N. A. Inogamov[2], and A. Yu. Dem'yanov[3]
[1]*Institute for Computer Aided Design, Moscow, Russia*
[2]*Landau Institute for Theoretical Physics, Moscow, Russia*
[3]*Moscow Institute for Physics and Technology, Moscow, Russia*

Dynamics of turbulent mixing due to the Rayleigh-Taylor instability is considered. The mixing layer consists of a single horizontal array of large scale structures. The characteristics of these structures are studied by the spectral and statistical methods. Stimulation of mixing by long-wavelength noise is studied. It is demonstrated that, for a typical homogeneous unscaled noise,time-squared self-similarity is retained. The threshold amplitude of random broadband noise is determined, below which these noise can be ignored. The mixing deceleration by the side boundaries is studied. The stimulation and deceleration effects sizably influence the mixing coefficient, increasing and decreasing it respectively.

Abstract No. T22

Statistical Mechanics Large Scale Model for the Evolution of the Multi-Mode Kelvin Helmholtz Instability

A. Rikanati[1,2], U. Alon[3], and D. Shvarts[1,2]
[1]*Nuclear Research Center Negev, Israel*
[2]*Ben-Gurion University, Negev, Israel*
[3]*Weizmann Institute of Science, Israel*

The nonlinear growth of the multi-mode incompressible Kelvin-Helmholtz (KH) shear flow instability at all density ratios is treated by a large scale statistical-mechanics eddy-pairing model, based on a vortex model for the single eddy behavior and the process of two eddy-pairing. Using an adaptation of the statistical merger model by Alon et. al [1994], a linear time growth of the mixing zone is obtained, resulting in the linear time growth coefficient for several density ratios as well as an asymptotic lognormal eddy size distribution and the average eddy life time probability. Very good agreement with full numerical simulations and experiments is achieved.

References:

U. Alon, J. Hecht, D. Mukamel and D. Shvarts, Phys. Rev. Lett. 72, 2867 (1994).

Abstract No. T23

Effects of High Initial Amplitudes and High Mach Numbers on the Evolution of the RM Instability: I. Theoretical Study

A. Rikanati[1,2], D. Oron[1], O. Sadot[1,2], and D. Shvarts[1,2]
[1]*Nuclear Research Center Negev, Israel*
[2]*Ben-Gurion University, Beer-Sheva, Israel*

Recent shock tube experiments [Aleshin et al. 1997] and laser driven experiments [Dimonte et al.1998] resulted in an initial bubble growth velocity smaller then that predicted by the matching impulsive models [Richtmyer et. al. 196? and Meyer-Blewett 1972]. It was suggested that the reduction can be attributed to effects of both High Mach number and high initial amplitudes [Holems 2000].

In the present work two models are formulated describing the velocity reduction caused by the two effects. A vorticity deposition model is formulated for effects of high initial amplitudes and a "wall" model is formulated for describing effects of high Mach number caused by the proximity of the shock wave with the two fluid interface. Both in good agreement with the matching experimental results.

Implementing the above models for a range of initial conditions (low to high initial amplitudes and Mach numbers) and with the aid of full numerical simulations, previous experiments and new low and high Mach number shock tube experiments [Sadot et. al., present conference], the range of initial conditions is divided into regions of high Mach dominance, regions of high initial amplitudes dominance and "classical " regions were the two effects are negligible. Using the above mapping, it was found that effects of high initial amplitudes dominates most of the previous experiments.

References:

Aleshin et. al., in Proceedings of the Sixth International Workshop on the Physics of Compressible Turbulent Mixing edited by G. Jourdan & L. Houas, Marsielle France 1997. Page 1.

Dimonte G., Frerking C.E., Schnider M. and Remington B., Phys. of Plasmas 12, 304 (1996).

Holmes et. al., J. Fluid Mech 187, 329 (1999).

Meyer K.M. and Blewett P.J., Phys. of. Fluids 15, 753 (1972).

Richtmyer R.D., Commun. Pure Appl. Math. 13, 297 (1960).

Abstract No. T25

Compressible MHD Turbulence in Strongly Radiating Molecular Clouds in Astrophysics

D. D. Ryutov and B. A. Remington
Lawrence Livermore National Laboratory, Livermore, CA

Molecular clouds in astrophysics are often subjected to intense irradiation by nearby young stars. The ablation process ensues and a strong shock is driven into the cloud. In a number of cases, the radiative cooling time of the shocked matter is much shorter than the dynamical time of the cloud evolution. In such situations, possible pre-existing turbulent motions and turbulent magnetic fields can potentially contribute to the "stiffness" of the shocked material. We suggest simple models allowing quick evaluation of these effects. We conclude that the presence of a turbulent magnetic field can play a significant role, provided its amplitude is beyond some critical level, whereas the turbulent ram pressure of the unmagnetized medium can play only a relatively minor role. Implications for the dynamics of astrophysical molecular clouds are discussed.

PACS Nos.: 47.27.Jv, 47.65.+a, 95.30.Qd. 98.58.Db

This work was performed under the auspices of the U.S. Department of Energy by the University of California Lawrence Livermore National Laboratory under contract No. W-7405-Eng-48.

Abstract No. T26

Single-Velocity, Multi-Component Turbulent Transport Models for Interfacial Instability-Driven Flows

O. Schilling
Lawrence Livermore National Laboratory, Livermore, CA

A family of two-equation turbulent transport models is proposed for three-dimensional, single-velocity, multi-component turbulent flows driven by Rayleigh-Taylor, Richtmyer-Meshkov, and Kelvin-Helmholtz instabilities. The models are compressible versions of K-Z models, where K is the turbulent kinetic energy and Z is an auxiliary variable such as the turbulent kinetic energy dissipation rate, turbulent frequency, or turbulent lengthscale. Terms are proposed in these equations that account for buoyancy and compressibility effects. The relative merits of different K-Z models will be discussed, and preliminary *a priori* and *a posteriori* tests of the models using direct numerical simulation data for Rayleigh-Taylor instability-induced turbulent mixing will be presented. Future plans for model tests and applications to Richtmyer-Meshkov instability-induced turbulent mixing will also be discussed.

PACS Nos.: 47.20.Ma, 47.27.Eq, 47.40.Nm

This work was performed under the auspices of the U.S. Department of Energy by the University of California Lawrence Livermore National Laboratory under contract No. W-7405-Eng-48.

Abstract No. T28

Large- and Small-Scale Dynamics of Variable-Density Rayleigh-Taylor Instability-Induced Turbulent Mixing

O. Schilling and A. W. Cook
Lawrence Livermore National Laboratory, Livermore, CA

The statistical dynamics of the large- and small-scales in a three-dimensional turbulent mixing layer induced by Rayleigh-Taylor instability is studied using 512^2 x 2040 direct numerical simulation data. The terms in the evolution equations for the density-weighted kinetic energy, density-weighted enstrophy, and squared density are evaluated to study their relative contributions during the time-evolution. Particular consideration is given to the role of the baroclinic production and turbulent diffusion terms, as well as to the coupling between the density and velocity fields. The traditional method used to study the flow of energy between resolved (supergrid) and unresolved (subgrid) scales by introducing a cutoff wavenumber in Fourier space is generalized using a multi-resolution wavelet analysis, and used to quantify the forward cascade of kinetic energy, enstrophy, and the squared density from large to smaller scales, as well as the backward cascade from small to larger scales. The implications of this study for developing and assessing subgrid-scale and backscatter models for large-eddy simulation of Rayleigh-Taylor mixing are discussed. Wavelet analysis is ideally suited to studying evolving, anisotropic turbulent mixing, as wavelet-transformed spectra yield information regarding both the *scale* of structures and their *location* within the flow. The use of wavelet methods provides additional insight into the coupling between the large-scale, coherent flow (the bubbles and spikes formed during the merger process) and the small-scale, incoherent background flow (the smaller scale turbulence induced by Kelvin-Helmholtz instability and the turbulent energy transfer process).

PACS Nos.: 47.20.Ma, 47.27.Eq

This work was performed under the auspices of the U.S. Department of Energy by the University of California Lawrence Livermore National Laboratory under contract No. W-7405-Eng-48.

Abstract No. T30

Analytical Study of the Rayleigh-Taylor Instability in Compressible Fluids

M. Tricottet and S. Bouquet
Commissariat à l'Energie Atomique, Bruyères-le-Châtel, France

Since the observation of the explosion of the type II supernova, SN87a, Rayleigh-Taylorinstabilities (RTI) are suspected to play a key-role during the process of expansion of the envelope (due to the passage of the shock) [1,2,3,4].
In this paper we perform an analytical study of the RTI. In contrast to most of all previous studies [5,6,7], we examine the case of compressible fluids. In addition, both the static (time-independent acceleration) and the dynamical (time-dependent acceleration) cases are presented.
For these two cases we are able to derive a non-trivial analytical dispersion relationship. Comparisons are made, first, with the models developped for incompressible fluids and, as expected, for wave number, k, going to infinity (wavelengths going to zero) we recover the well-known result valid for incompressibility.
On the other hand, the influence of the time-dependence in the acceleration is shown and the differences with the static case are emphasized.

[1] Clayton, Principles of Stellar Evolution and Nucleosynthesis, Univ. of Chicago Press (1983)
[2] Fryxell et al., ApJ. 367, 619 (1991)
[3] Glanz, Science 276, 351 (1997)
[4] Kane et al., ApJ. Lett. 478, 75 (1997)
[5] Abarzhi, Phys. Rev. Lett. 81(2), 337 (1998)
[6] Velasquez et al., Astron. Astrophys. 334, 1060 (1998)
[7] Mikaelian, Phys. Rev. Lett. 80(3), 508 (1998)

Abstract No. T31

Analytic Nonlinear Growth of A Single-Mode Richtmyer-Meshkov Instability

M. Vandenboomgaerde
Commissariat à l'Energie Atomique, Bruyères-le-Châtel, France

Perturbation method where only the most secular terms are retained gives a simple result for the weakly nonlinear growth of a single-mode shock-accelerated interface [M.Vandenboomgaerde, C.Mugler, and S.Gauthier, Proceedings, 7th IWPCTM, St. Petersbourg, 1999]. This result writes as a series in integer powers of time. It can be considered as the Taylor expansion of an analytic function. We believe that such a function has been identified; it describes the evolution of the instability from the linear to intermediate nonlinear regime. Whereas the series has a finite radius of convergence, the function has no singularity. The accuracy of this analytic formula is checked against various 2D simulations. Comparisons with previous theoretical models are also presented.

Abstract No. T32

Efficient Perturbation Methods for Richtmyer-Meshkov and Rayleigh-Taylor Instabilities: Weakly Nonlinear Stage and Beyond

M. Vandenboomgaerde, C. Cherfils, D. Galmiche, S. Gauthier, and P. A. Raviard
Commissariat à l'Energie Atomique, Bruyères-le-Châtel, France

A perturbation method has been derived by Q.Zhang and S-I.Sohn [Phys.Fluids 9, 1106 (1997)] in order to predict the weakly nonlinear stage of the Richtmyer-Meshkov instability. Retaining the most secular terms has allowed us to drastically simplify this theory [M.Vandenboomgaerde, C.Mugler, and S.Gauthier, Proceedings, 7th IWPCTM, St Petersbourg, 1999].

We use this simplified but accurate approach to show the importance of the sign of the amplitude of the modes in the selection mode process. Such process is also studied beyond the weakly nonlinear stage. A class of homothetic interfaces is deduced fromthe theory. Its validity is checked against 2D simulations, even in the intermediate nonlinear regime.

Finally, this approach is used in order to solve the equations of the nonlinear stage of the Rayleigh-Taylor instability. We present comparisons between theory and various published test cases.

Abstract No. T33

Combined Shear and Buoyancy Instabilities

P. N. Wilson[1], M. J. Andrews[1], and F. H. Harlow[2]
[1]*Texas A & M University, College Station, TX*
[2]*Los Alamos National Laboratory, Los Alamos, NM*

Mixing layer experiments were performed at Texas A&M University with flows in shear, with an unstable buoyancy configuration and combined shear and (stabilizing, de-stabilizing) buoyancy. Two-time density correlations were measured, as well as single-point, second-order velocity correlations for the various flow configurations. A turbulence spectral transport model and a single-point turbulence transport model were investigated with their local formulation and later with non-local formulation in both physical and wave number space. Numerical simulations of the mixing layer were compared with experimental data and gave good agreement with the addition of terms to model non-local processes, such as, pressure fluctuations propagating into the surrounding fluid from the mix region, advection of small-scale eddies by large-scale structures, and vortex pairing resulting from Kelvin-Helmholtz instabilities. Results of the comparisons between theoretical models and numerical simulations and experimental data are presented.

Abstract No. T34

Rate of Growth of the Linear Richtmyer-Meshkov Instability

J. G. Wouchuk
E. T. S. I. Industriales, University of Castilla, Salamanca, Spain

A theoretical model is presented that calculates the exact asymptotic rate of growth of the perturbations present at a shocked corrugated contact surface. The model covers both situations: whether a shock or a rarefaction are reflected back in the first fluid. The asymptotic growth rate can be calculated with the desired accuracy for any value of the incident shock Mach number, fluids compressibilities or initial density contrast. The growth rate is obtained as the solution, either of a system of two coupled functional equations in the shock reflected situation, or of only one functional equation in the rarefaction reflected case. The model includes the compressible history of the sound wave reverberations between the corrugated fronts and the material interface. It is seen a quite high speed of convergence for the intermediate calculations. Good agreement with previous numerical and experimental works is shown.

PACS Nos.: 47.20.-k, 52.35.Py-, 52.35-T

Abstract No. T35

The Dependence of the Shock Induced Richtmyer-Meshkov Instability on Dimensionality and Density Ratio

A. Yosef-Hai[1], O. Sadot[1,2], D. Kartoon[1,2], D. Oron[2], E. Sarid[2], G. Ben-Dor[1], and D. Shvarts[1,2]
[1]*Ben-Gurion University, Beer-Sheva, Israel*
[2]*Nuclear Research Center, Negev, Israel*

The RM instability occurs when a shock wave passes through a perturbed interface between two fluids. As a result of the instability, small perturbations on the initial interface develop into an array of bubbles and spikes. The bubble front was found to be dominated by bubbles rising and competing[1]. It was previously shown that this evolution of a multi-mode random initial perturbations is strongly related to the evolution of the single-mode case.

For a single-mode perturbation the instability can be described by a linear stage, during which the growth is characterized by a constant velocity, followed by a nonlinear stage, during which the growth velocity reaches an asymptotic 1/t behavior[2]. Simple drag-buoyancy considerations can be used to derive the acceleration of a single bubble. Assuming two fluids with different densities ρ_H and ρ_L and bubble of wave length λ the equation of motion is:

$$(1)\quad (\rho_L + C_a\rho_H)\frac{dU}{dt} = (\rho_H - \rho_L)g - \frac{C_d}{\lambda}\rho_H U^2$$

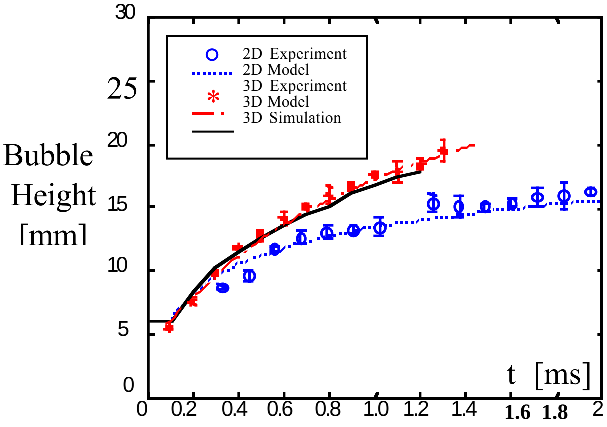
The two constants C_a and C_d, which are the added mass coefficient and the drag coefficient respectively, are determined by equating Eq. 1 to the prediction of a potential flow model[2]. For the 2D case C_a=2 and C_d=6π, for the 3D case C_a=1 and C_d=2π. The asymptotic solution of Eq. 1 for RM is achieved by neglecting the effect of the shock (g=0). By doing so the bubble asymptotic acceleration is derived:

$$(2)\quad \frac{\quad}{dt} = -\frac{\quad _{H}}{\rho_L + C_a\rho_H}\cdot\frac{\quad}{\lambda}$$

The growth rate is the solution of Eq.2. By introducing the coefficients as described above, the dependence of the late time growth rate on the dimensionality and density ratio is found. The results are summarized in the following Table:

	$\rho_H/\rho_L \to 1$	$\rho_H/\rho_L \to$
2D	$\frac{}{1}\ \frac{}{\lambda}$	$\frac{3\pi}{}\ \frac{t}{}$
3D	$\frac{}{1}\ \frac{}{\lambda}$	$\frac{}{1}\ \frac{}{\lambda}$

In the present work a set of shock tube experiments were made to verify the model's prediction. A thin membrane, on which the 2D and 3D initial perturbations were imposed, separated the two gases. Different pairs of gases were used to achieve different density ratios. The evolution of the shock-wave induced mixing zone was measured by high speed laser schlieren photography. The linear and asymptotic stages were observed. The results were found to be in good agreement with both model and simulations. See the following Figure for the case of $\rho_H / \rho_L = 5$.



References:

[1] Alon U., Hecht J., Ofer D. and Shvarts D. 1995 Phys. Rev. Lett. 74, 534.

[2] Hecht J., Alon U. and Shvarts D., 1994 Phys. Fluids 6, 4019.

Abstract No. T36

A New Framework for Transitional and Turbulent Mixing

Y. Zhou, H. F. Robey, and A. C. Buckingham
Lawrence Livermore National Laboratory, Livermore, CA

We develop a framework, based on the current knowledge of turbulence theory and using phenomenological treatment, for the characterization of turbulent mixing evolving from shock and gravity driven instabilities. The procedure is designed to supplement and connect the history of the flow development from the early stages of the Rayleigh-Taylor and Richtmyer-Meshkov instabilities into the fully developed turbulent flow regime under the conditions of high pressure, high temperature, elevated Reynolds number flow and material mixing. We first demonstrate an analogy between the buoyancy drag model and the one equation turbulence transport closure model. We show that in simplifying the latter transport model to form the buoyancy drag model, the multiple length scales of physical turbulence are drastically reduced to essentially a single, dominant length scale. Furthermore, we show that in the buoyancy drag model several other terms representing specific additional contributions of physical turbulence in the one equation transport model are omitted in the simplification. Next, we compile the key parameters that are needed to characterize both initial transitional flow and its subsequent evolution into fully developed turbulent flow. Although all important length scales are well known and well described in turbulent fluid dynamics literature, we pay special attention here to their time dependent features because of our special focus on description of the transient states and their evolution in transitional and turbulent material mixing. As a result, we have formed a generalization of the transition criteria proposed by Dimotakis (*J. Fluid Mechanics*, ***409***, 69 (2000)). We illustrate the utility of our framework for transitional and turbulent mixing by applying it to a classical fluid dynamics RTI experiment conducted at Cambridge University and, a laser experiment carried out in the Omega laser facility at the University of Rochester.

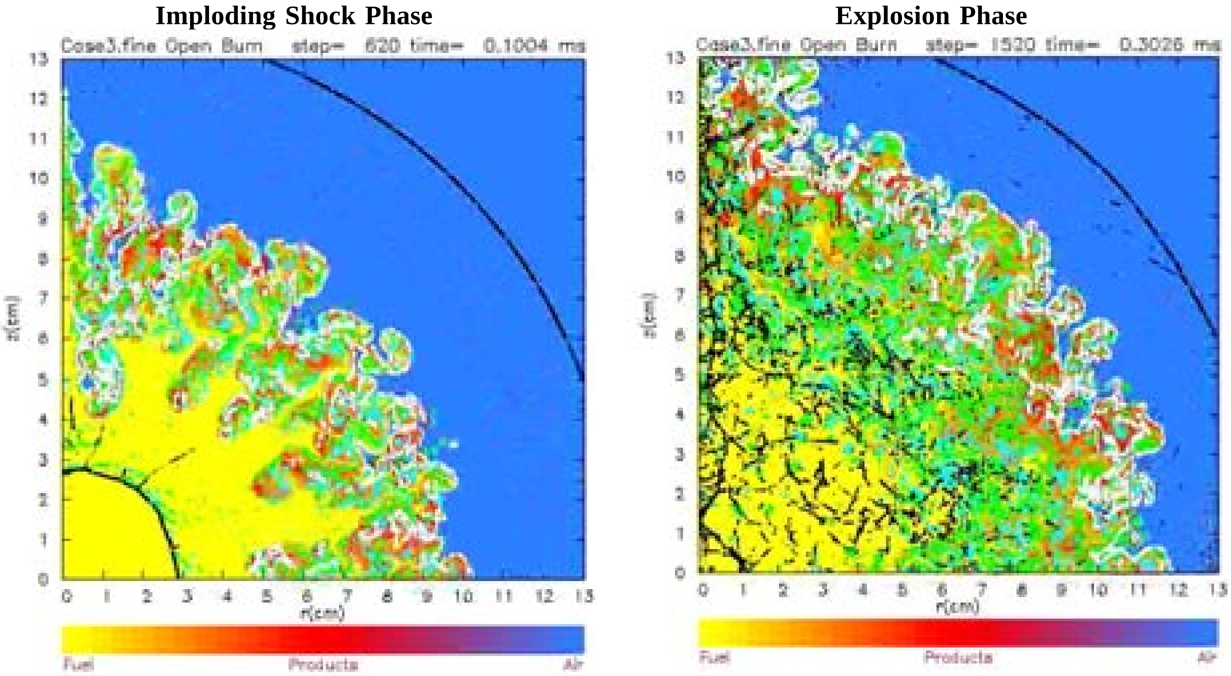
This work was performed under the auspices of the U.S. Department of Energy by the University of California Lawrence Livermore National Laboratory under contract No. W-7405-Eng-48.

Abstract No. T37

Spherical Combustion Layer in a TNT Explosion

A. L. Kuhl[1] and R. E. Ferguson[2]
[1]*Lawrence Livermore National Laboratory, Livermore, CA*
[2]*Krispin Technologies Inc, Rockville, MD*

A theoretical model of combustion in explosions at large Reynolds, Peclet and Damkohler numbers is described. A key feature of the model is that combustion is treated as material transformations in the Le Chatelier plane, rather than "heat release". In the limit considered here, combustion becomes concentrated in thin exothermic sheets (boundaries between fuel and oxidizer). The products expand along the sheet, thereby inducing vorticity on either side of the sheet that continues to feed the process. The results illustrate the linking between turbulence (vorticity) and exothermicity (dilatation) in the limit of fast chemistry, thereby demonstrating the controlling role that fluid dynamics plays in such flows.



Imploding Shock Phase **Explosion Phase**

Figure 1. Cross-sectional view of the combustion field generated by the detonation of a 1-g spherical TNT charge. TNT explosion products (shown as *yellow*) mix with air (depicted in *blue*) to form combustion products (represented as *red*). Exothermic cells are marked with *white* dots. Vorticity contours are *turquoise* (positive) and *chartreuse* (negative), while compressional dilatation contours are *black*.

This work was performed under the auspices of the U.S. Department of Energy by the University of California Lawrence Livermore National Laboratory under contract No. W-7405-Eng-48.

Abstract No. T38

Spectral Analysis of Turbulent Flows Induced by RT and RM Instabilities

V. F. Tishkin and N. V. Zmitrenko
Institute for Mathematical Modeling of the Russian Academy of Sciences, Moscow, Russia

The results of analysis of spectral characteristics of a velocity field for two unstable hydrodynamic problems are examined in this report. One of this problem involves direct simulation of turbulent mixing experiment, which has done for the case of Richtmyer-Meshkov instability. Results of simulation describe main characteristics of developing mixing zone, i.e. shape and sizes of turbulent layer. The spectral analysis has revealed a presence of an interval connected with an enstrophy transfer to small-scale oscillations.

Another problem relates to classic case or Rayleigh-Taylor instability. The analysis of this case has shown that an inertial interval is observed.

Both problems were treated with the help of 3D hydrodynamic code NUT. The spectral analysis was fulfilled by means of specially alaborated for this problems code SPAN.

Supported by ISTC project # 1495.

Abstract No. T39

Pattern Detection, Compression and Denoising of Rayleigh-Taylor Mix Data Using Discrete Wavelet Transform Techniques

B. B. Afeyan[1], P. Ramaprabhu[2], and M. J. Andrews[2]

[1]*Polymath Research Incorporated, Pleasanton, CA*
[2]*Texas A & M University, College Station, TX*

Sequential single point density measurements have been collected from a statistically steady Rayleigh-Taylor mix. The experiment allows long collection times, and thus highly detailed statistical analyses are possible. We have studied this data using a number of discrete wavelet transform techniques in order to denoise, compress and detect patterns and correlations in these ideal representations of intermittent data. By comparing the statistical properties of the evolution of RT at various points downstream, we can establish the minimum number of wavelet coefficients whose evolution can capture the most significant aspects of the turbulent flow. To this end, scale based as well as largest coefficient thresholding are compared and contrasted and the choice of optimum wavelets for the tasks as hand identified. instability-induced turbulent mixing will also be discussed.

Authors Contact Information

Abarzhi, Snejana I.
Department of Applied Mathematics
State University of New York at Stony Brook
Stony Brook, NY 11794-3600
Phone: 631-632-9360
Fax: 631-632-8490
E-mail: snezha@ams.sunysb.edu

Abe, M.
Institute of Laser Engineering
Osaka University
Suita, Osaka 565 Japan

Afeyan, Bedros
Polymath Research Incorporated
827 Bonde Court
Pleasanton, CA 94566
Phone: (925) 417-0609
Fax: (925) 417-0684
E-mail: bedros@polymath-usa.com

Allen, A. M.
University of Oxford
University Offices
Wellington Square
Oxford OX1 2JD. UK
Phone: +44 1865 270000
Fax: +44 1865 270708

Alon, U.
Weizmann Institute of Science
PO Box 26
Rehovot 76100 Israel
Phone: + 972-8-934-2111
Fax: + 972-8-934-4107
E-mail: uri.alon@weizmann.ac.il

Anderson, M. H.
University of Wisconsin at Madison
1500 Engineering Drive
Madison, WI 53706
Phone: (608) 263-2802
Fax: (608) 263-7541
E-mail: manderson@engr.wisc.edu

Andrews, Malcolm
Department of Mechanical Engineering
Texas A & M University
MS 3123
College Station, TX 77843-3123
Phone: (409) 847-8843
Fax: (409) 845 3081
E-mail: malcolm@chagal.tamu.edu

Anisimov, V. I.
Russian Federal Nuclear Center-VNIITF
P.O. Box 245
456770 Snezhinsk, Russia
E-mail: v.i.anisimov@vniitf.ru

Anuchin, M. G.
Russian Federal Nuclear Center-VNIITF
P.O. Box 245
456770 Snezhinsk, Russia

Arazi, L.
Tel Aviv University
P.O. Box 39040
Tel Aviv 69978
Israel

Ardashova, R. I.
Russian Federal Nuclear Center-VNIITF
P.O. Box 245
456770 Snezhinsk, Russia

Arnett, D.
The University of Arizona
P.O. Box: 210096
Tucson, AZ 85721
Phone: (520) 621-9587
E-mail:: darnett@as.arizona.edu

Ashurst, William T.
Sandia National Laboratory
P.O. Box 969, MS 9051
Livermore, CA 94551-0969
Phone: (925) 294-2274
Fax: (925) 294-2595
E-mail:: ASHURS@sandia.gov

Azechi, Hiroshi
Institute of Laser Engineering
Osaka University
Suita, Osaka 565 Japan
Phone: 81-879-8770
Fax: 81-877-4799
E-mail: azechi@ile.osaka-u.ac.jp

Bailly, P.
Commissariat à l'Energie Atomique
BP 12 - 91680 Bruyères-le-Châtel

Baishev, A. I.
Russian Federal Nuclear Center-VNIITF
P.O. Box 245
456770 Snezhinsk, Russia

Balabin, Serguei
Russian Federal Nuclear Center-VNIITF
P.O. Box 245
456770 Snezhinsk, Russia
Fax: (351-72) 3 20 77
E-mail: kucherenko@five.ch70.chel.su

Barnes, Christopher W.
Los Alamos National Laboratory
P.O. Box 1663
Los Alamos, NM 87545
Phone: (505) 665-5687
E-mail:: cbarnes@lanl.gov

Barton, C.
Atomic Weapons Establishment
Aldermaston
Reading, Berkshire
RG7 4PR UK
Phone: +44 (0)1734 814111
Fax: +44 (0)1734 815320

Batha, Steven
Los Alamos National Laboratory
P.O. Box 1663, MS E526
Los Alamos, NM 87545
Phone: (505) 665-5898
Fax: (505) 665-4409
E-mail: sbatha@lanl.gov

Belak, James F.
Lawrence Livermore National Laboratory
P.O. Box 808, L-045
Livermore, CA 94551
Phone: (925) 422-6061
Fax: (925) 422-2851
E-mail: belak1@llnlg.gov

Belomestnih, A. V.
Russian Federal Nuclear Center-VNIITF
P.O. Box 245
456770 Snezhinsk, Russia

Ben-Dor, Gabi
Ben-Gurion University of the Negev
Faculty of Engineering Sciences
Beer Sheva, 84105, Israel
Phone: 972-7-6461212
Fax: 972-7-6472936
E-mail: bendor@menix.bgu.ac.il

Benjamin, Robert F.
Los Alamos National Laboratory
P.O. Box 1663, MS P940
Los Alamos, NM 87545
Phone: (505) 667-8116
Fax: (505) 665-3359
E-mail: rfb@lanl.gov

Biello, J.
University of Chicago
933 East 56th Street
Chicago, IL 60637
Phone: (773) 702-1234

Bliznetsov, M. V.
Russian Federal Nuclear Center-VNIIEF
Mir Avenue, 37, Sarov
Nizhnii Novgorod Region, 607190, Russia
Fax: (831-30) 459-58
E-mail: root@gdd.vniief.ru

Boehly, T. R.
Laboratory for Laser Energetics
University of Rochester
250 East River Road
Rochester, New York 14623-1299
Phone: (716) 275-0254
E-mail: trb@lle.rochester.edu

Bonazza, Riccardo
Department of Engineering. Physics
University of Wisconsin at Madison
1500 Engineering Drive
Madison, WI 53706
Phone: (608) 265-2337
Fax: (608) 262-6707
E-mail: bonazza@engr.wisc.edu

Bouquet, Serge
Commissariat à l'Energie Atomique
PDPTA-BP 12
Bruyeres-le-Chatel, France 91680
Phone: +33-1-69-26-51-83
Fax: +33-1-69-26-71-06
E-mail: bouquet@bruyeres.cea.fr

Braun, David G.
Lawrence Livermore National Laboratory
P.O. Box 808, L-031
Livermore, CA 94551
Phone: (925) 423-6275
Fax: (925) 423-9969
E-mail: braun1@llnl.gov

Breidenthal, Robert
Department of Aeronautics and Astronautics
University of Washington
Box 352400
Seattle, WA 98195-2400
Phone: (206) 685-1098
Fax: (206) 685-0217
E-mail: breidenthal@aa.washington.edu

Brouillette, Martin
Department of Mechanical Engineering
Université de Sherbrooke
Sherbrooke, Quebec J1K 2R1 Canada
Phone: (819) 821-7144
Fax: (819) 821-7163
E-mail: martin.brouillette@gme.usherb.ca

Buckingham, Alfred C.
Lawrence Livermore National Laboratory
P.O. Box 808, L-23
Livermore, CA 94551
Phone: (925) 423-4828
Fax: (925) 422-2644
E-mail: alfredcb@llnl.gov

Budil, Kimberly S.
Lawrence Livermore National Laboratory
P. O. Box 808, L-97
Livermore, CA 94551
Phone: (925) 423-8098
Fax: (925) 422-0779
E-mail: budil1@llnl.gov

Cabot, William H.
Lawrence Livermore National Laboratory
P.O. Box 808, L-22
Livermore, CA 94551
Phone: (925) 423-9272
Fax: (925) 423-0925
E-mail: cabot1@llnl.gov

Calder, A. C.
Department of Astronomy and Astrophysics
University of Chicago
5640 South Ellis Ave.
Chicago, IL 60637
Phone: (773) 834-3904
Fax: (773) 834-3230
E-mail:: calder@flash.uchicago.edu

Chebotareva, E. I.
Krzhizhanovsky Power Engineering Institute
ENIN, Leninsky pr. 19, GSP-1
Moscow, 117927 Russia
Phone: (7-095) 955-31-07
Fax: (7-095) 954-42-50
E-mail: S.G.Zaytsev@mtu-net.ru

Cheng, Baolian
Los Alamos National Laboratory
P.O. Box 1663, MS D413
Los Alamos, NM 87545
Phone: (505) 667-4701
Fax: (505) 667-3726
E-mail: bcheng@lanl.gov

Clark, Timothy T.
Los Alamos National Laboratory
P.O. Box 1663, MS B213
Los Alamos, NM 87545
Phone: (505) 665-4858
Fax: (505) 665-3003
E-mail: ttc@llnl.gov

Clerouin-Cherfils, Catherine
Commissariat à l'Energie Atomique
CEA/DRIF
BP 12, 91680, Bruyeres-le-Chatel, France
Phone: 33 1 69 26 57 38
Fax: 33 1 69 26 70 94
E-mail: cherfils@bruyeres.cea.fr

Colvin, Jeffrey. D.
Lawrence Livermore National Laboratory
P.O. Box 808, L-021
Livermore, CA 94551
Phone: (925) 422-3273
Fax: (925) 423-8945
E-mail: colvin5@llnl.gov

Cook, Andrew W.
Lawrence Livermore National Laboratory
P.O. Box 808, L-22
Livermore, CA 94551
Phone: (925) 423-2856
Fax: (925) 423-0925
E-mail: awcook@llnl.gov

Dalziel, Stuart
DAMTP, University of Cambridge
Silver Street, Cambridge CB3 9EW, England
Phone: (44) (1223) 337 911
Fax: (44) (1223) 337 918
E-mail: s.dalziel@damtp.cam.ac.uk

Dannenberg, K.
University of Michigan
Space Research Lab, Rm 1216
2245 Hayward
Ann Arbor, MI 48104

Darlington, Rebecca M.
Lawrence Livermore National Laboratory
P.O. Box 808, L-95
Livermore, CA 94551
Phone: (925) 424-3422
E-mail: darlington1@llnl.gov

Delettrez, J. A.
Laboratory for Laser Energetics
University of Rochester
Rochester, NY 14623-1299
Phone: (716) 275-5374
E-mail: jdel@lle.rochester.edu

Demyanov, A. Yu.
Landau Institute for Theoretical Physics
Kosygnina St. 2, Moscow
117940, GSP-1
V-334 RUSSIA

Dimits, Andris M.
Lawrence Livermore National Laboratory
P.O. Box 808, L-630
Livermore, CA 94551
Phone: (925) 422-0211
Fax: (925) 423-3484
E-mail: dimits1@llnl.gov

Dimonte, Guy
Lawrence Livermore National Laboratory
P.O. Box 808, L-43
Livermore, CA 94551
Phone: (925) 423-0596
Fax: (925) 423-5998
E-mail: dimonte1@llnl.gov

Dittrich, Thomas R.
Lawrence Livermore National Laboratory
P.O. Box 808, L-023
Livermore, CA 94551
Phone: (925) 422-4706
Fax: (925) 423-8945
E-mail: dittrich1@llnl.gov

Don, Wai-Sun
Division of Applied Mathematics
Brown University
Box F
Providence, RI 02912
Phone: (401) 863-2250
E-mail:: Wai-Sun_Don@brown.edu

Drake, R. Paul
University of Michigan
2245 Hayward
Ann Arbor, MI 48104
Phone: (734) 763-4072
Fax: (734) 647-3083
E-mail: rpdrake@umich.edu

Drennov, O. B.
Russian Federal Nuclear Center-VNIIEF
Mir Avenue, 37, Sarov
Nizhnii Novgorod Region, 607190, Russia
Fax: (831-30) 459-58
E-mail: root@gdd.vniief.ru

Dudin, V. D.
Russian Federal Nuclear Center-VNIIEF
Mir Avenue, 37, Sarov
Nizhnii Novgorod Region, 607190, Russia
Fax: (831-30) 459-58
E-mail: root@gdd.vniief.ru

Dulov, A. V.
Russian Federal Nuclear Center-VNIITF
P.O. Box 245
456770 Snezhinsk, Russia

Dunne, A. M.
Atomic Weapons Establishment
Aldermaston
Reading, Berkshire
RG7 4PR UK

Dursi, L.
Department of Astronomy and Astrophysics
University of Chicago
5640 South Ellis Ave.
Chicago, IL 60637
Phone: (773) 834-1059
Fax: (773) 834-3230

Dutta, S.
State University of New York at Stony Brook
P-138A Math Tower
Stony Brook, NY 11794-3600

Edwards, Michael J.
Lawrence Livermore National Laboratory
P.O. Box 808, L-21
Livermore, CA 94551
Phone: (925) 422-1189
Fax: (925) 423-8945
E-mail: edwards39@llnl.gov

Elbaz, Y.
Ben-Gurion University
Beer-Sheva
Israel 84015
Phone: 972-8-6568836
Fax: 972-8-6567878
E-mail: elbazyo@bgumail.bgu.ac.il

Eliason, Donald E.
Lawrence Livermore National Laboratory
P.O. Box 808, L-103
Livermore, CA 94551
Phone: (925) 423-5625
Fax: (925) 422-6388
E-mail: eliason@merlin.llnl.gov

Epstein, Reuben
Laboratory for Laser Energetics
University of Rochester
Rochester, NY 14623-1299
Phone: (716) 275-5405
E-mail: reps@lle.rochester.edu

Farley, David
Institute of Laser Engineering
Osaka University
Suita, Osaka 565, Japan
E-mail: dfarley@epri.com

Fryxell, Bruce
Enrico Fermi Institute and Laboratory for Astrophysics and
Space Research
University of Chicago
933 East 56th Street
Chicago, IL 60637
Phone: (773) 704-3226
Fax: (773) 704-3230
E-mail:: fryxell@uffda.asci.uchicago.edu

Fujioka, S.
Institute of Laser Engineering,
2-6, Yamada-oka, Suita,
Osaka 565-0871 Japan

Fukuda, Y.
Institute of Laser Engineering,
2-6, Yamada-oka, Suita,
Osaka 565-0871 Japan

Galmiche, Didier Jean Marie
Commissariat à l’Energie Atomique
BP12 91680 Bruyeres-le-Chatel, France
Phone: 33 1 69 26 40 05
Fax: 33 1 69 26 70 94
E-mail: galmiche@bruyeres.cea.fr

Garasi, C.
Sandia National Laboratory
P.O. Box 969, 0819
Livermore, CA 94551-0969
Phone: (505) 284-2691
Fax: (505) 844-0918
E-mail: CJGARAS@sandia.gov

Gauthier, Serge
Centre d'Etudes de Limeil-Valenton
BP 27 Villeneuve St. Georges cedex
94195, FRANCE
E-mail: gauthier@limeil.cea.fr

Gavrilova, E. S.
Russian Federal Nuclear Center-VNIIEF
Mir Avenue, 37, Sarov
Nizhnii Novgorod Region, 607190, Russia
Fax: (831-30) 459-58
E-mail: root@gdd.vniief.ru

George, E.
State University of New York at Stony Brook
P-138A Math Tower
Stony Brook, NY 11794-3600

Gerasimov, Serguei
Russian Federal Nuclear Center, VNIIEF
Mir Avenue, 37, Sarov
Nizhnii Novgorod Region, 607190, Russia
Phone: (7-83130) 45 009
Fax: (7-83130) 45 958
E-mail: root@gdd.vniief.ru

Glebov, V. Yu.
Laboratory for Laser Energetics
University of Rochester
250 East River Road
Rochester, New York 14623-1299
Phone: (716) 275-7454
E-mail: vgle@lle.rochester.edu

Glendinning, Gail
Lawrence Livermore National Laboratory
P.O. Box 808, L-21
Livermore, CA 94551
Phone: (925) 423-3065
Fax: (925) 423-8945
E-mail: glendinning1@llnl.gov

Glimm, James
Department of Applied Mathematics and Statistics
State University of New York at Stony Brook
P-138A Math Tower
Stony Brook, NY 11794-3600
Phone: (631) 632-8355
FAX: (631) 632-8490
E-mail: glimm@ams.sunysb.edu

Goncharov, V. N.
Laboratory for Laser Energetics
University of Rochester
250 East River Road
Rochester, New York 14623-1299
Phone: (716) 275-1017
E-mail: vgon@lle.rochester.edu

Goodwin, Bruce T.
Lawrence Livermore National Laboratory
P.O. Box 808, L-160
Livermore, CA 94551
Phone: (925) 423-7736
Fax: (925) 424-2723
E-mail: goodwin2@llnl.gov

Gottlieb, David I.
Division of Applied Mathematics
Brown University
Providence, RI 02912
Phone: (401) 863-2266
E-mail:: David.Gottlieb@brown.edu

Graham, Mary J.
Lawrence Livermore National Laboratory
P.O. Box 808, L-312
Livermore, CA 94551
Phone: (925) 424-4222
Fax: (925) 422-8920
E-mail: mjgraham@llnl.gov

Greenough, Jeffrey A.
Lawrence Livermore National Laboratory
P.O. Box 808, L-30
Livermore, CA 94551
Phone: (925) 423-3211
Fax: (925) 424-6764
E-mail: greenough1@llnl.gov

Grieves, Brian
Atomic Weapons Establishment
Aldermaston
Reading, Berkshire
RG7 4PR UK
Phone: +44 (0)1734 814111
Fax: +44 (0)1734 815320
E-mail:: brian.grieves@awe.co.uk

Grove, John W.
Los Alamos National Laboratory
P.O. Box 1663, MS D413
Los Alamos, New Mexico, 87545
Phone: (505) 667-0723
Fax: (505) 665-4972
E-mail: jgrove@lanl.gov

Gubkov, E. V.
Russian Federal Nuclear Center-VNIIEF
Mir Avenue, 37, Sarov
Nizhnii Novgorod Region, 607190, Russia
Phone: (831-30) 450 09
Fax: (831-30) 459 58
E-mail: root@gdd.vniief.ru

Gulak, Y.
Department of Mechanical and Aerospace Engineering
Rutgers University
98 Brett Rd.
Piscataway, NJ 08854
Phone: (732) 445-5627
Fax: (732) 445-3124
E-mail: YGULAK@RCI.RUTGERS.EDU

Gupta, S.
Department of Mechanical and Aerospace Engineering
Rutgers University
98 Brett Rd.
Piscataway, NJ 08854
Phone: (732) 445-5627
Fax: (732) 445-3124

Haan, Steven W.
Lawrence Livermore National Laboratory
P.O. Box 808, L-023
Livermore, CA 94551
Phone: (925) 422-4715
Fax: (925) 423-8945
E-mail: haan1@llnl.gov

Haas, Jean Francois
Commissariat à l'Energie Atomique
CEA/DIF/DCRE/SCSE BP 12
Bruyeres le Chatel, 91680
France
Phone: 33-1-69-26-52-94
Fax: 33-1-69-26-70-62
E-mail: jean-francois.haas@cea.fr

Harlow, Francis H.
Los Alamos National Laboratory
P.O. Box 1663, MS B216
Los Alamos, NM 87545
Phone: (505) 667-9090
E-mail: fhharlow@lanl.gov

Hatchett, Stephen P.
Lawrence Livermore National Laboratory
P.O. Box 808, L-016
Livermore, CA 94551
Phone: (925) 422-5916
Fax: (925) 423-5112
E-mail: hatchett1@llnl.gov

Hauer, A.
Los Alamos National Laboratory
P.O. Box 1663
Los Alamos, NM 87545
Phone: (505) 667-5167
Fax: (505) 667-0405
E-mail: hauer@lanl.gov

Hébert, C. H.
Department of Mechanical Engineering
Université de Sherbrooke
Sherbrooke, Quebec J1K 2R1 Canada

Hinkel, Denise
Lawrence Livermore National Laboratory
P.O. Box 808, L-038
Livermore, CA 94551
Phone: (925) 423-2626
Fax: (925) 423-2157
E-mail: hinkel1@llnl.gov

Holder, David
Atomic Weapons Establishment
Building H27, Aldermaston
Reading, Berkshire, RG7 4PR, United Kingdom
Phone: 0118 982 5592
Fax: 0118 982 4816
E-mail:: david.holder@awe.co.uk

Holford, Joanne M.
University of Cambridge
Silver Street
Cambridge , UK CB3 9EW
Phone: +44 1223 337858
Fax: +44 1223 337918
E-mail:: J.M.Holford@DAMTP.CAM.AC.UK

Holmes, Richard L.
Los Alamos National Laboratory
P.O. Box 1663, MS B220
Los Alamos, NM 87545
Phone: (505) 667-3598
Fax: (505) 665-2227
E-mail: holmes@lanl.gov

Hosseini, S. H. R.
Shock Wave Research Center, Institute of Fluid Science
Tohoku University
2-1-1 Katahira, Aoba-ku
Sendai 980-77, Japan
E-mail:: hosseini@rainbow.ifs.tohoku.ac.jp

Houas, Lazhar
I.U.S.T.I. / Umr CNRS 6595
Technopole de Chateau Gombert
5 rue Enrico Fermi
13453 Marseille Cedex 13 France
Phone: 33 (0)4 91 10 69 30
Fax: 33 (0)4 91 10 69 69
E-mail: houas@iusti.univ-mrs.fr

Hsing, Warren W.
Lawrence Livermore National Laboratory
P.O. Box 808, L-21
Livermore, CA 94551
Phone: (925) 423-2849
Fax: (925) 423-8945
E-mail:: hsing@llnl.gov

Hurricane, Omar
Lawrence Livermore National Laboratory
P.O. Box 808, L-22
Livermore, CA 94551
Phone: (925) 424-2701
Fax: (925) 423-0925
E-mail: hurricane1@llnl.gov

Inogamov, Nail
Landau Inst. for Theor. Phys.
Kosygnina St. 2, Moscow
117940, GSP-1
V-334 RUSSIA
Phone: 095 425 8767
FAX: 095 938 2077
E-mail: itf@ips.ac.msk.su

Jacobs, Jeffrey W.
Department of Aerospace and Mechanical Engineering
University of Arizona
Bldg. 16, Room 301
Tucson, AZ 85721
Phone: (602) 621-8459
Fax: (602) 621-8191
E-mail: jacobs@ame.arizona.edu

Jameson, Leland M.
Lawrence Livermore National Laboratory
P.O. Box 808, L-312
Livermore, CA 94551
Phone: (925) 424-6160
E-mail: jameson3@llnl.gov

Jones, Oggden
Lawrence Livermore National Laboratory
P.O. Box 808, L-030
Livermore, CA 94551
Phone: (925) 423-1872
Fax: (925) 423-9969
E-mail:: jones96@llnl.gov

Jourdan, Georges
Universite de Provence
IUSTI-CNRS Umr 139
Centre Saint Jerome -- Case 321
13397 Marseille Cedex 20 France
Phone: 33 (0) 491106930
Fax: 33 (0) 491106969
E-mail: jourdan@iusti-dipha.univ-mrs.fr

Kalantar, Daniel
Lawrence Livermore National Laboratory
P.O. Box 808, L- 472
Livermore, CA 94551
Phone: (925) 422-6147
Fax: (925) 422-8395
E-mail: kalantar1@llnl.gov

Kamm, R. J.
Los Alamos National Laboratory
P.O. Box 1663
Los Alamos NM, 87545
Phone: (505) 667-1918
E-mail:: kammj@lanl.gov

Kane, Jave O.
Lawrence Livermore National Laboratory
P.O. Box 808, L-411
Livermore, CA 94551
Phone: (925) 424-5805
Fax: (925) 423-2463
E-mail:: jave@llnl.gov

Kang, Young-Gwang
Kwangju Institute of Science and Technology
1 Oryong-dong
Kwangju, 500-712, South Korea
Phone: 82-62-970-2310
Fax: 82-62-970-2304
E-mail: ygkang@kjist.ac.kr

Kartoon, Daniela
Department of Physics
Nuclear Research Center Negev
P.O. Box 9001
Beer-Sheva, 84190, Israel
Phone: 972-8-6568845
Fax: 972-8-6567878
E-mail:: danyk@bgumail.bgu.ac.il

Keiter, P.
University of Michigan
Space Research Lab, Rm 1216
2245 Hayward
Ann Arbor, MI 48104

Kerstein, Alan R.
Sandia National Laboratory
P.O. Box 969, MS 9051
Livermore, CA 94551-0969
Phone: (925) 294-2390
Fax: (925) 294-1004
E-mail: kerstein@ca.sandia.gov

Kim, H.
Department of Mechanical and Aerospace Engineering
Rutgers University
98 Brett Rd.
Piscataway, NJ 08854

Klein, Richard I.
Lawrence Livermore National Laboratory
P.O. Box 808, L-023
Livermore, CA 94551
Phone: (925) 422-3548
Fax: (925) 423-0925
E-mail: rklein@llnl.gov

Knauer, J.
Department of Mechanical and Aerospace Engineering
Rutgers University
98 Brett Rd.
Piscataway, NJ 08854

Kobayashi, K.
Osaka University
2-6, Yamada-oka, Suita,
Osaka 565-0871 Japan

Korreck, K. E.
University of Michigan
Space Research Lab, Rm 1216
2245 Hayward
Ann Arbor, MI 48104

Kozelkov, O. E.
Russian Federal Nuclear Center-VNIITF
P.O. Box 245
456770 Snezhinsk, Russia

Kozlov, V. I.
Russian Federal Nuclear Center-VNIIEF
Mir Avenue, 37, Sarov
Nizhnii Novgorod Region, 607190 Russia
Fax: (831-30) 4-57-72
E-mail: otd1_0903@spd.vniief.ru

Ktitorov, Vladimir M.
Russian Federal Nuclear Center-VNIIEF
Mir Avenue, 37, Sarov
Nizhnii Novgorod Region, 607190 Russia
Phone: 831-30 1-36-65
Fax: 831-30 5-45-65
E-mail: mvn_072e@rfnc.nnov.su

Kucherenko, Yuri A.
Russian Federal Nuclear Center-VNIITF
P.O. Box 245
456770 Snezhinsk, Russia
Fax: (351-72) 3 20 77
E-mail: kucherenko@five.ch70.chel.su

Kuhl, Allen L.
Lawrence Livermore National Laboratory
P.O. Box 808, L-30
Livermore, CA 94551
Phone: (925) 422-4777
Fax: (925) 424-6764
E-mail: kuhl2@llnl.gov

Kumar, M.
Department of Physics
Nuclear Research Center Negev
P.O. Box 9001
Beer-Sheva, 84190, Israel

Kushnir, D.
Department of Physics
Nuclear Research Center Negev
P.O. Box 9001
Beer-Sheva, 84190, Israel

Lanier, N. E.
Los Alamos National Laboratory
P.O. Box 1663, MS
Los Alamos NM, 87545
Phone: (505) 665-0236
Fax: (505) 665-3686
E-mail:: nlanier@lanl.gov

Lasinski, Barbara F.
Lawrence Livermore National Laboratory
P.O. Box 808, L-038
Livermore, CA 94551
Phone: (925) 422-5443
Fax: (925) 423-9208
E-mail:: blasinski@llnl.gov

Lassis, A.
Commissariat à l'Energie Atomique
BP 12
Bruyeres le Chatel, 91680, France

Layes, G.
IUSTI
Technopole Chateau-Gombert – 5,
Rue Enrico Fermi
Marseille, 13013 France

Lebedev, Alexander
Russian Federal Nuclear Center-VNIIEF
Mir Avenue, 37, Sarov
Nizhnii Novgorod Region, 607190, Russia
Phone: (831-30) 450 09
Fax: (831-30) 459 58
E-mail: root@gdd.vniief.ru

Lebo, Ivan
Laser Fusion Department
PN Lebedev Physics Institute
Leninsky prospect 53
117294 Russia, Moscow
Phone: 095-132-68-47
Fax: 095-132-11-96
E-mail: lebo@sci.fian.msk.su

Legrand, Michel
Commissariat à l'Energie Atomique
DAM Ile de France
BP12, Bruyeres le Chatel, 91680, France
Phone: 33-1-69-26-57-09
Fax: 33-1-69-26-70-94
E-mail: michel.legrand@cea.fr

Levy, Kedem
Physics Department
Ben Gurion University of the Negev
P.O. B 653, Beer-Sheva 84105, Israel
Phone: 972-8-6568844
Fax: 972-8-6567878
E-Mail: klevy@bgumail.bgu.ac.il

Li, Xiaolin
Department of Applied Mathematics and Statistics
State University of New York at Stony Brook
1-119 Math Tower
Stony Brook, NY 11794-3600
Phone: (631) 632-8353
Fax: (631) 632-8490
E-mail: linli@ams.sunysb.edu

Linn, Rodman R.
Los Alamos National Laboratory
P.O. Box 1663
Los Alamos NM, 87545
Phone: (505) 665-6254
E-mail:: rrl@lanl.gov

Llor, Antoine
Commissariat à l'Energie Atomique
BP 12
Bruyeres le Chatel, 91680, France
Phone: 33 1 69 26 49 38
Fax: 33 1 69 26 70 97
E-mail: antoine.llor@cea.fr

Logvinov, A.
Russian Federal Nuclear Center, VNIIEF
Mir Avenue, 37, Sarov
Nizhnii Novgorod Region, 607190, Russia
E-mail: root@gdd.vniief.ru

Lorenz, Karl T.
Lawrence Livermore National Laboratory
P.O. Box 808, L-472
Livermore, CA 94551
Phone: (925) 424-4200
E-mail: lorenz3@llnl.gov

Louis, Hedley
Lawrence Livermore National Laboratory
P.O. Box 808, L-472
Livermore, CA 94551
Phone: (925) 4242-9937
E-mail: louis1@llnl.gov

Loveridge –Smith, A.
Oxford University
University Offices
Wellington, Oxford, OX1 2JD UK
Phone: +44 1865 270000
Fax: +44 1865 270708

MacNeice, P.
NASA Goddard Space Flight Center
Greenbelt, MD

Magelssen, Glenn R.
Los Alamos National Laboratory
P.O. Box 1663
Los Alamos NM, 87545
Phone: (505) 667-6519
E-mail:: grm@lanl.gov

Magnaudet, J.
Institut de Mécanique des Fluides de Toulouse
31400 Toulouse
Toulouse, France

Marchese, A.
State University of New York at Stony Brook
P-138A Math Tower
Stony Brook, NY 11794-3600

Marinak, Michael M.
Lawrence Livermore National Laboratory
P.O. Box 808, L-023
Livermore, CA 94551
Phone: (925) 423-8458
Fax: (925) 423-9969
E-mail:: marinak1@llnl.gov

Matsuoka, C.
10-13,Dogo-Himata,Matsuyama 790-8577
Japan

Mazilin, I. M.
Krzhizhanovsky Power Engineering Institute
ENIN, Leninsky pr. 19, GSP-1
Moscow, 117927 Russia

McAbee, Thomas L.
Lawrence Livermore National Laboratory
P.O. Box 808, L-170
Livermore, CA 94551
Phone: (925) 422-3398
Fax: (925) 424-2723
E-mail: mcabee@viper.llnl.gov

McCray, R.
University of Colorado, Boulder
Colorado 80309
Phone: (303) 492-1411

McKenty, P. W.
Laboratory for Laser Energetics
University of Rochester
250 East River Road
Rochester, New York 14623-1299

Medvedev, V. M.
Russian Federal Nuclear Center-VNIITF
P.O. Box 245
456770 Snezhinsk, Russia

Meiron, Daniel I.
Department of Applied and Computational Mathematics
California Institute of Technology
MC 217-50
Pasadena, CA 91125
Phone: (626) 395-4563
Fax: (626) 578-0124
E-mail: dim@acm.caltech.edu

Meshkov, Evgeni E.
Russian Federal Nuclear Center-VNIIEF
Mir Avenue, 37, Sarov
Nizhnii Novgorod Region, 607190, Russia
Fax: 831-305-4565
E-mail: root@gdd.vniief.ru

Meyers, M. A.
University of California at San Diego
9500 Gilman Drive
La Jolla, CA 92093-0411

Mikaelian, Karnig O.
Lawrence Livermore National Laboratory
P.O. Box 808, L-97
Livermore, CA 94551
Phone: (925) 422-5449
Fax: (925) 423-7228

Mikhaylov, A. L.
Russian Federal Nuclear Center, VNIIEF
Mir Avenue, 37, Sarov
Nizhnii Novgorod Region, 607190, Russia
E-mail: root@gdd.vniief.ru

Miles, Aaron
Lawrence Livermore National Laboratory
P.O. Box 808, L-12
Livermore, CA 94551
Phone: (925) 423-8131
Fax: (925) 422-8920
E-Mail: miles15@llnl.gov

Miller, Paul L.
Lawrence Livermore National Laboratory
P.O. Box 808, L-22
Livermore, CA 94551
Phone: (925) 423-6455
Fax: (925) 423-0925
E-mail: pmiller@llnl.gov

Minich, Roger
Lawrence Livermore National Laboratory
P. O. Box 808, L-097
Livermore, CA 94551
Phone: (925) 422-4552
Fax: (925) 422-0779
E-mail:: minich1@llnl.gov

Miyanaga, N.
Osaka University
2-6, Yamada-oka, Suita,
Osaka 565-0871 Japan

Mizuta, A.
Osaka University
2-6, Yamada-oka, Suita,
Osaka 565-0871 Japan

Montlaurent, P.
Commissariat à l'Energie Atomique
BP 12, 91680
Bruyeres-le-Chatel, France

Moreno, Juan
Lawrence Livermore National Laboratory
P. O. Box 808, L-031
Livermore, CA 94551
Phone: (925) 423-4170
Fax: (925) 424-6764
E-mail:: jcmoreno@llnl.gov

Morris, A. P.
Atomic Weapons Establishment
Aldermaston
Reading
Berkshire RG7 4PR England

Munro, David H.
Lawrence Livermore National Laboratory
P. O. Box 808, L-023
Livermore, CA 94551
Phone: (925) 422-5428
Fax: (925) 423-9969
E-mail:: dmunro@llnl.gov

Murphy, T. J.
Los Alamos National Laboratory
P.O. Box 1663
Los Alamos NM, 87545
Phone: (505) 665-5697
Fax: (505) 996-4366
E-mail:: tjmurphy@lanl.gov

Murzakov, V. D.
Russian Federal Nuclear Center-VNIITF
P.O. Box 245
456770 Snezhinsk, Russia

Nagatomo, H.
Osaka University
2-6, Yamada-oka, Suita,
Osaka 565-0871 Japan

Nakai, M.
2-6, Yamada-oka, Suita,
Osaka 565-0871 Japan

Nash, Jeffrey K.
Lawrence Livermore National Laboratory
P. O. Box 808, L-15
Livermore, CA 94551
Phone: (925) 422-7255
E-mail:: jknash@llnl.gov

Neuvazhayev, Vladimir
Russian Federal Nuclear Center-VNIITF
P.O. Box 245
456770 Snezhinsk, Russia
Phone: 351-72-55675
Fax: 351-72-32077
E-mail: nio3@ch70.chel.su

Nevmerzhitsky, Nikolay
Russian Federal Nuclear Center, VNIIEF
Mir Avenue, 37, Sarov
Nizhnii Novgorod Region, 607190, Russia
Phone: (831-30) 450 09
Fax: (831-30) 459 58
E-mail: root@gdd.vniief.ru

Niederhaus, Charles E.
NASA Glenn Research Center
21000 Brookpark Rd., MS-77-5
Cleveland, OH 44135
Phone: (216) 433-5461
Fax: (216) 433-8050
E-mail:: charles.niederhaus@grc.nasa.gov

Nikishin, Vladislav
Institute for Mathematical Modeling (IMM)
Russian Academy of Science
Miusskaya 4a, 125047, Moscow, Russia
Phone: 007(095) 250-79-35
Fax: 007(095) 972-07-23
E-mail: nikishin\#4@imamod.msk.su

Nikulin, A.
Russian Federal Nuclear Center-VNIIEF
Mir Avenue, 37, Sarov
Nizhnii Novgorod Region, 607190 Russia
E-mail:: root@gdd.vniief.ru

Nishihara, Katsunobu
Institute of Laser Engineering
Osaka University
2-6, Yamada-oka, Suita,
Osaka 565-0871 Japan
Phone: 81-6-6879-8725
Fax: 81-6-6877-4799
E-mail: nishihara@ile.osaka-u.ac.jp

Nishikino, M.
2-6, Yamada-oka, Suita,
Osaka 565-0871 Japan

Nizovtsev, P. N.
Russian Federal Nuclear Center-VNIIEF
Mir Avenue, 37, Sarov
Nizhnii Novgorod Region, 607190 Russia
E-mail:: root@gdd.vniief.ru

Nomoto, K.
University of Tokyo
7-3-1 Hongo, Bunkyo-ku, Tokyo 113-8654, Japan
Phone: +81-3-3812-2111

Oakley, J. G.
Department of Engineering. Physics
University of Wisconsin at Madison
1500 Engineering Drive
Madison, WI 53706

Olson, K.
NASA Goddard Space Flight Center
Greenbelt, MD

Oparin, A. M.
Institute for Computer Aided Design,
Vtoraya Brestskaya ul., 19/18, 123056
Moscow, Russia
Phone: (095) 250-96-30
Fax: (095) 250-89-28
E-mail: oparin@cpd.landau.ac.ru

Oron, Dan
Department of Physics
Nuclear Research Center - Negev
P.O. Box 9001
Beer-Sheva, 84190, Israel
Phone: 972-7-6568736
Fax: 972-7-6567878
E-mail: danor@bgumail.bgu.ac.il

Paisley, Dennis
Los Alamos National Laboratory
P.O. Box 1663
Los Alamos NM, 87545
Phone: (505) 667-7837
E-mail:: dxp@lanl.gov

Pantano, C.
University of California at San Diego
9500 Gilman Drive
La Jolla, CA 92093-0411

Parker, Kenneth W.
Atomic Weapons Establishment
Aldermaston
Reading
Berkshire RG7 4PR England
Phone: +44 118 9827578
Fax: +44 118 9824844
E-mail:: Kenneth.W.Parker@awe.co.uk

Parshukov, I. E.
Russian Federal Nuclear Center-VNIITF
P.O. Box 245
456770 Snezhinsk, Russia

Peng, O.
Rutgers University
98 Brett Rd.
Piscataway, NJ 08854

Perry, Theodore S.
Lawrence Livermore National Laboratory
P.O. Box 808, L-23
Livermore, CA 94551
Phone: (925) 423-2065
Fax: (925) 424-3294
E-mail: tedperry@llnl.gov

Peyser, Thomas A.
Lawrence Livermore National Laboratory
P.O. Box 808, L-23
Livermore, CA 94551
Phone: (925) 423-6454
Fax: (925) 423-0925
E-mail: tpeyser@llnl.gov

Piskunov, Yu. A.
Russian Federal Nuclear Center-VNIITF
P.O. Box 245
456770 Snezhinsk, Russia

Polionov, Arkadi
Russian Federal Nuclear Center
Institute of Technical Physics
Chelyabinsk 70
P.O. Box 245, Russia
Phone: 351-722-3977
Fax: 351-723-2077
E-mail: nio3@ch70.chel.su

Pollaine, Steven
Lawrence Livermore National Laboratory
P.O. Box 808, L-30
Livermore, CA 94551
Phone: (925) 422-5950
Fax: (925) 423-9208
E-mail: pollaine@llnl.gov

Popov, V. N.
Russian Federal Nuclear Center-VNIITF
P.O. Box 245
456770 Snezhinsk, Russia

Pound, M.
University of Maryland
College Park, MD 20742
Phone (301) 405-1000

Prestridge, Katherine P.
Los Alamos National Laboratory
P.O. Box 1663, MS P940
Los Alamos NM, 87545
Phone: (505) 667-8861
Fax: (505) 665-3359
E-mail: kpp@lanl.gov

Pullin, Dale I.
Department of Aeronautics
California Institute of Technology
1200 East California Boulevard, MS 105-50
Pasadena, CA 91125
Phone: (626) 395-6081
Fax: (626) 441-2222
E-mail:: dale@galcit.caltech.edu

Pylaev, Anatoly
Russian Federal Nuclear Center-VNIITF
P.O. Box 245
456770 Snezhinsk, Chelyabinsk region, Russia
Fax: (351-72) 3 20 77
E-mail: kucherenko@five.ch70.chel.su

Radha, P. B.
Laboratory for Laser Energetics
University of Rochester
Rochester, NY 14623-1299

Raevskii, Viktor
All Russian Sci & Research Institute of Experimental Physics
607200, Arzamas - 16
Nizhny Novgorod Region, Russia
Fax: 831-305-4565
E-mail: otd3_2305@rfnc.nnov.su

Rampaprabhu, P.
Department of Mechanical Engineering
Texas A & M University
MS 3123
College Station, TX 77843-3123

Raviard, P. A.
Commissariat à l’Energie Atomique
BP 12, 91680
Bruyeres-le-Chatel, France

Rayer, C.
Commissariat à l’Energie Atomique
BP 12, 91680
Bruyeres-le-Chatel, France

Razin, A. N.
Russian Federal Nuclear Center-VNIIEF
Mir Avenue, 37, Sarov
Nizhnii Novgorod Region, 607190
E-mail:: root@gdd.vniief.ru

Rebrov, S. V.
Russian Federal Nuclear Center-VNIIEF
Mir Avenue, 37, Sarov
Nizhnii Novgorod Region, 607190
E-mail:: root@gdd.vniief.ru

Remington, Bruce A.
Lawrence Livermore National Laboratory
P.O. Box 808, L-21
Livermore, CA 94551
Phone: (925) 423-2712
Fax: (925) 422-8395
E-mail: remington2@llnl.gov

Renaud, Francois
Commissariat à l'Energie Atomique
CEA/DRIF/DCSA/SET
BP 12, 91680
Bruyeres-le-Chatel, France
Phone: 33 1 69 26 40 81
Fax: 33 1 69 26 71 02

Ricker, P.
University of Chicago
933 East 56th Street
Chicago, IL 60637

Rider, William J.
Los Alamos National Laboratory
P.O. Box 1663, MS D413
Los Alamos NM, 87545
Phone: (505) 665-4162
Fax: (505) 667-3726
E-mail: wjr@lanl.gov

Rightley, Paul M.
Los Alamos National Laboratory
P.O. Box 1663, MS P940
Los Alamos NM, 87545
Phone: (505) 667-0460
Fax: (505) 665-3359
E-mail: pright@lanl.gov

Rikanati, Avi
Physics Department
Nuclear Research Center - Negev
P.O. Box 9001
Beer-Sheva, 84190, Israel
Phone: 972-7-6568736
Fax: 972-7-6567878
E-mail: rkavi@bgumail.bgu.ac.il

Robey, Harry F.
Lawrence Livermore National Laboratory
P.O. Box 808, L-21
Livermore, CA 94551
Phone: (925) 423-5669
FAX: (925) 422-3358
E-mail: robey1@llnl.gov

Robinson, A.
Sandia National Laboratory
P.O. Box 969, MS 9051
Livermore, CA 94551-0969

Rosner, Robert L.
Enrico Fermi Institute and Laboratory for Astrophysics
and Space Research
University of Chicago
933 East 56th Street
Chicago, IL 60637
Phone: (773) 702-0560
Fax: (773) 704-3230
E-mail:: rosner@uchicago.edu

Rothman, S.
Atomic Weapons Establishment
Aldermaston
Reading
Berkshire RG7 4PR England

Roualdes, P.
Centre d'Etudes de Gramat
Gramat. France

Rozanov, I. A.
Lebedev Physical Institute
Leninsky Pr. 53
117924, Moscow, Russia
E-mail:: Rozanov@sci.lebedev.ru

Rozanov, Vladislav
Lebedev Physical Institute
Leninsky Pr. 53
117924, Moscow, Russia
Phone: (095)-132-68-47
Fax: (095)-132 -11-96
E-mail: lebo@neur.lpi.msk.su

Ryutov, Dimitri D.
Lawrence Livermore National Laboratory
P.O. Box 808, L-630
Livermore, CA 94551
Phone: (925) 422-9832
E-mail: ryutov1@llnl.gov

Sadot, Oren
Department of Physics
Nuclear Research Center - Negev
P.O.B. 9001, Beer-Sheva 84109, Israel
Phone: 972-7-6567278
Fax: 972-7-6567878
E-mail: sorens@bgumail.bgu.ac.il

Sakaiya, T.
Institute of Laser Engineering
Osaka University
2-6 Yamadaoka Suita
Osaka, 565 Japan

Samtaney, Ravi
Department of Aeronautics
California Institute of Technology
MS 205-45
Pasadena, CA 91125
Phone: (626) 395-8030
Fax: (626) 449-2677
E-mail: ravi@ama.caltech.edu

Sapozhnikov, I. V.
Russian Federal Nuclear Center-VNIIEF
Mir Avenue, 37, Sarov
Nizhnii Novgorod Region, 607190, Russia

Sarid, Eli
Physics Department
Nuclear Research Center - Negev
P.O. Box 9001
Beer-Sheva, 84190, Israel
Phone: 972-7-6568736
Fax: 972-7-6567878
E-mail: fnsarid@weizmann.weizmann.ac.il

Sarkar, Sutanu
Department of Mechanical and Aerospace Engineering
University of California at San Diego
9500 Gilman Drive
La Jolla, CA 92093-0411
Phone: (858) 534-8243
Fax: (858) 534-7599
E-mail:: sarkar@mae.ucsd.edu

Schilling, Oleg
Lawrence Livermore National Laboratory
P.O. Box 808, L-22
Livermore, CA 94551
Phone: (925) 423-6879
Fax: (925) 423-0925
E-mail: schilling1@llnl.gov

Schurtz, G.
Commissariat à l'Energie Atomique
CEA/DRIF/DCSA/SET
BP12, 91680 Bruyeres-le-Chatel, France

Schwaederlè, Laurent
IUSTI
Technopole Chateau-Gombert – 5,
Rue Enrico Fermi
Marseille, 13013 France
Phone: 04 91 10 69 35
Fax: 04 91 10 69 69
E-Mail: schwaed@iusti.univ-mrs.fr

Sharp, David H.
Los Alamos National Laboratory
P.O. Box 1663, MS B285
Los Alamos, NM 87545
Phone: (505) 667-5266
Fax: (505) 665-3003
E-mail: dhs@lanl.gov

Shestachenko, Oleg
Russian Federal Nuclear Center-VNIITF
P.O. Box 245
456770 Snezhinsk, Chelyabinsk region, Russia
Fax: (351-72) 3 20 77
E-mail: kucherenko@five.ch70.chel.su

Shestakov, Alex
Lawrence Livermore National Laboratory
P.O. Box 808, L-38
Livermore, CA 94551
Phone: (925) 422-4213
Fax: (925) 423-9208
E-mail: shestakov1@llnl.gov

Shigemori, K.
Institute of Laser Engineering
Osaka University
2-6 Yamadaoka Suita
Osaka, 565 Japan

Shiraga, H.
Institute of Laser Engineering
Osaka University
2-6 Yamadaoka Suita
Osaka, 565 Japan

Shu, Chi-Wang
Division of Applied Mathematics
Brown University
Providence, RI 02912
Phone: (401) 863-2549
E-mail:: Chi-Wang_Shu@brown.edu

Shvarts, Dov
Department of Physics
Nuclear Research Center - Negev
P.O. Box 9001
Beer-Sheva, 84190, Israel
Phone: 972-7-6567500
Fax: 972-7-6567665
E-mail: shvarts@bgumail.bgu.ac.il

Silvani, X.
Institut de Mécanique des Fluides de Toulouse
31400 Toulouse
Toulouse, France

Sinitsina, S. N.
Russian Federal Nuclear Center-VNIIEF
Mir Avenue, 37, Sarov
Nizhnii Novgorod Region, 607190, Russia
E-mail:: root@gdd.vniief.ru

Sinkova, O. G.
Russian Federal Nuclear Center-VNIIEF
Mir Avenue, 37, Sarov
Nizhnii Novgorod Region, 607190, Russia
E-mail:: root@gdd.vniief.ru

Skupsky, S.
Laboratory for Laser Energetics
University of Rochester
Rochester, NY 14623-1299

Smalyuk, V. A.
Laboratory for Laser Energetics
University of Rochester
Rochester, NY 14623-1299

Smith, Alan V.
Building H27
Atomic Weapons Establishment
Aldermaston
Reading
Berkshire RG7 4PR England
Phone: 01189-825592
Fax: 01734-815320
E-mail: alan.smith@awe.co.uk

Sotskov, E.A.
Russian Federal Nuclear Center-VNIIEF
Mir Avenue, 37, Sarov
Nizhnii Novgorod Region, 607190, Russia
Fax: (831-30) 459 58
E-mail: root@gdd.vniief.ru

Souffland, Denis
Commissariat à l'Energie Atomique
CEA/DRIF/DCSA/SET
BP12, 91680 Bruyeres-le-Chatel, France
Phone: 33 1 69 26 59 77
Fax: 33 1 69 26 70 94
E-mail: soufflan@bruyeres.cea.fr

Srebro, Yair
Department of Physics
Ben-Gurion University of the Negev
Beer Sheva, 84105, Israel
Phone: 972-8-6568416
Fax: 972-8-656-7878
E-mail:: sibo@bgumail.bgu.ac.il

Stadnik, A. L.
Russian Federal Nuclear Center-VNIIEF
Mir Avenue, 37, Sarov
Nizhnii Novgorod Region, 607190, Russia
E-mail: root@gdd.vniief.ru

Statsenko, V. P.
Russian Federal Nuclear Center-VNIIEF
Mir Avenue, 37, Sarov
Nizhnii Novgorod Region, 607190, Russia
E-mail: root@gdd.vniief.ru

Steinkamp, Michael J.
Los Alamos National Laboratory
P.O. Box 1663, MS D413
Los Alamos, NM 87545
Phone: (505) 667-5837
Fax: (505) 667-3726
E-mail: steinmj@lanl.gov

Stoeckl, C.
Laboratory for Laser Energetics
University of Rochester
Rochester, NY 14623-1299

Stone, J.
University of Maryland
College Park, MD 20742
Phone (301) 405-1000

Sunahara, A.
Institute of Laser Engineering
Osaka University
2-6 Yamadaoka Suita
Osaka, 565 Japan
Phone: 81-6-879-8742
Fax: 81-6-877-4799
E-mail: suna@ile.osaka-u.ac.jp

Suter, Laurance
Lawrence Livermore National Laboratory
P. O. Box 808, L-031
Livermore, CA 94551
Phone: (925) 422-5423
Fax: (925) 423-9969
E-mail:: suter1@llnl.gov

Sviridov, E. V.
Russian Federal Nuclear Center-VNIITF
P.O. Box 245
456770 Snezhinsk, Russia

Takabe, Hideaki
Institute of Laser Engineering
Osaka University
Yamada-oka 2-6, Suita
Osaka 565, Japan
Phone: 81-6-877-5111 Ext. 6553
Fax: 81-6-877-4779
E-mail: takabe@ile.osaka-u.ac.jp

Takayama, Kazuyoshi
Shock Wave Research Center
Institute of Fluid Science
Tohoku University
2-1-1 Katahira, Aoba-ku
Sendai 980-77, Japan
Phone: 81-22-263-0895
Fax: 81-22-227-7390
E-mail: paul@bellanca.ifs.tohoku.ac.jp

Tamari, Y.
Institute of Laser Engineering (ILE)
Osaka University
2-6 Yamadoaka
Suita, Osaka 565-0871, Japan

Teyssier, R.
Commissariat a 'Energie Atomique
BP 12, 91680
Bruyeres-le-Chatel, France

Timmes, F.
University of Chicago
933 East 56th Street
Chicago, IL 60637

Tishkin, Vladimir
Institute for Mathematical Modeling
Russian Academy of Science
Miusskaya 4a
125047, Moscow, Russia
Phone: 007(095) 250-79-35
Fax: 007(095) 972-07-23
E-mail: tishkin@imamod.msk.su

Titov, S. N.
Krzhizhanovsky Power Engineering Institute
ENIN, Leninsky pr. 19, GSP-1
Moscow, 117927 Russia

Tomkins, Christopher
Los Alamos National Laboratory
P.O. Box 1663, MS 0454
Los Alamos, NM 87545
Phone: (505) 665-6228
Fax: (505) 665-4507
E-mail:: ctomkins@lanl.gov

Toqué, Nathalie
Universite de Montreal
#1, 6685 Saint Denis
Montreal, Canada H-85-851
Phone: 514-276-9014
E-mail:: Toque@astro.umontreal.ca

Tricottet, Matthieu
Commissariat à l'Energie Atomique
BP 12, 91680
Bruyeres-le-Chatel, France
E-mail:: Matthieu.Tricottet@cea.fr

Tufo, H.
University of Chicago
933 East 56th Street
Chicago, IL 60637

Turano, Edward J.
Lawrence Livermore National Laboratory
P.O. Box 808, L-15
Livermore, CA 94551
Phone: (925) 424-3508
E-mail:: turano1@llnl.gov

Turner, N.
University of Maryland
College Park, MD 20742
Phone (301) 405-1000

Tyaktev, A. A.
Russian Federal Nuclear Center-VNIITF
P.O. Box 245
456770 Snezhinsk, Russia

Uchayev, A. Ya.
Russian Federal Nuclear Center, VNIIEF
Mir Avenue, 37, Sarov
Nizhnii Novgorod Region, 607190, Russia

Vandenboomgaerde, Marc
Commissariat à l'Energie Atomique
BP 12, 91680
Bruyeres-le-Chatel, France
Phone: 33 01 69 26 66 68
Fax: 33 01 69 26 70 94
E-mail: marc.vandenboomgaerde@bruyeres.cea.fr

Verdon, Charles P.
Lawrence Livermore National Laboratory
P.O. Box 808, L-30
Livermore, CA 94551
Phone: (925) 423-4449
Fax: (925) 423-9969
E-mail:: verdon1@llnl.gov

Vlasov, Yu.
Russian Federal Nuclear Center, VNIIEF
Mir Avenue, 37, Sarov
Nizhnii Novgorod Region, 607190, Russia

Voelkl, Tobias
Department of Applied and Computational Mathematics
California Institute of Technology
M/C 217-50
Pasadena, CA 91125
Phone: (626) 395-8534
E-mail: tobias@its.caltech.edu

Vold, Erik L.
Los Alamos National Laboratory
P.O. Box 1663, MS D413
Los Alamos, NM 87545
Phone: (505) 665-5646
Fax: (505) 667-3726
E-mail: elv@lanl.gov

Volkov, V. I.
Russian Federal Nuclear Center-VNIITF
P.O. Box 245 456770
Snezhinsk, Chelyabinsk Region, Russia
E-mail: v.a.gordeychuk@vniitf.ru

Vorobieff, Peter V.
Department of Mechanical Engineering
University of New Mexico
ME Bldg. Rm. 424
Albuquerque, NM 87131
Phone: (505) 277-8347
Fax: (505) 277-1571
E-mail: kalmoth@me.unm.edu

Ward, David J.
Lawrence Livermore National Laboratory
P.O. Box 808, L-30
Livermore, CA 94551
Phone: (925) 423-3211
Fax: (925) 424-6764
E-mail: djw@llnl.gov

Ward, Richard A.
Lawrence Livermore National Laboratory
P.O. Box 808, L-13
Livermore, CA 94551
Phone: (925) 423-2679
Fax: (925) 422-4643
E-mail: raward@llnl.gov

Wark, J. S.
Oxford University
University Offices
Wellington, Oxford, OX1 2JD UK
Phone: +44 1865 270000
Fax: +44 1865 270708

Weber, Stephen V.
Lawrence Livermore National Laboratory
P.O. Box 808, L-16
Livermore, CA 94551
Phone: (925) 422-5433
Fax: (925) 423-9208
E-mail: svweber@llnl.gov

Wiley, Larry G.
Lawrence Livermore National Laboratory
P.O. Box 808, L-97
Livermore, CA 94551
Phone: (925) 423-2461
Fax: (925) 422-0779
E-mail: wiley1@llnl.gov

Wilson, P. N.
Department of Mechanical Engineering
Texas A & M University
MS 3123
College Station, TX 77843-3123

Wolfer, Wilhelm G.
Lawrence Livermore National Laboratory
P.O. Box 808, L-97
Livermore, CA 94551
Phone: (925) 423-1501
Fax: (925) 423-7040
E-mail:: wolfer1@llnl.gov

Wouchuk, Juan G.
E.T.S.I. Industriales
Universidad Castilla-La Mancha
Campus Universitario s/n
13071 Ciudad Real, Spain
Phone: (34) 926-29-53-00 x3826
Fax: (34) 926-29-53-61
E-mail: gwouchuk@ind-cr.uclm.es

Wunsch, Scott E.
Sandia National Laboratory
P.O. Box 969, MS 9051
Livermore, CA 94551-0969
Phone: (925) 294-4621
Fax: (925) 294-2595
E-mail: sewunsch@sandia.gov

Xu, Z.
State University of New York at Stony Brook
P-138A Math Tower
Stony Brook, NY 11794-3600

Yamada, Shoichi
Institute of Laser Engineering (ILE)
Osaka University
2-6 Yamadoaka
Suita, Osaka 565-0871, Japan
Phone: 81-6-6879-8747
Fax: 81-6-6879-8747
E-mail: syamada@ile.osaka-u.ac.jp

Yanilkin, Yury
Russian Federal Nuclear Center-VNIIEF
Mir Avenue, 37, Sarov
Nizhnii Novgorod Region, 607190, Russia
Phone: (831-30) 111 90
Fax: (831-30) 546 65
E-mail: yan@md08.vniief.ru

Yosef-Hai, Arnon
Department of Physics
Nuclear Research Center-Negev
P.O.B. 9001 Beer-Sheva, 84190, Israel
Phone: 972-8-6568913
Fax: 972-8-6567878
E-mail: ajoseph@bgumail.bgu.ac.il

Young, Y.-N.
University of Chicago
933 East 56th Street
Chicago, IL 60637

Youngs, David L.
Atomic Weapons Establishment
Building E3, AWE(A)
Reading, Berkshire
RG7 4PR, England
Phone: 0118 9826766
Fax: 0118 9815320
E-mail: dyoungs@awe.co.uk

Zabusky, Norman J.
Department of Mechanical and Aerospace Engineering
Rutgers University
98 Brett Rd.
Piscataway, NJ 08854
Phone: (732) 445-5869
Fax: (732) 445-3124
E-mail: nzabusky@caip.rutgers.edu

Zaytsev, Sergey G.
Krzhizhanovsky Power Engineering Institute
ENIN, Leninsky pr. 19, GSP-1
Moscow, 117927 Russia
Phone: (7-095) 955-31-07
Fax: (7-095) 954-42-50
E-mail: S.G.Zaytsev@mtu-net.ru

Zhakhovskii, V.
Institute of Laser Engineering
Osaka University
Suita, Osaka 565 Japan

Zhang, S.
Department of Mechanical and Aerospace Engineering
Rutgers University
98 Brett Rd.
Piscataway, NJ 08854

Zhang, Y.
State University of New York at Stony Brook
P-138A Math Tower
Stony Brook, NY 11794-3600

Zhmailo, Vadim A.
Russian Federal Nuclear Center-VNIIEF
Mir Avenue, 37, Sarov
Nizhnii Novgorod Region, 607190, Russia
Fax: 83130 54565
E-mail: rvg_092C@rfnc.nnov.su

Zhou, Ye K.
Lawrence Livermore National Laboratory
P.O. Box 808, L-23
Livermore, CA 94551
Phone: (925) 424-3624
E-mail:: zhou3@llnl.gov

Zingdale, N. V.
University of Chicago
933 East 56th Street
Chicago, IL 60637

Zmitrenko, Nikolay
Institute for Mathematical Modeling
Russian Academy of Science
Miusskaya 4a, 125047, Moscow, Russia
Phone: 007(095) 250-79-16
Fax: 007(095) 972-07-23
E-mail: nickzmit\#9@imamod.msk.su

Zoldi, Cindy A.
Los Alamos National Laboratory
P.O. Box 1663, MS B220
Los Alamos, NM 87544
Phone: (505) 667-6455
Fax: (505) 665-2227
E-mail: czoldi@lanl.gov

Zvorykin, V. D.
PN Lebedev Physics Institute
Leninsky prospect 53
117294 Russia, Moscow

Author Index