9th International Workshop on the Physics of Compressible Turbulent Mixing
Cambridge, UK
19-23 July 2004

Department of Applied Mathematics and Theoretical Physics
The University of Cambridge
Wilberforce Road, Cambridge CB3 0WA, ENGLAND
http://www.damtp.cam.ac.uk/ipwctm9/

Abstracts

See http://www.damtp.cam.ac.uk/iwpctm9/ for full colour version of abstracts.

Cover artwork: The main entrance to the Centre for Mathematical Sciences. Alison Hart/Stuart Dalziel
Logo: Rayleigh-Taylor instability in a tilted tank; based on an experiment by Joanne Holford.

Local Organizing Committee:

Stuart Dalziel (University of Cambridge)
Joanne Holford (University of Cambridge)[1]
David Leppinen (University of Cambridge)[2]
Robin Williams (AWE)
David Youngs (AWE)

International Scientific Committee:

Gabi Ben-Dor (Ben-Gurion University of the Negev, Beer-Sheeva)
Didier Besnard (CEA)
Tom Clark (LANL)
Stuart Dalziel (University of Cambridge)
Guy Dimonte (LANL)
Serge Gauthier (CEA)
James Glimm (Stony Brook)
Bruce Goodwin (LLNL)
Jean-Francois Haas (CEA)
Nelson Hoffman (LANL)
Lazhar Houas (IUSTI)
Jeff Jacobs (University of Arizona)
Yury Kucherenko (Russian Federal Nuclear Center-VNIITF)
Michel Legrand (CEA)
Dan Meiron (Caltech)
Evgueny Meshkov (Russian Federal Nuclear Center-VNIIEF)
Vladimir Neuvazhaev (Russian Federal Nuclear Center-VNIITF)
Tom Peyser (LLNL)
José Redondo (Universitat Politecnica de Catalunya, Barcelona)
Vladislav Rozanov (Lebedev Physical Institute, Moscow)
Oleg Schilling (LLNL)
David Sharp (LANL)
Dov Shvarts (Nuclear Research Center, Beer-Sheeva)
Eduard Son (Moscow Physical and Technical Institute)
Hideaki Takabe (University of Osaka)
Kazuyoshi Takayama (Tohoku University, Sendai)
David Youngs (AWE)
Sergey Zaytsev (ENIN, Moscow)

Previous workshops in series:

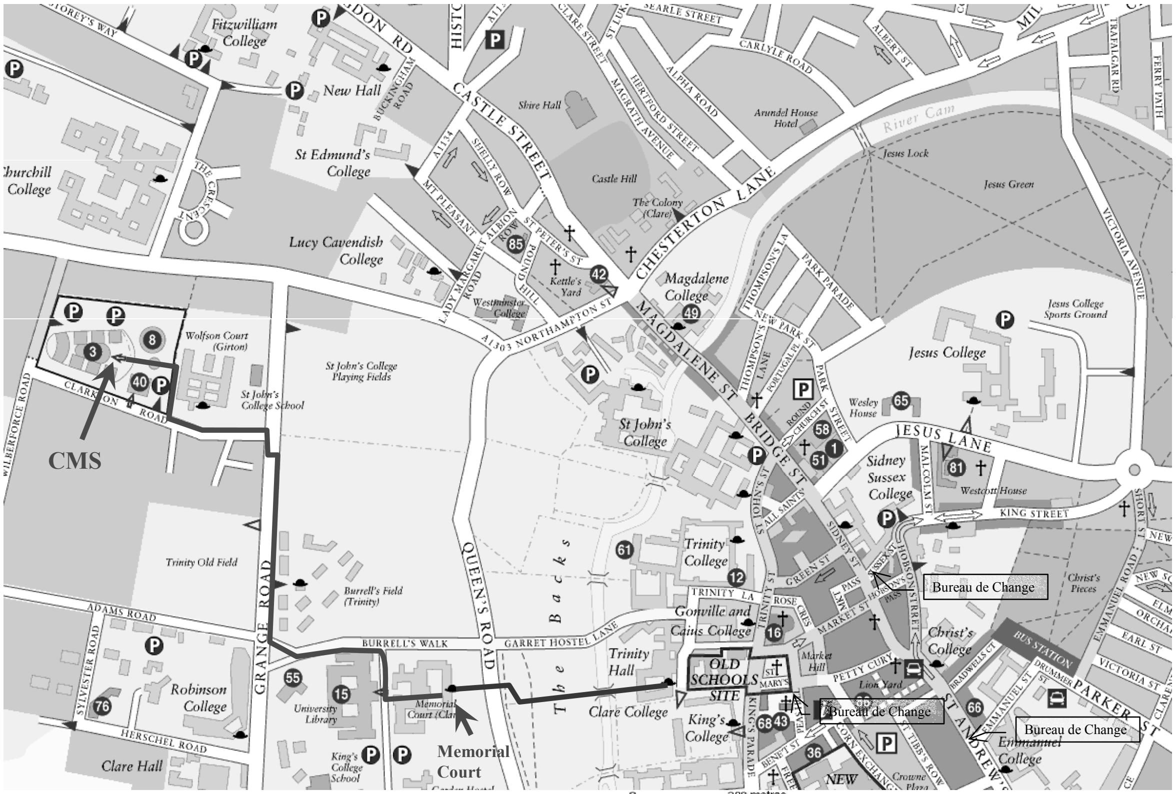
Princeton, NJ, USA (1988)
Pleasanton, CA, USA (1989)
Royaumont, France (1991)
Cambridge, UK (1993)
Stony Brook, NY, USA (1995)
Marseille, France (1997)
St. Petersburg, Russia (1999)
Pasadena, CA, USA (2001)

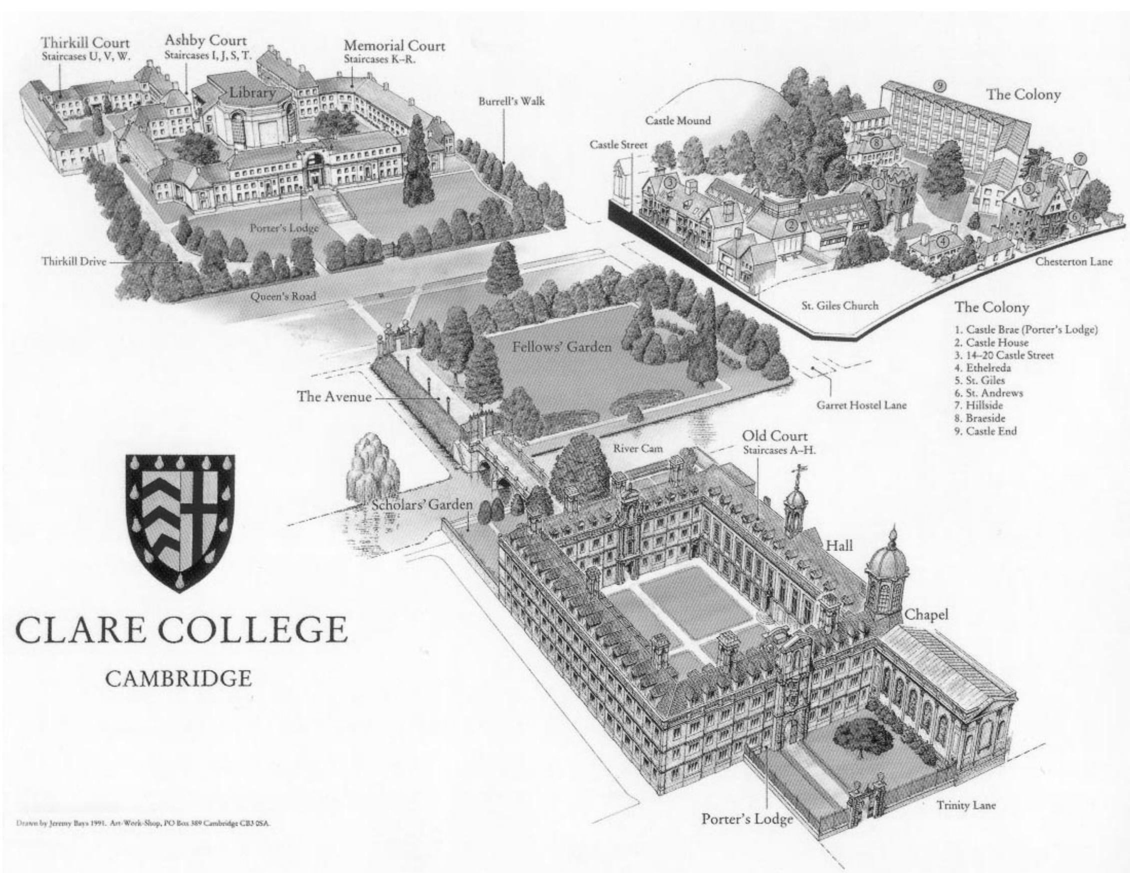
Sponsors:

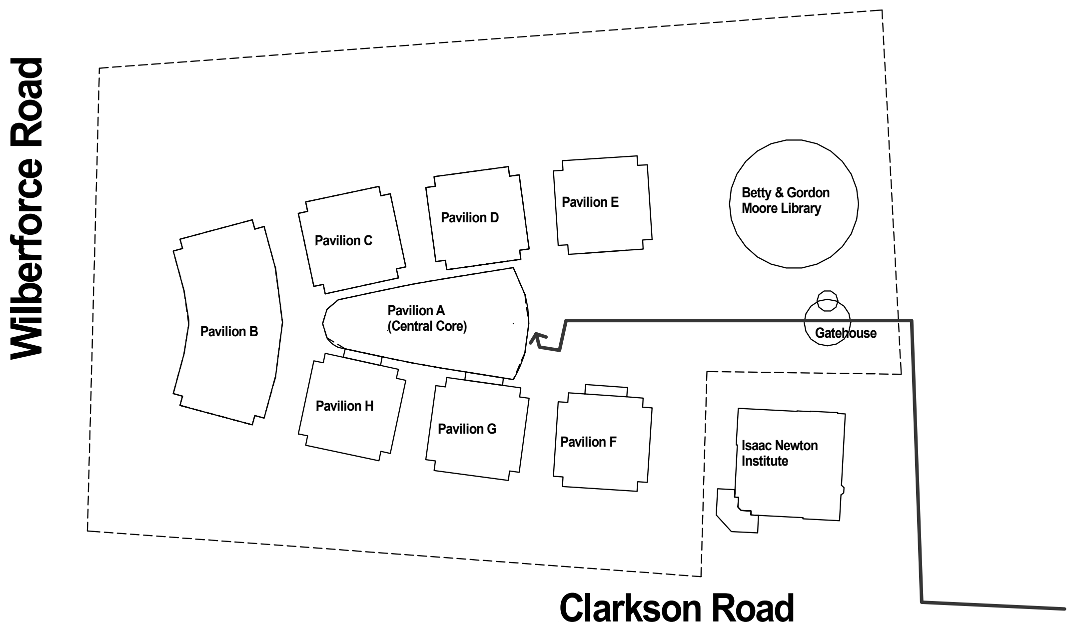
AWE, Aldermaston, UK
CEA/DAM, France

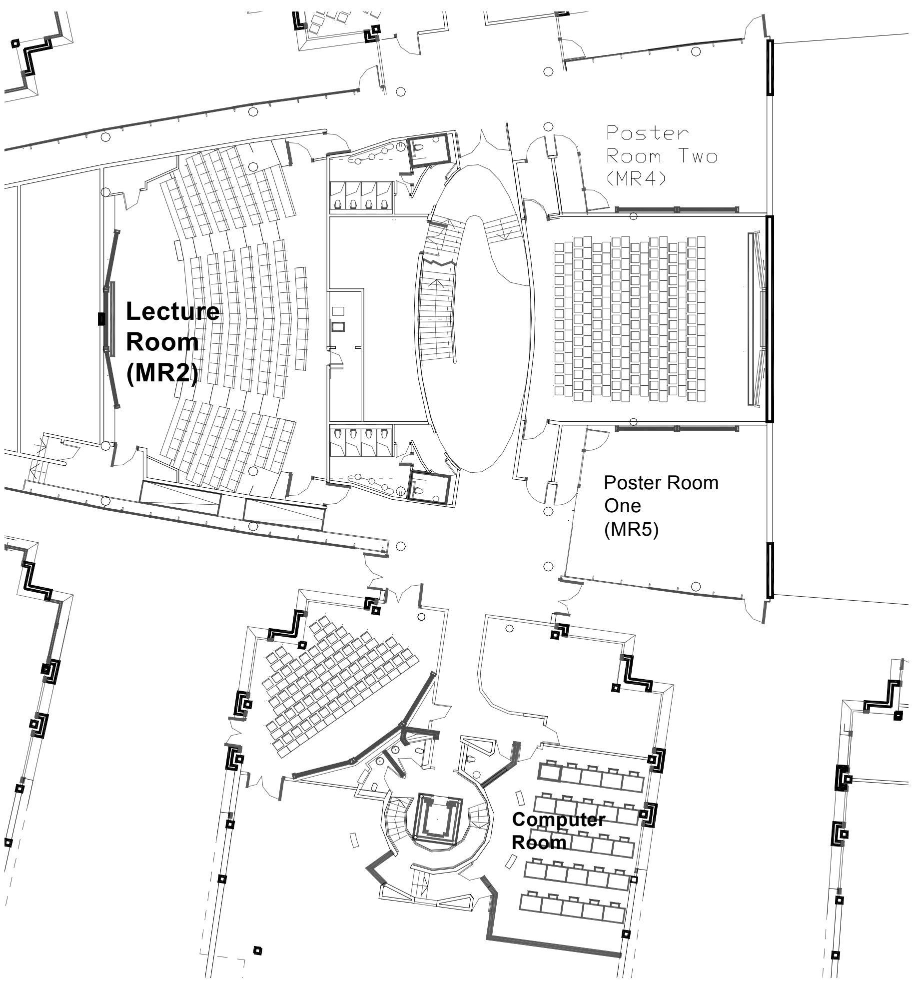
---

[1] 2002 [2] 2004


CMS
Memorial Court
Bureau de Change
Bureau de Change
Bureau de Change
Fitzwilliam College
New Hall
St Edmund's College
Lucy Cavendish College
Churchill College
Magdalene College
St John's College
Jesus College
Sidney Sussex College
Trinity College
Gonville and Caius College
Trinity Hall
Clare College
King's College
Christ's College
Emmanuel College
Robinson College
Clare Hall
Westminster College
Wolfson Court (Girton)
St John's College School
St John's College Playing Fields
Trinity Old Field
Burrell's Field (Trinity)
University Library
King's College School
Shire Hall
Castle Hill
The Colony (Clare)
Kettle's Yard
Jesus Green
Jesus Lock
Jesus College Sports Ground
Arundel House Hotel
Wesley House
Westcott House
Christ's Pieces
OLD SCHOOLS SITE
ST MARY'S
Market Hill
Lion Yard
River Cam
The Backs
CASTLE STREET
CHESTERTON LANE
MAGDALENE ST
BRIDGE ST
JESUS LANE
KING STREET
NORTHAMPTON ST
GRANGE ROAD
QUEEN'S ROAD
BURRELL'S WALK
GARRET HOSTEL LANE
CLARKSON ROAD
ADAMS ROAD
HERSCHEL ROAD
SYLVESTER ROAD
WILBERFORCE ROAD
HUNTINGDON RD
STOREY'S WAY
THE CRESCENT
MT PLEASANT
HUNTINGDON RD
TRINITY ST
TRINITY LA
KING'S PARADE
BENE'T ST
PETTY CURY
MARKET ST
GREEN ST
SIDNEY ST
HOBSON STREET
MALCOLM ST
PARK PARADE
THOMPSON'S LANE
PORTUGAL PL
ROUND CHURCH ST
PARK STREET
ALBERT ST
CARLYLE ROAD
ALPHA ROAD
SEARLE STREET
HERTFORD STREET
MAGRATH AVENUE
VICTORIA AVENUE
EMMANUEL ROAD
PARKER ST
BUS STATION
200 metres
200 yards


Thirkill Court
Staircases U, V, W.
Ashby Court
Staircases I, J, S, T.
Memorial Court
Staircases K–R.
Library
Burrell's Walk
Porter's Lodge
Thirkill Drive
Queen's Road
Castle Mound
Castle Street
The Colony
St. Giles Church
Chesterton Lane
The Colony
1. Castle Brae (Porter's Lodge)
2. Castle House
3. 14–20 Castle Street
4. Ethelreda
5. St. Giles
6. St. Andrews
7. Hillside
8. Braeside
9. Castle End
Fellows' Garden
The Avenue
Garret Hostel Lane
River Cam
Old Court
Staircases A–H.
Scholars' Garden
Hall
Chapel
CLARE COLLEGE
CAMBRIDGE
Porter's Lodge
Trinity Lane





Sketch plan of the Centre for Mathematical Sciences. All scientific sessions are on the Lower Ground floor, accessed by the stairs just inside the main doors. Oral presentations are in MR2, and poster presentations in MR4 and MR5. Refreshments will also be served in MR4 and MR5 at morning and afternoon breaks.

Sunday

08:00	Breakfast in Buttery *For those staying in Clare College only*
16:00	Registration opens Great Hall, Clare College
18:00	Drinks Scholars' Garden, Clare College
18:30	Welcome reception Great Hall, Clare College
20:00	College Bar opens

Reception menu (Clare College):

Buffet -- menu to be confirmed

Monday

07:45	Breakfast in Buttery *For those staying in Clare College only*
08:00	Registration desk opens at CMS
09:20	Welcome
Richtmyer-Meshkov instability	
09:40	On new possible directions of hydrodynamical instabilities and turbulent mixing investigations for the solution some practical problems E. Meshkov
10:20	The Mixing Transition in Rayleigh-Taylor Instability Andy Cook, Bill Cabot & Paul Miller
10:40	Break
Rayleigh-Taylor instability	
11:00	Experimental study into the turbulent mixing transition to a self-similar regime at constant acceleration of the interface of gases Yu.A. Kucherenko, O.E. Shestachenko, Yu.A. Piskunov, E.V. Sviridov, V.M. Medvedev & A.I. Baishev
11:20	Growth rate of mixing zone in a direct numerical simulation of Rayleigh-Taylor multimode instability development Vladislav Rozanov, Roman Stepanov, Mikhail Anuchin, Yury Yanilkin, Nadezhda Proncheva & Nikolai Zmitrenko
11:40	Spectral characteristics of turbulence driven by Rayleigh-Taylor instability Joanne Holford, Stuart Dalziel & David Youngs
12:00	3D numerical simulation of gravitational turbulent mixing with regard to molecular viscosity A.L. Studnik, V.P. Statsenko & Yu.V. Yanilkin
12:20	Discussion
12:40	Lunch Wolfson Court

Poster session 1		
14:20	Poster quick-talks	
15:00	Authors at posters	
15:40	Break	
Richtmyer-Meshkov instability		
16:00	Linear and Nonlinear Evolution of Richtmyer-Meshkov Instability Katsunobu Nishihara, Chihiro Matsuoka, Gustavo J. Wouchuk, Snezhana I. Abarzhi & Vasilii V. Zhakhovskii	
16:20	Freeze-out of the Richtmyer-Meshkov instability J.G. Wouchuk & K. Nishihara	
16:40	Nonlinear evolution of the Rayleigh-Taylor and Richtmyer-Meshkov unstable fluid interface S.I. Abarzhi, M. Herrmann, K Nishihara & J. Glimm	
17:00	Numerical simulation of turbulent stage of Richtmyer-Meshkov instability with multishock interaction V.F. Tishkin, M.Ye. Ladonkoina & N.V. Zmitrenko	
17:20	Radiatively induced Richtmyer-Meshkov instability Michel Legrand & Georges Fiorèse	
17:40	Discussion	

18:45 College Bar opens
19:30 Dinner (three course) in Great Hall
For those staying in Clare College and those staying elsewhere who booked meals in Clare College
20:30 College Bar re-opens

Lunch menu (Wolfson Court):

Buffet -- menu to be confirmed

Dinner menu (Clare College):

Salmon Mousse
Supreme of Guinea Fowl on a Bed of Lentils
Parisienne Potatoes – Selection of Vegetables
Passion Fruit Parfait on a Mango Coulis
Coffee

Tuesday

07:45	Breakfast in Buttery *For those staying in Clare College only*
Numerical approaches	
09:00	On implicit large eddy simulation for turbulent flows Fernando F. Grinstein
09:40	Pseudo-spectral Navier-Stokes simulations of compressible Rayleigh-Taylor instability Benjamin Le Creurer & Serge Gauthier
10:00	Numerical Experiments Using High-Resolution methods in Compressible and Turbulent Flows Marco Hahn & Dimitris Drikakis
10:20	The Relative Effectiveness High-Resolution Methods in Simulating Compressible Mixing William J. Rider, Jeff Greenough & James R. Kamm
10:40	Break
Turbulence modelling	
11:00	Derivation of a minimal 2-structure, 2-fluid and 2-turbulence (2SFK) model for gravitationally induced turbulent mixing layers. Antoine Llor, Pascal Bailly & Olivier Poujade
11:20	Interfacial Pressures and Shocks in a Multiphase Flow Model Daniel E. Klem
11:40	Exact expansion law for Richtmyer–Meshkov turbulent mixing zone N.A. Inogamov & A.M. Oparin
12:00	Self-similarity of flows induced by instabilities Ye Zhou & Timothy Clark
12:20	Discussion
12:40	Lunch Wolfson Court

Poster session 2	
14:20	Poster quick-talks
15:00	Authors at posters
15:40	Break
Mixing	
16:00	Multifractal structure and intermittent mixing in Rayleigh-Taylor driven fronts Jose M. Redondo & German Garzon
16:20	Recent developments in theory and simulation of turbulent mixing Baolian Cheng, Erwin George, James Glimm, Hyeonseong Jin, Xiaolin Li, David Sharp, Zhiliang Xu & Yongmin Zhang
16:40	On possibility of experimental determination of integral characteristics of molecular component of mixing by means of X-ray technique Yu.A. Kucherenko, S.I. Balabin, R.I. Ardashova, O.E. Kozelkov, A.V. Dulov & I.A. Romanov
17:00	Visualizing the onset and growth of secondary instabilities in Richtmyer–Meshkov-unstable flows Chris Tomkins, Sanjay Kumar, Peter Vorobieff, Mark Marr-Lyon, Cherie Goodenough & Robert Benjamin
17:20	Turbulent Mixing of Multiphase Flows in a Gravitational Field Edward Son
17:40	Discussion

18:45 College Bar opens

19:30 Dinner (three course) in Great Hall

For those staying in Clare College and those staying elsewhere who booked meals in Clare College

20:30 College Bar re-opens

Lunch menu (Wolfson Court):

Buffet -- menu to be confirmed

Dinner menu (Clare College):

Deep Fried Camembert with Lime Coulis
Honey Glazed Duck Breast in a Kumquat Sauce
Roast Potatoes - Selection of Vegetables
Pistachio & Chocolate Ice-Cream with a Vanilla Sauce
Coffee

Wednesday

07:45	Breakfast in Buttery *For those staying in Clare College only*
Shocks	
09:00	Emergence of detonation in the flowfield induced by Richtmyer-Meshkov instability Nikos Nikiforakis & Kevin R. Bates
09:40	On the mutual penetrations of two gases submitted to the Richtmyer-Meshkov instability: Part 1 - experiments Lazhar Houas, Georges Jourdan, Vincent Filpa, Guillaume Layes, Jérôme Giordano, Clément Amagat & Yves Burtschell
10:00	Large-eddy simulation of Richtmyer-Meshkov instability with re-shock D.J. Hill, D.I. Pullin & R.Deiterding
10:20	Measurements of turbulent mixing within an air/SF6 shocked and reshocked interface. Laurent Schwaederlé, Jean-François Haas, Philippe Montlaurent, Claude Rayer & Guillaume Seguin
10:40	Break
Astrophysics	
11:00	Shock propagation through multiphase media R. J. R. Williams & D. L. Youngs
11:20	Numerical simulations of pulsar wind-sn shell interaction A.V. Gorodnichev, G.V. Dolgoleva, V.A. Zhmailo, E.A. Novikova & V.P. Statsenko
11:40	Turbulent diffusion of a passive scalar in a bidimensional flow : Astrophysical application. Nathalie Toqué, François Lignières & Alain Vincent
12:00	Scintillations and interstellar Levy flights Stanislav Boldyrev & Carl R. Gwinn
12:20	Discussion
12:40	Lunch Wolfson Court

Complex acceleration	
14:20	Investigation of the hydrodynamic instability induced by multi-acceleration of a contact surface between two fluids E. Leinov, A. Formaozo, O. Sadot, E. Sarid, A. Yosef-Hai, D. Cartoon, Y. Elbaz, A.L. Levin, D. Shvarts & G. Den-Dor.
14:40	Rayleigh-Taylor and Richtmyer-Meshkov aspects of interface deceleration mixing Erik L. Vold
15:00	Numerical investigation of gravitational turbulent mixing with alternating-sign acceleration V.A. Zhmailo, O.G. Sin'kova, V.N. Sofronov, V.P. Statsenko, Yu.V. Yanilkin, A.P. Guzhova & A.S. Pavlunin
15:20	Nonlinear mixing behavior of the three-dimensional Rayleigh-Taylor instability at a decelerating interface R.P. Drake, D.R. Leibrandt, E.C. Harding, C.C. Kuranz, M. Blackburn, H.F. Robey, B.A. Remington, M.J. Edwards, A.R. Miles, T.S. Perry, R.J. Wallace, H. Louis, J.P. Knauer & D. Arnett
15:40	Break
Density contrast and compressibility	
16:00	Experiments on the three-dimensional incompressible Richtmyer-Meshkov instability Jeffrey Jacobs & Patricia Chapman
16:20	Study into development of turbulent mixing at gas-liquid interface with accelerations from 10^2 g_0 to 10^5 g_0 N.V.Nevmerzhitsky, E.A.Sotskov & M.V.Bliznetsov
16:40	Large-eddy simulation of Rayleigh-Taylor turbulence with compressible miscible fluids Juan Pedro Mellado, Sutanu Sarkar & Ye Zhou
17:00	Large eddy simulations of miscible Rayleigh-Taylor instability T.W. Mattner, D.I. Pullin, & P.E. Dimotakis
17:20	Experimental study into the Rayleigh-Taylor instability evolution in a continuous distribution density layer Yu.A. Kucherenko, A.P. Pylaev, V.D. Murzakov, A.V. Belomestnih, V.N. Popov & A.A. Tyaktev
17:40	Discussion

Banquet	
19:00	Pre-dinner drinks in Scholars' Garden
19:30	Banquet in Great Hall
21:00	College Bar opens

Lunch menu (Wolfson Court):

Buffet -- menu to be confirmed

Banquet menu (Clare College):

Goat Cheese Terrine wrapped in Filo Pastry on a bed of Peperonata
Poached Fillet of Salmon in a Red Pepper Essence
Noisettes of Lamb with a Confit of Red Onions
Gratin Dauphinois -- Spiced Red Cabbage -- Sauté Parsnips
White Peach and Strawberry Parfait on a Chocolate Coulis
Coffee -- Petits Fours

Guest speaker: *Professor Lord Julian Hunt of Chesterton, CB, MA, PhD, FIMA, FRS*

Thursday

07:45	Breakfast in Buttery *For those staying in Clare College only*
ICF	
09:00	Mixing in thick-walled and pulse-shaped directly driven ICF capsule implosions. D.C. Wilson, F.J. Marshall, P.W. McKenty, V.Yu. Glebov, C. Stoeckl, C.K. Li, F.H. Séguin, D.G. Hicks, R.D. Petrasso, C.W. Cranfill, G.D. Pollak & W.J. Powers
09:20	Time dependent mix in a converging burning capsule G.A. Kyrala, D.A. Haynes , M.A. Gunderson , D.C. Wilson, C. Christensen, F.J. Marshall, V.Yu. Glebov, C. Stoeckl, C.K. Li, F.H. Séguin, R.D. Petrasso, J. Frenje , S.P. Regan, V.A.Smalyuk & J.R. Rygg
09:40	Linear stability analysis of self-similar solutions for ablation fronts in ICF Florian Abéguilé, Carine Boudesocque-Dubois, Jean-Marie Clarisse & Serge Gauthier
10:00	Postponement of saturation of the Richtmyer-Meshkov instability by convergence J. R. Fincke, N. E. Lanier, S. H. Batha, J. M. Taccetti, R. M. Hueckstaedt, G. R. Magelssen, N..D. Delameter, M. M. Balkey, S. D. Rothman, K. M. Parker & C. J. Horsfield
10:20	2D CALE simulations of directly driven shaped implosions* K.O. Mikaelian, H.-S. Park, H.F. Robey, R.E. Tipton, D.P. Rowley, R.J. Wallace, C.K. Li, R.D. Petrasso, J.A. Frenje, F.H. Seguin, R. Rygg, V.Yu. Glebov & F.J. Marshall
10:40	Break
Geometry	
11:00	Effect of initial conditions on compressible mixing for multimode systems driven by a strong blast wave A.R. Miles, M.J. Edwards, J.A. Greenough & H.F. Robey
11:20	Colliding surface instability for a high velocity impact Vladimir Demchenko
11:40	Shock tube Richtmyer-Meshkov experiments: inverse chevron and half height D.A. Holder & C.J. Barton
12:00	Study of converging reflected shock waves and Richtmyer-Meshkov instability in spherical geometry S. H. R. Hosseini, K. Takayama & T. Saito
12:20	Discussion
12:40	Lunch Wolfson Court

Shapes	
14:20	Experimental and computational investigations of shock-accelerated gas bubbles B. Motl, J. Niederhaus, D. Ranjan, M. Anderson, J. Greenough, J. Oakley, R. Bonazza & L. Smith
14:40	Validating the FLASH Code: two- and three-dimensional simulations of shock-cylinder interaction Greg Weirs, Tomek Plewa, Todd Dupont, Vikram Dwarkadas, Chris Tomkins & Mark Marr-Lyon
15:00	An experimental study of the interaction of three Richtmyer-Meshkov-unstable gas cylinders Sanjay Kumar, Peter Vorobieff, Greg Orlicz, Christopher Tomkins, Cherie Goodenough & Robert Benjamin
15:20	Experimental investigation on the behaviour of a shock accelerated spherical gas inhomogeneity Guillaume Layes, Georges Jourdan, Lazhar Houas, Denis Souffland & François Renaud
15:40	Break

Initial conditions	
16:00	Effect of initial conditions on self-similar turbulent mixing David L Youngs
16:20	Dependence of self-similar Rayleigh-Taylor growth on initial conditions Guy Dimonte, Praveen Ramaprabhu & Malcolm Andrews
16:40	The effect of initial conditions on late time asymptotics and mixing for multimode Richtmyer-Meshov Instability J.A. Greenough & E.Burke
17:00	Recovery of Rayleigh-Taylor mixing from unstably stratified flow past a cylinder Wayne N. Kraft & Malcolm J. Andrews
17:20	Direct numerical simulations of miscible, small Atwood number Rayleigh-Taylor instability-induced mixing Oleg Schilling, Nicholas Mueschke & Malcolm Andrews
17:40	Discussion

18:45	College Bar opens
19:30	Dinner (three course) in Great Hall *For those staying in Clare College and those staying elsewhere who booked meals in Clare College*
20:30	College Bar re-opens

Lunch menu (Wolfson Court)

Buffet -- menu to be confirmed

Dinner menu (Clare College):

Courgette and Chilli Terrine
Strips of Turkey Breast in Marsala Sauce
Parisienne Potatoes – Selection of Vegetables
Soufflé Benedictine
Coffee

Friday

07:45	Breakfast in Buttery *For those staying in Clare College only*

Other approaches	
09:00	Stochastic model of turbulent mixing by the Rayleigh-Taylor and Richtmyer-Meshkov instabilities S.I. Abarzhi, G. Blanquart, S. Fedotov & H. Pitsch
09:20	The multiparametric statistical analysis of hydrodynamic instabilities, based on wavelet preprocessing and neuronetwork classification Anton Nuzhny, Vladislav Rozanov, Roman Stepanov & Alexander Shumsky
09:40	Using the Green's function method to calculate pressure fluctuations in compressible multifluids Baolian Cheng & Charles W. Cranfill
10:00	Laser shock tube. Research & Development. Ivan Lebo & Vladimir Zvorykin
10:20	Break

Future developments & NIF	
10:40	Suppression of the Richtmyer-Meshkov instability in the presence of a magnetic field Dale Pullin, Ravi Samtaney & Vincent Wheatley
11:00	Turbulent jets? B.H. Wilde, P.A. Rosen, J.M. Foster, T.S. Perry, R.F. Coker, P.A. Keiter, G.R. Bennett, D.B. Sinars, M.J. Steinkamp, B.E. Blue, H.F. Robey, A.M. Khokhlov, M.L. Gittings, J.P. Knauer, R.P. Drake, R.B. Campbell, A. Frank & T.A. Mehlhorn
11:20	Study of short-wavelength perturbation growth on a NIF double-shell ignition target design Jose Milovich, Peter Amendt, Michael Marinak, Harry Robey & Robert Tipton
11:40	A NIF 3-D high Mach number feature experiment Stephen Weber, S. Gail Glendinning, Harry Robey, Peter Stry & D. Tod Woods
12:00	Discussion & Farewell
12:30	Lunch Wolfson Court

Lunch menu (Wolfson Court)

Buffet -- menu to be confirmed

Poster Session 1 (Monday)

Simulation by the Mah-3 code of the interfaces using an mixed cells and markers	N.N. Anuchina, N.S. Es'kov, V.A. Gordeyhuck, O.M. Kozyrev & V.I. Volkov
Numerical simulation of Rayleigh-Taylor instability in a spherically stagnating system using the MAH codes	N.N. Anuchina, V.I. Volkov, O.S. Ilyutina & O.M. Kozyrev
Monotone integrated large eddy simulation of open shear flows	A.J. Aspden & N. Nikiforakis
Percolation effects and coherent structures in turbulent flows.	O.G. Bakunin.
Shock wave structure reconstruction in reacting gases	A. S. Baryshnikov, I. V.Basargin, M. V.Chistyakova & M. A. Rydalevskaya
Studies of Richtmyer-Meshkov instability growth in gases at flow Mach numbers from 2 to 9	M.B.Bliznetsov, N.V.Nevmerhzitsky, E.A.Sotskov, L.V.Tochilina & E.D.Sen'kovsky
A linear perturbation computation method for hydrodynamic stability studies of complex flows: application to an ICF target implosion	Carine Boudesocque-Dubois, Jean-Marie Clarisse & Jean-Luc Willien
Bubble motion in inclined pipes	A.Yu. Demianov, N.A. Inogamov & A.M. Oparin
Numerical LES models of Richtmeyer-Meshkov and Rayleigh-Taylor instabilities	German Garzon, Jose M. Redondo, Vladislav Rozanov & Sergey Gushkov
Shock Bubble Interaction - numerical simulations	Jérôme Giordano, Yves Burtschell, Guillaume Layes, Georges Jourdan & Lazhar Houas
The Richtmyer-Meshkov Instability in Cylindrical Geometry: Experiments and Simulation*	M.J. Graham Lindquist, K.S. Budil, J. Grove & B.A. Remington
The problem of Kelvin-Helmholtz instability on contact boundary of finite width and ICF applications	S. Yu. Gus'kov, A. Caruso, V. B. Rozanov, R.V. Stepanov, C. Strangio & N.V. Zmitrenko
Three-dimensional simulations of Richtmyer-Meshkov experiments	R.M. Hueckstaedt, S.H. Batha, M.M. Balkey, N.D. Delamater, J.R. Fincke, R.L. Holmes, N.E. Lanier, G.R. Magelssen, J.M. Taccetti, J.M. Scott, C.J. Horsfield, K.M. Parker & S.D. Rothman
About the opportunity of use of the color photo for visualization of the zone of turbulent mixing in experiments on the shock tube with the GEM-driver	V. Kozlov, A. Levushov & E. Meshkov
Experimental study of the late-time evolution of single-mode Richtmyer-Meshkov instability	Vitaliy Krivets, John Stockero & Jeffrey Jacobs

Experimental study into the initial perturbation spectrum influence upon the delay of the turbulent mixing evolution in systems with transitional layers	Yu.A. Kucherenko, S.I. Balabin, R.I. Ardashova, O.E. Kozelkov, A.V. Dulov & I.A. Romanov
Study on the shock-bubbles Interaction in the two bubbles case	K. Levy, O. Sadot, E. Sarid, A. Yosef-Hai, D. Cartoon, Y. Elbaz, D. Shvarts & G. Den-Dor.
1D numerical simulations of various self similar accelerated turbulent mixing layers using the 2SFK model.	Antoine Llor, Pascal Bailly & Olivier Poujade
Convective Instability of self-similar gravitational collapse with radiative transfer	M. Murakami
Investigation of mix after reshock in a cylindrical geometry.	Kenneth Parker, C.J. Horsfield, S.D. Rothman, M.M. Balkey, S.H. Batha, N.D. Delamater, J.R. Fincke, R. Hueckstaedt, N.E. Lanier, G.R. Magelssen & M. Taccetti
An overview of Rayleigh-Taylor experiments at Texas A&M University	Praveen Ramaprabhu & Malcolm J. Andrews
The effects of viscosity and mass diffusion in hydrodynamically unstable plasma flows	H.F. Robey
Experimental investigation of the Rayleigh-Taylor instability using a magnetorheological fluid	C. Selig, J. White, M. Anderson, J. Oakley & R. Bonazza
Direct 3d numerical simulation of shear turbulent mixing	O.G. Sin’kova, V.P. Statsenko, Yu.V. Yanilkin & V.A. Zhmailo
Joint growth of local perturbation and zone of turbulent mixing at gas-jelly interface	E.A. Sotskov, N.V. Nevmerhzitsky, M.V. Bliznetsov & E.D. Sen’kovsky
Experimental study of initial stage of instability development on gases interface under influence of shock wave front acceleration	A.V. Vasilenko
3D modelling of cylindrical implosion experiments	R.J.R. Williams, D.L. Youngs & K.W. Parker
General characteristics of a mixing zone development in a direct simulations of hydrodynamics instabilities with a random phase regular multimode perturbations	Nikolai Zmitrenko, Vladimir Tishkin, Vladislav Rozanov, Roman Stepanov, Mikhail Anuchin & Yury Yanilkin

Poster Session 2 (Tuesday)

RT mixing of a thin liquid layer on the rigid wall moving with deceleration	Yu. Alekhanov, A. Levushov, A. Logvinov, S. Lomtev & E. Meshkov,
Numerical simulation of Rayleigh-Taylor instability evolution in cylindrical and spherical geometries for the cases of two and three spatial variables	N.N. Anuchina , V.I. Volkov , N.S. Es'kov, O.S. Ilyutina & O.M. Kozyrev
Second order closure turbulence model (1D code MUZA), empiric constants fitting	Mikhail Anuchin & Maksim Anuchin
Investigation of gravitational turbulent mixing at sign-variable acceleration	Sergey Baban & Alexander Kozlovskih
Convergent shock tube: new design, first results	C.J. Barton & D.A. Holder
Development of 2-d perturbations of gas - gas interface in experiments on the shock tube with the gem-driver.	M. Bliznetsov, V. Dudin, O. Krivonos, A. Levushov, E.E. Meshkov & V. Fadeev
Evolution of the three-dimensional Rayleigh-Taylor instability	B.E. Blue, A.R. Miles, J.M. Foster, T.S. Perry, P.A. Keiter, P.A. Rosen, R.F. Coker & B. H. Wilde
Methodology and diagnostics in large Rayleigh-Taylor instability simulations	W. Cabot & A.W. Cook
On the mutual penetrations of two gases submitted to the Richtmyer-Meshkov instability: Part 2 - numerical simulations	Jérôme Giordano, Yves Burtschell, Clément Amagat, Vincent Filpa, Guillaume Layes, Georges Jourdan & Lazhar Houas
The role of initial conditions on mixing efficiency for convective flows	Pilar L. Gonzalez-Nieto, Carlos Yague, Jose L. Cano & Jose M. Redondo
Implementation of a turbulent mix model in a 2D ALE code	Brian Grieves
Interacting thermals	Alison C. Hart & Stuart B. Dalziel
The experiment result analysis of turbulent mixing at moderate Reynolds numbers in a gravity field of the Earth.	Alexander Kozlovskih, Vadim Anisimov & Sergey Baban.
Visualization of Rayleigh-Taylor instability	Wayne N. Kraft & Malcolm J. Andrews
On possibility of experimental determination of molecular component of non-stationary turbulent mixing	Yu.A. Kucherenko, A.P. Pylaev, V.D. Murzakov, A.V. Belomestnih, V.N. Popov & A.A. Tyaktev
Application of Ronchi method for visualization of a turbulent mixing zone in shock tube experiments	A. Levushov, A. Logvinov, E. Meshkov & V. Popov

Volume fraction profiles of transport structures in Rayleigh-Taylor turbulent mixing zone: evidence of enhanced diffusion processes	Antoine Llor, Pascal Bailly & Olivier Poujade
Potential role of scaling factor in turbulent mixing problem	E.E. Meshkov, N.V. Nevmerzhitskii,V.G. Rogachev & Yu.V. Yanilkin
The analysis of experiments and calculations for determination of intensity of turbulent mixing on the basis of turbulent mixing model of diffusion type	V.E. Neuvazhayev
Numerical simulation of influence of turbulent mixing zone on local perturbation growth under Rayleigh-Taylor instability conditions	V.A. Raevsky, S.N. Sinitsyna, A.L. Stadnik & Yu.V. Yanilkin
MEDIC-2F: a one-dimensional diffusive mixing model. Application to LMJ target simulations.	François Renaud & Denis Souffland
Investigation of the large-scale and statistical properties of Richtmyer-Meshkov instability-induced mixing	Oleg Schilling, Marco Latini, Wai-Sun Don & Barna Bihari
Numerical simulation of an experiment to study turbulent mixing on multiple shock wave passage through interface	O.G. Sin'kova, V.P. Statsenko, Yu.V. Yanilkin & A.R. Guzhova
Direct numerical simulation of shear-gravitational turbulent mixing	O.G. Sin'kova, V.P. Statsenko, Yu.V. Yanilkin & V.A. Zhmailo
Statistical properties of 2D RT-induced mixing at nonlinear and transient stages for 6-modes ensemble	Roman Stepanov, Vladislav Rozanov & Nikolai Zmitrenko
Analytic model for the single-mode Richtmyer-Meshkov instability from the linear to the nonlinear regime.	Marc Vandenboomgaerde
Compressible aspects in simulations of multi-mode Rayleigh-Taylor mixing	Erik L. Vold
Spontaneous acoustic emission in a non ideal gas in the presence of a piston	J.G. Wouchuk & J. Lopez Cavada.

Nonlinear evolution of the Rayleigh-Taylor and Richtmyer-Meshkov unstable fluid interface

S.I. Abarzhi[1], M. Herrmann[1], K. Nishihara[2] & J. Glimm[3]

1. Center for Turbulence Research,
Stanford, USA
snezha@summer8.stanford.edu

2. Institute of Laser Engineering,
Osaka University, Japan

3. Department of Applied Mathematics,
SUNY Stony Brook, USA

The Rayleigh-Taylor (Richtmyer-Meshkov) instability develops at the interface between two fluids, when a light fluid accelerates a heavy fluid. The instability dynamics is governed by a system of conservation laws, which are nonlinear partial differential equations with the initial conditions and the boundary conditions at the fluid interface. Singular aspects of the interface evolution cause theoretical difficulties and preclude elementary methods of solution. We report the theoretical and numerical results, which describe the nonlinear dynamics of the RT/RM large-scale coherent structure.

Our theoretical approach to the problem is based on group theory. We apply the separation of scales in the governing equations, and account for the non-local properties of the flow that has singularities. Nonlinear asymptotic solutions are found to describe the large-scale coherent dynamics of bubbles and spikes in the Rayleigh-Taylor and Richtmyer-Meshkov instabilities for fluids with a finite density ratio in general three-dimensional case. The theory yields a non-trivial dependence of the bubble velocity and curvature on the density ratio, and reveals an important qualitative distinction between the dynamics of the Rayleigh-Taylor and Richtmyer-Meshkov bubbles. Our analysis determines the key properties of the spatial RT and RM flows, predicts new universal properties of the interface dynamics, and finds the invariants of flow in both RTI and RMI. Our numerical simulations track the interface dynamics explicitly. The theoretical and numerical results are in a very good agreement with each other and with existing observations. New sensitive diagnostic parameters are identified for experiments.

Stochastic model of turbulent mixing by the Rayleigh-Taylor and Richtmyer-Meshkov instabilities

S.I. Abarzhi[1], G. Blanquart[1], S. Fedotov[2] & H. Pitsch[1]

1. Center for Turbulence Research,
Stanford, USA
snezha@summer8.stanford.edu

2. Department of Mathematics,
Institute for Science and Technology,
University of Manchester, UK

The turbulent mixing produced by the Rayleigh-Taylor and Richtmyer-Meshkov instabilities is of extreme importance in inertial confinement fusion, astrophysics, and many other applications. We suggest a new stochastic model to describe the mixing process. The system of governing equations consists of the equation of motion, which balances inertial, buoyant, and random dissipative forces in the flow, the Kolmogorov condition for the mean value of the dissipation energy, and a stochastic differential equation for fluctuations of the dissipation energy with a log-normal distribution. The free parameter of the model is adjusted to fit the observations. The probability density function for the position, velocity and the dissipation energy is a solution of the Fokker-Planck equation. We have shown that the growth-rate of the mixing zone is very sensitive to the stochastic effects. Several scenarios are analyzed to describe the generation of inertial scales in the flow in the cases of Rayleigh-Taylor and Richtmyer-Meshkov instabilities. For an ensemble of bubbles and spikes, the partition function of the bubble/spike position is obtained for various density ratios and the acceleration history. Our results agree with existing data and suggest new diagnostic parameters for observations.

Linear stability analysis of self-similar solutions for ablation fronts in ICF

Florian Abéguilé[1,2], Carine Boudesocque-Dubois[2], Jean-Marie Clarisse[2] & Serge Gauthier[2]

1. Laboratoire de Modélisation en Mécanique,
Université Pierre et Marie Curie, France
abeguile@lmm.jussieu.fr
http://www.lmm.jussieu.fr

2. CEA/Bruyères-le-Châtel, France
carine.boudesocque@cea.fr
jean-marie.clarisse@cea.fr
serge.gauthier@cea.fr
http://www-dam.cea.fr

The stability of an ablative flow is of importance in inertial confinement fusion (ICF). Here we exhibit a family of exact self-similar solutions of gas dynamics equations with nonlinear heat conduction for semi-infinite slabs of perfect gases. Such self-similar solutions arise for particular but realistic initial and boundary conditions—boundary pressure and incoming heat flux follow time power laws—and are representative of the early stage during the ablation of a pellet heated with a laser, *i.e.*, a shock wave propagates upstream of a thermal front. Following the work of Boudesocque-Dubois *et al.* (2000), these solutions are computed using a dynamical multidomain Chebyshev pseudo-spectral method (Abéguilé *et al.*, 2003). A wide variety of ablation configurations may thus be obtained. Linear stability analyses of such time dependent solutions are performed by solving an initial and boundary value problem for linear perturbations. The numerical methods are based on a dynamical multidomain Chebyshev pseudo-spectral method and an operator splitting between a hyperbolic system and a parabolic equation (Boudesocque-Dubois *et al.*, 2003; Abéguilé *et al.*, 2003). Here, focusing on the laser imprint problem, we have considered boundary heat flux perturbations and obtained space-time evolutions of flow perturbations for a wide range of wavenumbers. By contrast with steady low Mach number models for ablation front, we obtain that: (a) maximum perturbation amplitudes in the thin ablation layer are reached for transverse wavenumber $k_\perp = 0$; (b) the damping of ablation front perturbations is clearly related to thermal diffusion; (c) ablation front perturbations seem to persist although the transverse wave number increases.

References

Boudesocque-Dubois, C. 2000 PhD thesis, Univ. Paris 6, France.

Boudesocque-Dubois, C., Clarisse, J.-M. & Gauthier, S. 2000 ECLIM, Prague.

Boudesocque-Dubois, C., Clarisse, J.-M. & Gauthier, S. 2003 A spectral Chebyshev method for linear stability analysis of one-dimensional exact solutions of gas dynamics; *J. Comp. Phys.*, **184**, 592-618.

Abéguilé, F., Boudesocque-Dubois, C., Clarisse, J.-M. & Gauthier, S. 2003 33rd Anomalous Absoprtion Conference, Lake Placid, US.

Abéguilé, F. 2004 PhD thesis, Univ. Paris 6, France.

RT mixing of a thin liquid layer on the rigid wall moving with deceleration

Yu. Alekhanov[2], A. Levushov[1,2], A. Logvinov[1,2], S. Lomtev[2] & E. Meshkov[1,2]

[1]Russian Federal Nuclear Center - VNIIEF,
Sarov, Russia

[2]Sarov Physical-Technical Institute
meshkov@sarfti.sarov.ru

Results of investigation of development of RT mixing air and a thin (~0.5 mm) a layer of water at an end face of the piston moving with deceleration ($\sim 2 \cdot 10^4$-$10^5 m/s^2$) are presented. These experiments confirm an opportunity of realization of a method to obtain of a mix atomized liquids with gas by means of the piston machine [1].

The opportunity of use of the given effect: a) for obtaining of a mix atomized waters with air for suppression of fires and b) preparation of a fuel-air mix in engines of internal combustion is discussed

t = 0 ms 0,43 ms 0,86ms 1,29 ms 1,72 ms 2,15 ms

Developments of turbulent mixing of a thin layer of water at a stage deceleration of the piston (2) due to development of RT instability. The flat piston with thickness of ~22 mm was accelerated in the channel of square section $40 \times 40 mm^2$ by pressure of products of a detonation of a mix of acetylene with oxygen (1). The layer of water thickness of ~0.5 mm (in a small deepening ($15 \times 15 mm^2$) at an end face of the piston) turns to a drop cloud (3) with the thickness of ~25 mm. Time is counted from the moment of occurrence of the piston in the frame.

References

1. E.Meshkov, N.Nevmerzhitsky. A method of receiving of a mix atomized liquids with gas. Patent RF #2220009, 2003.

Simulation by the Mah-3 code of the interfaces using an mixed cells and markers

N.N. Anuchina, N.S. Es'kov, V.A. Gordeyhuck, O.M. Kozyrev & V.I. Volkov

Russian Federal Nuclear Center – Zababakhin Institute of Technical Physics, Snezhinsk, Russia
v.a.gordeychuk@vniitf.ru
http://www.vniitf.ru

The paper presents a 3D method of describing interface with unstructured mesh of markers, which is implemented in the MAH-3 code (Anuchina *et al*. (1997)).

2D and 3D test problems set-up and computed data are presented for comparison two methods: method of material mixture concentrations and markers method.

Algorithms of marker-based control the interface location in time on an Eulerian mesh and influence on calculation of convective fluids flows.

The numerical results show, that the proposed markers method allows the robust calculation of the interface location and having less error.

References

Anuchina, N.N., Gordeyhuck, V.A., Es'kov, N.S., Ilyutina, O.S., Kozyrev, O.M. & Volkov, V.I. 1997 Three-Dimensional Numerical Simulation of Rayleigh-Taylor Instability by MAH-3 Code; In Proc. of 6th International Workshop on The Physics of Compressible Turbulent Mixing, Institut Universitaire des Systemes Thermiques Industriels, Marseille, France, 24-28.

Numerical simulation of Rayleigh-Taylor instability evolution in cylindrical and spherical geometries for the cases of two and three spatial variables

N.N. Anuchina , V.I.Volkov , N.S. Es'kov, O.S. Ilyutina & O.M. Kozyrev

Russian Federal Nuclear Center – Zababakhin Institute of Technical Physics,
Snezhinsk, Russia
v.i.volkov@vniitf.ru
http://www.vniitf.ru

Numerical simulations for cylindrical and spherical geometries are presented, which study linear and non-linear stages of evolution of small perturbations at the interface of two incompressible, non-viscous, non-heat-conducting liquids being under effect of Rayleigh-Taylor instability. Initial perturbations of the interface are considered for two cases: when the flow is described with two and three spatial variables. Results of the numerical simulations of the linear evolution stage for the small perturbations are in good agreement with the analytical laws of small single-mode perturbation evolution, derived in linearized formulation (basic solution is at rest) for cylindrical and spherical geometries. Effect of dimensionality of space and geometry (plane, cylindrical or spherical) on the evolution of perturbations is studied for non-linear stage. Basic characteristics of the difference methods implemented in MAH and MAH-3 software packages used for numerical studies are briefly described.

Numerical simulation of Rayleigh-Taylor instability in a spherically stagnating system using the MAH codes

N.N. Anuchina, V.I. Volkov, O.S. Ilyutina & O.M. Kozyrev

Russian Federal Nuclear Center – Zababakhin Institute of Technical Physics,
Snezhinsk, Russia
o.s.ilyutina@vniitf.ru
http://www.vniitf.ru

The Rayleigh-Taylor instability play a prominent role in various areas of fundamental and applied physics, specially inertial confinement fusion (ICF). If the fuel-pusher mixing is induced by the Rayleigh-Taylor instability of the contact surface, the total nuclear reaction yield will be reduced.

In the paper (Hattori *et al.*(1986)), authors investigated the linear stage of the Rayleigh-Taylor instability by modeling the stagnation dynamics with a self-similar solution.

In the present paper the results of the 2D and 3D numerical modeling of the linear and non-linear stages of the Rayleigh-Taylor instability are presented. Statement of numerical experiments was proposed in (Hattori *et al.*(1986)). The modeling was performed by using the MAH (Anuchina *et al.* (1992)) and MAH-3 (Anuchina *et al.* (2000)) program packages. At the linear stage numerical results are in good agreement with the analitical solution. For the perturbations with identical maximal value of penetration of easy gas in a heavy one the curves of bubble growth (2D, 3D), and a curve of jet growth (3D) coincide.

References

1. Hattori, F., Takabe, H. & Mima, K. 1986 Rayleigh-Taylor Instability in a Spherically Stagnating System; The Physics of Fluids, Volume 29, Number 5.
2. Anuchina, N.N., Volkov, V.I. & Es'kov, N.S. 1992 Numerical Modeling of Multi-Dimensional Flows with large deformations. Report at Russian; U.S. Weapons Laboratories introductory technical exchange in computational and computer science. Livermore.
3. Anuchina, N.N., Volkov, V.I., Gordeychuk, V.A., Es'kov, N.S, Ilyutina, O. S. & Kozyrev, O.M. 2000 3D Numerical simulation of Rayleigh-Taylor instability using MAH-3 code; Laser and Particle Beams, 18, 175-181.

Second order closure turbulence model (1D code MUZA), empiric constants fitting

Mikhail Anuchin & Maksim Anuchin

Russian Federal Nuclear Centre – Zababakhin All-Russian Institute of Technical Physics,
Snezhinsk, Russia
M.G.Anuchin@VNIITF.ru

A second order closure model for compressible turbulent flows is proposed. Closure hypothesis are based on the analogy to that for incompressible and stratified flows.

A short-cut variant of the model with algebraic equations for turbulent fluxes is formulated in local equilibrium approximation. In the frame of algebraic model the problem of turbulent mixing layer development on an interface between two fluids is considered for small density drop. Estimations of empiric constants values are fulfilled using experimental data on shear and gravitational mixing at the interface and atmospheric surface layer also.

The model is implemented in 1D hydrodynamic code "MUZA". Raleigh-Taylor turbulence test simulations approved the model adequacy. Numerical optimization of empiric constants gives the values close to the estimated ones.

Monotone integrated large eddy simulation of open shear flows

A.J. Aspden & N. Nikiforakis

Department of Applied Mathematics and Theoretical Physics
University of Cambridge
a.j.aspden@damtp.cam.ac.uk, n.nikiforakis@damtp.cam.ac.uk

In a buoyant atmospheric plume the latent heat release due to condensation of water vapour provides a secondary source of buoyancy away from the origin of the plume. This disrupts the eddy structure and so Taylor's entrainment hypothesis, based on similarity, is no longer appropriate. Bhat and Narasimha (1996) reproduced the eddy disruption in the laboratory by using electrodes to heat an acidic jet in a deionised ambient. This paper addresses this problem numerically with the aim to increase the understanding of the mechanism by which the jet eddy structure is disrupted and its effect on entrainment. Similar mechanisms exist in related buoyancy-driven flows such as a Rayleigh-Taylor instability. The code used is VARDEN, an incompressible, variable-density Navier-Stokes solver written at the Center for Computational Sciences and Engineering, Lawrence Berkeley National Laboratory, which is capable of performing Monotone Integrated Large Eddy Simulation (MILES). This is a form of LES designed to capture inherently the correct flow of energy through the inertial range and the decay at the grid-scale cut-off. The method does not use an explicit turbulence model and hence makes no assumptions on the structure of the flow, which lends itself to an investigation of the flow in question.

Investigation of gravitational turbulent mixing at sign-variable acceleration

Sergey Baban & Alexander Kozlovskih

RFNC–VNIITF,
Snezhinsk, Russia
s.a.baban@vniitf.ru

We considered the modification of turbulent mixing model for the description of a separation at sign-variable acceleration. The model was obtained from the analysis of the equations for turbulent flows of concentration and density. $K\varepsilon$ model [1] was added with items and the equation, containing the coefficient of heterogeneity Γ.

The model was investigated in case of two incompressible fluids in a field of gravity. It is shown, that in an unstable case the dimensionless velocity of development of turbulent zone depends on the coefficient of heterogeneity Γ. This fact is a possible explanation of a distinction of experimental data. The stable phase begins, when the sign of acceleration changes. The zone of turbulent mixing decreases in this case. This fact is in the consent with experimental data [2] and results of direct numerical simulation [3]. Development of a mixing zone depends from Γ in this case. There is a full separation if Γ=1 and separation does not occur if Γ=0.

References

1. V.E. Neuvazhayev, V.G. Yakovlev. 1988 //VANT, Theoretical and applied physics, (1), p. 28-36.
2. Yu.A. Kucherenko, V.E. Neuvazhayev, A.P. Pylaev. 1994 //DAN, 334, №4 p. 445-448.
3. D.L. Youngs. 1997 // Proc of the Sixth International Workshop on the Physics of Compressible Turbulent Mixing, France, Marseille, p.534-538.

Percolation effects and coherent structures in turbulent flows

O.G. Bakunin.

Russian Research Center "Kurchatov Institute",
Nuclear Fusion Institute.
Bakunin@nfi.kiae.ru, Oleg_Bakunin@yahoo.com

Essential deviation of transport processes in turbulent fluids and plasma from classical behaviour leads to a necessity of search of new approaches and scaling laws. This paper deals with the relationship between the scalings based upon fractal and upon percolation concepts of turbulence. Renormalization methods of quasi-linear equations in anisotropic mediums are considered. The anisotropy of medium is thought to be due to the presence of a strong magnetic field. It is shown that the Corrsin conjecture about diffusive nature of decorrelations appears to be the basis for such renormalization. The problem of relation between the Lagrangeian correlation function and the Euler one is considered in anisotropic medium. Effectiveness of Corsin's randomization to describe the transport of particles for the model with zonal flow is demonstrated. The common character of correlation approximation for the models of Corrsin's, Taylor-McNamara's is is discussed. The Dreizin-Dykhne model [1], the Kadomtsev-Pogutse method [2], and double diffusion [3] are investigated in detail. The analysis is made of "returns" effects role and memory effects [3-4]. The relation between the description methods of transport in systems with convective cells and percolation method is considered.

The description methods of the strong longitudinal correlation effects are analyzed [5]. The fractional differential equation describing transverse transport in a model with strong longitudinal correlations is obtained. Using the Euler correlation function in the power form $C(x)\sim x^{-a}$ allow us to obtain the relationship between the Hurst factor H and the correlation exponent a. Obtained expression $H=1-a/4$ points out more slowly rate of correlation decay for superdiffusive regimes. This result is in agreement with an analogous scaling law for isotropic medium [4].

The power form of the correlation function allows us to use methods of the percolation theory [5-6]. However, in the frame of monoscale percolation there is not opportunity to describe complex anisotropic effects. There is another way to investigate correlation effects and hierarchy of scales in the frame of multiscale percolation [4]. In that approach drift effects play main role, this differs strongly from the Kolmogorov approach for the description of scale hierarchy. The influence of correlation effects on the limit of applicability of multiscale graded percolation is considered. In that theory the correlation function of the velocity scales as l^{-a}. On the other hand, fractal theory leads to the scaling $l\sim t^{H}$, where H is the Hurst factor. A close examination of fractal and percolation concepts allow us to obtain not only the value of exponent , but also the relationship between H and a. This result is in agreement with the scaling law from quasi-linear approach $H=1-a/4$.

Correlation effects for the Manhattan grid model (generalized Dreizin-Dykhne model) for $H=2/3$ are investigated. Generalization of double diffusion on isotropic case for $H=2/5$ is considered. These models allow us to interpret the superdiffusion behaviour in self-organized criticality and subdiffusion one in transport barriers.

References

[1] Dreizin Yu A and Dykhne A M 1973 Sov. Phys. JETP **36** 127

[2] B. Kadomtsev, O. Pogutse, Plasma Phys. Controlled Nucl. Fusion Res., 1978 649-659.

[3] Balescu R 2000 Plasma Phys. Controll.Fusion **42** B649-B656

[4] Isichenko M B 1992 Rev. Mod. Phys. **64** 961

[5] Bakunin O.G. 2003 Physics-Uspekhi **64(7)**

[6] Bakunin O.G. 2003 Plasma Phys.Cont.Fusion **45** (2003) p1909

Convergent shock tube: new design, first results

C J Barton & D A Holder

AWE, Aldermaston, UK
chris.barton@awe.co.uk
http://www.awe.co.uk/

This paper reports on the progress of the convergent shock tube (CST) project. The latest results from the old CST are presented and some of its limitations noted. A triangular notch perturbation experiment was presented at the last meeting of this workshop (Holder et al. 2003), an improved set of experimental results will be presented compared to results from the TURMOIL 3D large eddy simulation (LES). The limitations of the old CST were used as a basis for its redesign.

Details of the new design are discussed to illustrate the problems highlighted in conducting experimental work with the CST. Some information on the manufacture of the new facility will be discussed focusing on the areas where machining limitations had a potential to compromise the design and the solutions found.

Commissioning of the new facility will be discussed and comments made on its performance and operational issues. Shadowgraphy images of the shock profile in the test cell will be presented. An initial series of unperturbed Richtmyer-Meshkov instability experiments featuring a plane – plane interface, air / dense gas / air configuration will be presented as a benchmark for subsequent perturbed mix experiments.

References

Holder, D.A., Smith, A.V., Barton, C.J. and Youngs, D.L., 2003 Mix experiments using a two-dimensional convergent shock-tube. Laser and Particle Beams *21*, 403-409.

Shock wave structure reconstruction in reacting gases

A. S. Baryshnikov, I. V.Basargin, M. V.Chistyakova[1] & M. A. Rydalevskaya[2]

1. Laborotory of Plasmagasedynamics,
IOffe Physi, Russia
a1.bar@mail.ioffe.ru

2. Department of Mathematics and Mechanics,
University of St.Petersburg, Russia
Alexandr.Polyansky@paloma.spbu.ru

In a long time in Russia and abroad an influence of endothermic physical-chemical processes (dissociation, ionization) on stability and structure of shock wave flow was investigated. Three effects should be distinguished: flow instability in front of body bow in some polyatomic gases, instability of flow behind ionizing shock wave and reconstruction of shock wave flow structure in plasma of decay discharge of argon and air. It's well studied the shock wave instability in consequence of dissociation of some polyatomic gases behind bow shock wave. Analysis of spectra of disturbances energy in flow behind shock wave, calculation of interaction of model vortex with shock front showed that energy and time characteristics of disturbances calculated coincide with dissociation energy and disturbances evolution time in experiments. Physical mechanism of instability in reacted gases is connected with baroclined type of reacting flow behind bow shock wave. Further investigations of instability of planed-parallel flow indicate that instability is realized for high frequency disturbances. Such kind of instability is preferable for applications, but today there are now any catalysis for initiation of some processes needed for instability in air. In the same time there was finding like effect of shock wave destruction at spreading it in plasma of decay discharge in air. Last time attention was paid to influence of the effect on aerodynamics of bodies. There is some uncertainty in measurements of this influence: one indicates increase of body drag whereas another indicates decrease. This fact is clear for us, because our results of experiments after processing with aid of computer showed that results of drag measurements depend on conditions of experiment. This fact let us understand a physical mechanism of the effect which is connected with dispersion of wave energy due to the physical-chemical processes in plasma. Indeed this effect could not be due to thermal nor electro-dynamical effects. Experimental measurements in decaying plasma after offset of discharge show that and in long of 10 milliseconds (when there are no electrons) character of effect was the same as in plasma. In long of the same value of time in region of former discharge the main exited states of oxygen are remained and decayed. Bound values of shock wave velocity at which the shock wave still exist in plasma were explored. It is the speed of small disturbances responsible for effect investigated and coincides with quantity of speed calculated. At calculations physical-chemical processes and there influence on the sound speed were investigated on base of the gas kinetics theory. System of determining extensive parameters was revealed and then transition to the conjugate intensive thermodynamics parameters was realized.

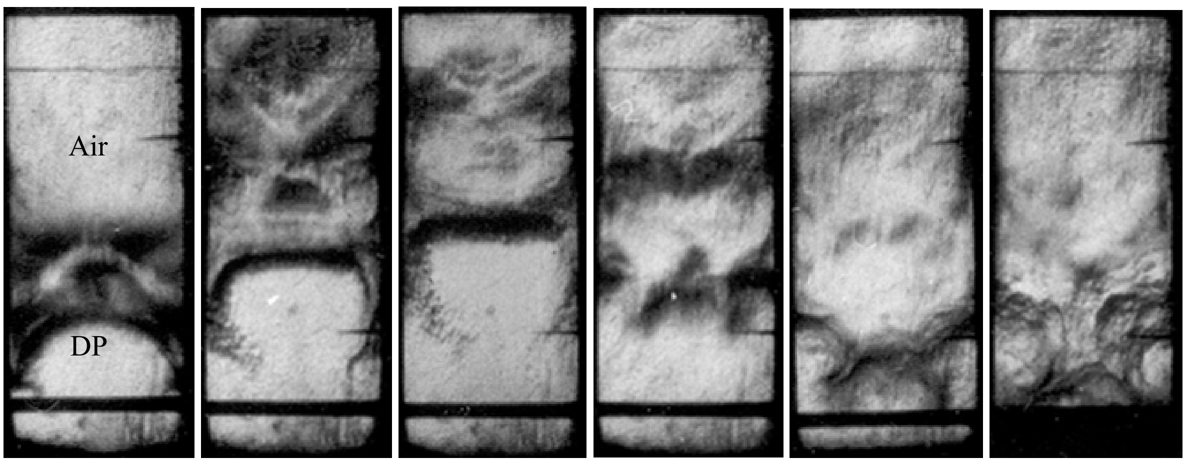
Development of 2-d perturbations of gas - gas interface in experiments on the shock tube with the gem-driver

M. Bliznetsov[1], V. Dudin[1], O. Krivonos[1], A. Levushov[1,2], E.E. Meshkov[1,2] & V. Fadeev[1]

[1]Russian Federal Nuclear Center - VNIIEF, Sarov, Russia

[2]Sarov Physical-Technical Institute
meshkov@sarfti.sarov.ru

Experimental data research of development of 2-D perturbations on the interface between detonation products (DP) of a gas explosive mixture (GEM) (mixture of acetylene with oxygen) and air (see figure) are presented. Experiments were carried out in a shock tube with cross-section of the channel of 8x8 cm^2 in the following geometry: *a rigid wall 1 – GEM layer (1,18см) - a layer of air (21,85см) - a rigid wall 2*. A similar shock tube works under the method described in [1]. 2-D perturbations are created by initiation of a detonation of GEM layer by electric explosion of 1÷4 wires located in parallel on a wall 1.



Development of 2-D perturbation on interface: DP - air at initiation of GEM detonation by electro-explosion of one wire located on a wall 1

References

Meshkov E.E. One Approach to the Experimental Study of Hydrodynamic Instabilities: Creation of a Gas-Gas Interface Using the Dynamic Technique. The Proc of the 5th IWPCTM, Stony Brook, USA, **1995**, p.237.

Studies of Richtmyer-Meshkov instability growth in gases at flow Mach numbers from 2 to 9

M.B. Bliznetsov, N.V. Nevmerhzitsky, E.A. Sotskov, L.V. Tochilina & E.D. Sen'kovsky

RFNC-VNIIEF, Russia, Sarov
postmaster@gdd.vniief.ru

The paper presents results of experimental studies of development of turbulent mixing of gases having different densities, when shock wave with Mach number from 2 to 9 passes their interface.

It is revealed that when increasing Mach number of flow, small-scale structures appear in the zone of turbulent mixing, width of the mixing zone is changed.

Evolution of the three-dimensional Rayleigh-Taylor instability

B.E. Blue[1], A.R. Miles[1], J.M. Foster[2], T.S. Perry[1], P.A. Keiter[3], P.A. Rosen[2], R.F. Coker[3] & B.H. Wilde[3]

1. Lawrence Livermore National Laboratory,
L-021, 7000 East Ave, Livermore, CA 94550, USA
Email: blue3@llnl.gov

2. AWE,
Aldermaston, UK

3. Los Alamos National Laboratory,
Los Alamos, NM, USA

Results are reported from an experiment in which the evolution of the Rayleigh-Taylor (RT) instability from a well characterized, broad spectrum, three-dimensional (3D) initial condition was measured. The experiment was performed at the OMEGA laser facility as part of a series of supersonic jet experiments. In this experiment, a 1 ns 1.4 kJ laser pulse launched a strong blast wave into an 825 micron thick titanium washer that was backed by a 100 mg/cc foam. The rear surface of the washer had random 3D surface roughness with an average peak-to-valley amplitude of 2.5 microns. The blast wave shocked and then decelerated the titanium-foam interface causing perturbation growth due to RT.

In order to diagnose the growth of the perturbations at late times (up to 400 ns), we have developed and improved a point-projection imaging technique. We were able to measure both the hydrodynamic evolution of the RT spikes via absorption radiography and also the blast wave evolution via phase contrast imaging on the same diagnostic. Details of this technique will be presented.

This work is performed under the auspices of the U. S. Department of Energy by Los Alamos National Laboratory under Contract No. W-7405-ENG-36 and by Lawrence Livermore National Laboratory under Contract No. W-7405-ENG-48.

Scintillations and interstellar Levy flights

Stanislav Boldyrev[1] & Carl R. Gwinn[2]

1. Department of Astronomy and Astrophysics,
University of Chicago, USA
boldyrev@uchicago.edu

2. Department of Physics
University of California, Santa Barbara, USA
cgwinn@physics.ucsb.edu

Observations of radio signals from distant pulsars provide a valuable tool for investigation of interstellar turbulence. The time-shapes of the signals are the result of pulse broadening by the fluctuating electron density in the interstellar medium. While the scaling of the shapes with the signal frequency is well understood, the observed anomalous scaling with respect to the pulsar distance has remained a puzzle for more than 30 years.

We propose a new model for interstellar electron density fluctuations, which explains the observed scaling relations. We suggest that these fluctuations obey Lévy statistics rather than Gaussian statistics, as assumed in previous treatments of interstellar scintillations. We argue that such statistics can naturally arise as a result of random density fragmentation and advection by sonic or super-sonic turbulence in the interstellar medium. A ray propagating through such a non-homogeneous medium performs a Lévy flight rather than the standard Gaussian random walk.

References

Boldyrev, S. & Gwinn, C. R. 2003; *Phys. Rev. Lett.* **91**, 131101.

Boldyrev, S. & Gwinn, C.R. 2003; *Astrophys. J.* **584**, 791.

A linear perturbation computation method for hydrodynamic stability studies of complex flows: application to an ICF target implosion

Carine Boudesocque-Dubois, Jean-Marie Clarisse & Jean-Luc Willien

CEA Bruyères le Châtel,
France
carine.boudesocque@cea.fr
jean-marie.clarisse@cea.fr
jean-luc.willien@cea.fr
http://www-dam.cea.fr

Linear hydrodynamic instabilities in inertial confinement fusion (ICF) target implosions have been previously investigated using linear perturbation codes (*e.g.* Henderson *et al.*, 1974; Dufour *et al.* 1984). In the context of indirect drive implosions, a simple physical model may be retained which corresponds to that of ideal gas dynamics with electronic heat conduction and a laser energy deposition modelling. The resulting systems of equations which are incompletely parabolic, are here written in Lagrangian coordinates for both the spherical symmetric flow and its linear three-dimensional perturbations. Each system is treated using an operator splitting between a hyperbolic reduced system and a parabolic equation. The proposed numerical method significantly differs from previous linear perturbation computation methods, which were based on artificial viscosity schemes (Henderson *et al.*, 1974; Grishina, 1980; Dufour *et al.*, 1984), in that it relies on a finite-volume formulation and explicit Godunov-type schemes (Clarisse *et al.*, 2004) for the hyperbolic reduced systems. The complementary nonlinear/linear parabolic equations are classically handled using semi-implicit iterative/direct methods. Despite the additional difficulties raised by the linear perturbation computations of the symmetric flow discontinuities (*i.e.*, shock-waves), the present numerical method is both reliable and fairly accurate and, above all, is less expensive than 2D-numerical methods by, at least, two orders of magnitude, given the spatially grid coarseness commonly advised for hydrodynamic instability calculations. This feature may be profitably used to obtain detailed descriptions of linear perturbation evolutions during target implosions. Such capabilities will be illustrated by linear perturbation results, obtained with the linear perturbation code *SILEX*, for a *Laser MégaJoule* direct-drive designed ICF target.

References

Clarisse, J.-M., Jaouen, S., and Raviart, P.-A. 2004 A Godunov-type method in Lagrangian coordinates for computing linearly-perturbed planar-symmetric flows of gas dynamics; *J. Comput. Phys.*, to appear.

Dufour, J.-M., Galmiche, D., and Sitt, B. 1984 Investigation of hydrodynamic stability of high aspect ratio targets in laser implosion experiments; in *Laser Interaction and Related Plasma Phenomena*, Plenum Publishing Corp., 709-730.

Grishina, G.A. 1980 Linear approximation method in gas dynamics problem numerical computations; *USSR Academy of Sciences IAM*, preprint 121, Moscow.

Henderson, D.B., McCrory, R.L., and Morse, R.L. 1974 Ablation stability of laser-driven implosions; *Phys. Rev. Let.*, **33**:4.

Methodology and diagnostics in large Rayleigh-Taylor instability simulations

W. Cabot & A.W. Cook

Lawrence Livermore National Laboratory,
Livermore, CA USA
cabot1@llnl.gov

High-resolution three-dimensional numerical simulations of planar Rayleigh-Taylor instability using up to 1152×1152×1152 grid points were performed on ASCI supercomputers at LLNL with the *Miranda* code. Miscible fluids with a 3:1 density ratio were used, whose initial interface is seeded with multimode perturbations. Details of the high-order numerical methods and the runtime diagnostics employed in these simulations are presented. An artificial viscosity and diffusivity were employed with negligible molecular contribution to allow the widest range of spatial scales possible. Visualizations and statistics from the simulations are shown, which are providing new insight into the mixing process in Rayleigh-Taylor 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 W-7405-Eng-48.

UCRL-ABS-201770

Using the green's function method to calculate pressure fluctuations in compressible multifluids

Baolian Cheng & Charles W. Cranfill

Los Alamos National Laboratory
bcheng@lanl.gov

In this paper, we present a pressure equation describing fluctuations in a turbulent mixing layer between two fluids. In the comoving frame of the mixing layer, the pressure fluctuation satisfies a decaying wave equation that can be solved analytically using the Green's function method. The obtained 1-D analytic solution for pressure fluctuations across the mixing layer displays the desired features required by the BHR turbulence transport model. It is shown that the pressure fluctuations, generated by shocks or instabilities in the mixing region, decay exponentially away from the mixing layer. This new solution could provide a theoretical foundation for the current artificial nonlocal length-scale equation used in the BHR model. The solutions successfully reduce to the well known incompressible form in the limit of large sound speed.

PACS: 47.40, 52.35

Recent developments in theory and simulation of turbulent mixing

Baolian Cheng[1], Erwin George[2], James Glimm[2,3], Hyeonseong Jin[2], Xiaolin Li[2], David Sharp[1], Zhiliang Xu[2] & Yongmin Zhang[2]

1. Los Alamos National Laboratory,
Los Alamos, NM, USA
bcheng@lanl.gov; dhs@t13.lanl.gov

2. StonyBrook University, USA,
glimm@ams.sunysb.edu; george@ams.sunysb.edu; hjin@ams.sunysb.edu; linli@ams.sunysb.edu; xuzhi@ams.sunysb.edu; yzhang@ams.sunysb.edu

3. Brookhaven National Laboratory, NY, USA

We report on recent developments of the authors and coworkers on theory and simulation of turbulent mixing. Our main theoretical results are new and improved closures for averaged equations. We have simulations consistent with experiment for RT mixing and a quantitative explanation of the failure of many simulation codes to do this. New front tracking algorithms will enable improved simulations of the complex microphyics of mixing.

1. Theory

We report on two new developments for the closure of averaged equations. We continue our study of the complete first order closure of the multiphase equations, in that each phase has complete and independent thermodynamic parameters. We extend the incompressible closure to an arbitrary number n of fluids. We specify the interfacial velocities as a function of the phase mean velocities in a new closure relation. For n = 2 compressible fluids, a new closure satisfies energy conservation and for smooth flows, conservation of phase entropy. An analysis of the entropy of averaging supports this closure.

2. Simulations

Analysis of interfacial mass diffusion in most simulations can account quantitatively for observed simulation-experimental discrepancies. A similar analysis accounts for compressibility induced density stratification effects on RT mixing rates, even in the absence of interfacial mass diffusion. Experimentally validated RT mixing methods (using front tracking) are used to predict turbulent combustion rates in the RT burning of a type Ia supernova.

3. Numerical methods

A totally conservative front tracking algorithm has been developed, which yields higher order convergence rates even with solution discontinuities. This algorithm will allow feasible simulations of greatly improved quality of the microphysics of mixing.

Front Tracking has been merged with the AMR capability of the LLNL OVERTURE code. It has also obtained a rad-hydro capability through merger with the 1D rad-hydro code Hydes.

The mixing transition in Rayleigh-Taylor instability

Andy Cook, Bill Cabot & Paul Miller

Lawrence Livermore National Laboratory
7000 East Ave.
Livermore, CA 94550-9234 USA
awcook@llnl.gov
cabot1@llnl.gov
pmiller@llnl.gov

A mixing transition has been observed in a high-resolution large-eddy simulation of Rayleigh-Taylor instability. During the transition, an inertial range forms in the velocity spectrum and the rate of growth of the mixing zone is reduced. By measuring growth of the layer in units of dominant initial wavelength, criteria are established for reaching the hypothetical self-similar state of the mixing layer. A model including mixing effects is derived for the growth rate. The rate of growth of the mixing layer is determined by the net mass flux through the plane associated with the initial location of the interface. All of the information necessary for predicting the growth rate is contained in this plane. The model incorporates an effective Atwood number and provides a good match to the simulation data. The model suggests reduced growth for miscible fluids, compared to the immiscible case.

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.

Pseudo-spectral Navier-Stokes simulations of compressible Rayleigh-Taylor instability

Benjamin Le Creurer & Serge Gauthier

CEA, Bruyères-le-Châtel, F
benjamin.le-creurer@cea.fr, serge.gauthier@cea.fr

Numerical simulation of transitional and turbulent flows requires highly accurate schemes. Such simulations are usually carried out with spectral methods. However flows with stiff and unsteady gradients - such as those occurring in Rayleigh-Taylor (RT) instability - require specific techniques: in these cases, one has to resort to transformation of coordinates. Guillard, Malé and Peyret (1992) introduced an adaptive procedure in which a coordinate transform was chosen to minimize the weighted second Sobolev norm of the solution. These results were generalized to the multidomain approach and we have shown that the criterion based on the minimum of the norm may also be used to determine the best location of the subdomain interfaces (Renaud & Gauthier, 1997). This adaption may be carried out dynamically to follow strong gradients.

A two (Fournier *et al.*, 2001) and then a three-dimensional pseudo-spectral numerical code has been developed along these guide-lines. It solves the full Navier-Stokes for a binary mixture with constant transport coefficients (viscosity, thermal conductivity and diffusion of species) by using a Fourier-Fourier-Chebyshev decomposition. This code has been parallelized with MPI with a two-level distribution of processors.

On the other hand, the linear stability analysis of the RT flow is performed within the normal mode framework in which the initial value problem is reduced to a boundary value problem. It is solved by diagonalizing the finite dimensional matrix corresponding to the linear Navier-Stokes operator. The numerical method also uses the multidomain decomposition. We obtain dispersion curves and eigenfunctions for various values of the dimensionless parameters of the model (Reynolds, Schmidt and Prandtl numbers) (Serre & Gauthier, 2002). It has been shown that the physical model described above exhibits a cut-off wavenumber beyond which the RT flow is stable.

Finally data analysis software has been developed which handles the results of the simulations. In particular, it provides 1D mean profiles versus time, spectra of any physical variables and Fourier decomposition of the quasi-interface.

Results and analyses of 3D numerical simulations will be detailed at the conference.

References

Guillard, H. & Malé, J.-M. & Peyret, R. 1992 Adaptive spectral methods with application to mixing layer computation; *J. Comput. Phys.* **102**, 114-127.

Renaud, F. & Gauthier, S. 1997 A dynamical pseudo-spectral domain decomposition technique : application to viscous compressible flows; *J. Comput. Phys.*, **131**, 89-108.

Fournier, É. & Gauthier, S. & Renaud, F. 2001 2D pseudo-spectral parallel Navier-Stokes simulations of compressible Rayleigh-Taylor instability; *Comput. Fluids*, **31**, 569-587.

Serre, É. & Gauthier, S. 2002 An auto-adaptive multidomain spectral technique for linear stability analysis : application to viscous compressible flows; *J. Sci. Comput.*, Vol. 17, n 1-4.

Colliding surface instability for a high velocity impact

Vladimir Demchenko

Department of Computational Numerical Mathematics,
Moscow Institute of Physics and Technology (State University), Russia,
vdem@cnm.op.mipt.ru

Physical processes accompanying high velocity impact phenomena with relative velocities 1-1000 km/s attract particular attention of mechanics and physicists over the past decades [1]. This is due to the wide prevalence of these effects in present-day technology and fundamental science. For example, they occur in inertial confinement fusion demonstration experiments with multi-layer targets (breakeven), in the development of spacecraft and vehicle meteor protection, in explosive welding and strengthening, in studying the matter properties in physical experiments with superhigh pressure values of order 0.1-1000Gbar and so on.

Sometimes the interaction surface turns out to be unstable and the characteristic recurring disturbances of a conic [2] or a similar shape form on it.

In this paper problems of instability development on colliding surfaces for a high velocity impact are studied by numerical simulation method using mass, impulse and energy conservation laws in continuum.

Using the numerical computional results the new mechanism of the instability development from the initial shape disturbances on interacting plate's surfaces is suggested, in which fundamental aspects are:

1.Mass flows deflection behind a curved shock wave front;

2.The interaction of the secondary compressed and shock waves with the primary shock waves.

The quantitative dependence of specific surface mixed matter mass of colliding plates on the initial radius of axially symmetric given shape disturbance is obtained. The specific surface mixed mass maximal value is displaced with time from the short wave part of the spectrum to the long wave one. The self-similar behavior of the specific surface mixed mass dependence on the dimensionless magnitude equal to the ratio of the plate's thickness to the product of the relative impact velocity multiplied by the process time from the moment of the plates contact to the rarefaction waves arrival at interface of two materials is detected [3-5].

References

1.High-Velocity Impact Phenomena. edited by Ray Kinslow 1970; Academic Press New York and London.

2.Yakovlev, I.V. 1973 Instability of interface between impact surface boundaries; FGV,9,3, 447-452.

3.Demchenko, V.V. 1999 Hydrodynamic instability for the high-velocity impact; Proc. of the 7th IWPCTM, St.-Petersburg, Russia, 391-397.

4.Demchenko, V.V.,Sergeyev, M.A. 2002 Hydrodynamic instability at the high velocity impact; Mathem. Modeling, 14, 10, 87-94(in Russian)

5. Demchenko, V.V.,Sergeyev, M.A. 2003 Colliding surface instability for the high velocity impact;Izv.AN. MZhG, 6, 110-120 (in Russian).

Bubble motion in inclined pipes

A.Yu.Demianov[1], N.A.Inogamov[2] & A.M.Oparin[3]

1. Moscow Institute of Physics and Technology,
Dolgoprudny, Moscow region, Russia
sn@co.ru

2. Landau Institute for Theoretical Physics,
Chernogolovka, Moscow region, Russia
nail@landau.ac.ru

3. Institute for Computer Aided Design,
Moscow, Russia
a.oparin@icad.org.ru

We analyze strongly nonlinear fluid motion with free surface in vertical, inclined, and horizontal pipes. The problem concerning rise of buoyant bubbles in vertical pipes is closely connected to a problem of Rayleigh–Taylor instability. Inclined pipes are intensively investigated in connection with problems of transportation of gas-liquid or liquid-liquid flows.

We develop new approach to the problem of motion of large bubbles in wide pipes (large and wide mean that capillary scale is small). As against the previous approaches based for inclined case on semiempirical methods, in the given work the analytical methods concerning to the theory of potential are used.

We have calculated velocity of rise for plane and circular inclined pipes. We have carried out the comparative analysis of vertical bubbles with round (2D, 3D), wedge type (2D, $\theta = 120^0$) and conic (3D, $\theta \approx 114.8^0$) tops, where θ is the angle at top point of bubble. For the first time velocity of rise of conical bubble and its angle θ have been obtained. We present better estimate for rise velocity of 2D bubble with wedge type top than was previously known.

We do careful comparison of obtained solutions for two and three-dimensional spaces. It is shown, that not always increase of dimension leads to an increase in velocity of rise of bubbles (as it is usually supposed).

For the first time direct numerical simulation (DNS) is applied for studies of flows with free boundary in inclined pipes. Direct numerical simulations allow us, first, to check up accuracy of our analytical models and, second, to receive general picture of motion.

This work has been supported by RBRF (grants 02–02–17499, 03–01–00700) and scientific schools (NSh–2045.2003.2, NSh–70.2003.1).

Dependence of self-similar Rayleigh-Taylor growth on initial conditions

Guy Dimonte[1], **Praveen Ramaprabhu**[1] **& Malcolm Andrews**[2]

1. Los Alamos National Laboratory, Los Alamos, NM 87545 (dimonte@lanl.gov)

2. Texas A & M University, College Station, TX

In the self-similar regime, Rayleigh-Taylor bubbles are found to grow as $h_b \sim \alpha_b Agt^2 \sim \lambda_b / \beta_b$ where $h_b \equiv$ amplitude, $\lambda_b \equiv$ dominant wavelength, $A \equiv$ Atwood number, $g \equiv$ acceleration, and $t \equiv$ time. The self-similarity ratio is found to be $\beta_b \sim 1/4\text{-}1/2$ in experiments and numerical simulations. However, the acceleration constant varies from $\alpha_b \sim 0.04\text{-}0.08$ in experiments and $\alpha_b \sim 0.02\text{-}0.08$ in 3D simulations. This variability may be due to numerics or it may signal a dependence on additional attributes like the initial perturbations. This can occur because the self-similar growth can proceed in two limiting ways:

nonlinear coupling of saturated modes (merger)

amplification and saturation of ambient modes (competition)

The mode-coupling limit has been widely investigated with 3D simulations by imposing only short wavelength modes, such as by Youngs [1994] and the Alpha-Group [1]. Here, we investigate both processes by considering initial perturbations with (1) an annular spectrum and (2) a broadband spectrum $\propto \lambda^2$ as suggested by Inogamov [1978]. We develop a model [2] that combines the essential results of Birkhoff [1955] and Haan [1989] and compare the results with LEM experiments [2000] and high-resolution 3D simulations [3]. We find that, with the annular spectrum, α_b and β_b are insensitive to the initial amplitude whereas, with the broadband perturbations, α_b and β_b increase weakly with the initial rms amplitude/wavelength.

References

G. Dimonte, D. L. Youngs, A. Dimits, S. Weber, S. Wunsch, M. J. Andrews, P. Ramaprabhu, A.C. Calder, *et al*, "A comparative study of the turbulent RT instability using high-resolution 3D numerical simulations: The Alpha-Group collaboration", Phys Fluids (2004)

Guy Dimonte, "Dependence of turbulent RT instability on initial perturbations", Phys Rev E (2004)

P. Ramaprabhu, G. Dimonte, M. J. Andrews, "3D simulations of turbulent RT instability with different initial perturbations", submitted to J. Fluid Mech (2004)

Nonlinear mixing behavior of the three-dimensional Rayleigh-Taylor instability at a decelerating interface

R.P. Drake[1], D.R. Leibrandt[1], E.C. Harding[1], C.C. Kuranz[1], M. Blackburn[1], H.F. Robey[2], B.A. Remington[2], M.J. Edwards[2], A.R. Miles[2], T.S. Perry[2], R.J. Wallace[2], H. Louis[2], J.P. Knauer[3] & D. Arnett[4]

1. University of Michigan
rpdrake@umich.edu

2. Lawrence Livermore National Laboratory

3. University of Rochester

4. University of Arizona

Results are reported from an experiment to explore the evolution of the Rayleigh-Taylor (RT) instability from intentionally three-dimensional (3D) initial conditions at an embedded, decelerating interface in a high-Reynolds-number flow. The experiments used ~ 5 kJ of laser energy to produce a blast wave in polyimide and/or brominated plastic having an initial pressure of ~ 50 Mbars. This blast wave shocked and then decelerated the perturbed interface between the first material and lower-density, C foam. This caused the formation of a decelerating interface with an Atwood number ~2/3, producing a long-term positive growth rate for the RT instability. The initial perturbations were a 3D perturbation in an "egg-crate" pattern with feature spacings of 71 µm in two orthogonal directions and peak-to-valley amplitudes of 5 µm. The resulting RT spikes appear to overtake the shock waves, moving at a large fraction of the pre-deceleration, "free-fall" velocity. Their morphology also becomes complex. This result was unanticipated by prior simulations and models.

Financial support for this work included funding from the U.S. Department of Energy to the University of Michigan under grants DE-FG03-99DP00284 and DE-FG03-00SF22021, and to the Lawrence Livermore National Laboratory under Contract No. W-7405-ENG48.

Postponement of saturation of the Richtmyer-Meshkov instability by convergence

J.R. Fincke[1], N.E. Lanier[1], S.H. Batha[1], J.M. Taccetti[1], R.M. Hueckstaedt[1], G.R. Magelssen[1], N.D. Delameter[1], M.M. Balkey[1], S.D. Rothman[2], K.M. Parker[2] & C. J. Horsfield[2]

1. Los Alamos National Laboratory
Los Alamos, New Mexico 87545
jfincke@lanl.gov

2. AWE
Aldermaston, UK

Strongly driven cylindrically convergent implosions with well characterized surface perturbations were conducted on the OMEGA laser (Broehly, et al (1977)). The cylindrical targets, consisting of a low density foam core and an aluminum shell covered by an epoxy ablator, are directly driven by fifty laser beams (18±0.3 kJ, 351 nm, 1 ns pulse width). The outer surface of the aluminum shell is machined to form perturbations with wavenumbers ($k = 2\pi/\lambda$, μm^{-1}) $0.08 < k < 2.5$ (λ = 2.5, 9, 25, and 75 μm) and initial amplitudes $0.03 < \eta_0/\lambda < 0.8$. The perturbations are in the in the r-z plane with r being the radius in cylindrical coordinates and z is the axis of the cylinder. The aluminum shell is calculated to preheat to ≈3 eV prior to interaction with the Mach 6 shock launched by the laser drive. The Atwood number is ≈0.6.

We observe that the perturbations continue to grow approximately linearly, and even exhibit a noticeable increase in growth rate with time well into the amplitude range where saturation is expected in planar geometry. In planar geometry mode saturation and transition to a slow growing spike and bubble configuration has been experimentally observed at $\eta/\lambda \approx 0.3$ (Dimonte (1993). We, however, observe no evidence of saturation for an η/λ ratio as large as 5. The perturbation growth rate is observed to scale proportionally with k for $\eta_0 k < 1.4$, while for $\eta_0 k \geq 5$ wavenumber scaling is violated and what is likely a transition to turbulent growth is observed. The rate at which the apparent mix width grows, a consequence of both convergence and instability growth, is consistent with Bell's linear theory (Bell (1951)) of perturbation growth in a converging geometry.

References

Bell, G. I., 1951 Taylor instability on cylinders and spheres in the small amplitude approximation, LA-1321, LANL.

Broehly, et al 1977 Initial performance of the OMEGA laser system, Opt. Commun, **133**, 495.

Dimonte, G. and Remington, B., 1993 Richtmyer-Meshkov Experiments on the Nova Laser at high compression, Phys. Rev. Lett., **70**, 1806.

Numerical LES models of Richtmeyer-Meschkov and Rayleigh-Taylor instabilities

German Garzon[1], Jose M. Redondo[1], Vladislav Rozanov[2] & Sergey Gushkov[2]

1 Departament Fisica Aplicada, UPC Barcelona, Spain
redondo@fa.upc.es

2 FIAN Lebedev Institute, Moscow, Russia

The relation between fractal analysis and spectral analysis can be very useful to determine the evolution of scales. Presently the emerging picture of the mixing process is as follows. Initially a pure RT instability with lengthscale appears, together with the disturbances caused from the initial set-up (Youngs 1989). The growth and merging of disturbances favors the appearance of several distinct blobs, bubbles or protuberances which produce shear instabilities on their sides. These sometimes develop further secondary accelerated and sheared instabilities. After 2/3 of the tank three dimensional effects have broadened the spectrum of lengthscales widely enough as to have a fractal structure in the visual range with dimensions ranging between 2.15 and 2.40. Some differences may be detected in the maximum fractal dimension evolution in time for experiments with different Schmidt or Prandtl numbers as described in Redondo (1996). The use of a Pseudo Keulegan number allows to relate the mixing ability of a front to both the molecular properties and to the initial range of velocities and scales able to develop. The difference between RT and RM fronts is analyzed in terms of spectral distribution of the scalar and vector fields (volume fraction, velocity and vorticity).

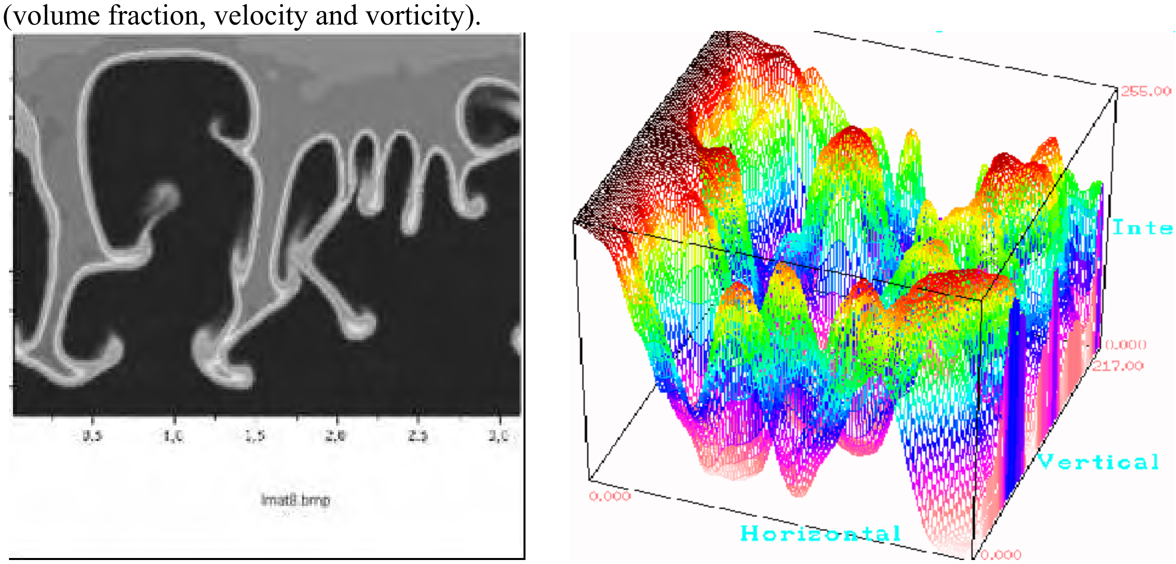


Figure 1. Structure of the RM and RT fronts.

Information about the mixing can be extracted from the thickening of the edges examined with Laplacian filters in both the RT and RM simulations, The use of higher moments of the density and velocity differences shows the differences between the more and less active mixing regions, (Linden and Redondo 2002). The RM fronts generally exhibit lower fractal dimensions than comparable RT fronts.

References

Youngs D.L. (1989) “Modelling turbulent mixing by Rayleigh-Taylor Instability”. Physica D 37, 270-287.

Redondo J.M. (1996) “Vertical microstructure and mixing in stratified flows” Advances in Turbulence VI. Eds. S. Gavrilakis et al. 605-608.

Linden P.F. and Redondo J.M. (2002) Turbulent mixing in Geophysical Flows, Ed. CIMNE. Barcelona

On the mutual penetrations of two gases submitted to the Richtmyer-Meshkov instability: Part 2 - numerical simulations

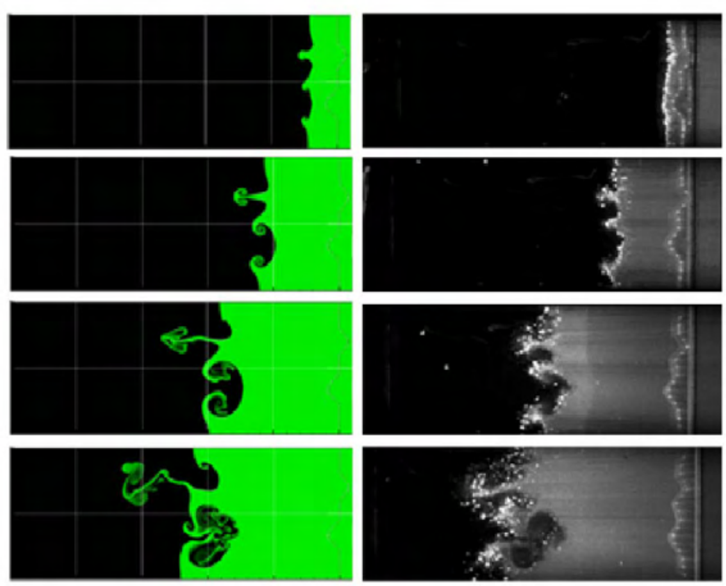
Jérôme Giordano[1], Yves Burtschell[1], Clément Amagat[2], Vincent Filpa[2], Guillaume Layes[1], Georges Jourdan[1] & Lazhar Houas[1]

1. Polytech'Marseille DME - IUSTI/UMR CNRS 6595
13453 Marseille Cedex 13, France
jerome.giordano@polytech.univ-mrs.fr

2. Ecole de l'Air de Salon,
BA 701, 13661 Salon Air, France

This paper deals with the numerical simulation of the mutual penetrations of two gases submitted to the Richtmyer-Meshkov instability. This simulation is compared with experiments. We have studied the evolution of an initially perturbed interface between a couple of gases (heavy/light or light/heavy). Thus, we may characterize the influence of the initial perturbation amplitude and wavelength on the Richtmyer-Meshkov instability.

Our numerical code, named CARBUR, is a finite volume code which describes compressible viscous fluid flows. The solution of Navier-Stokes equations is made by a second order scheme, for both space and time. Moreover, Van Leer slope limiter and an exact Riemann solver are used.



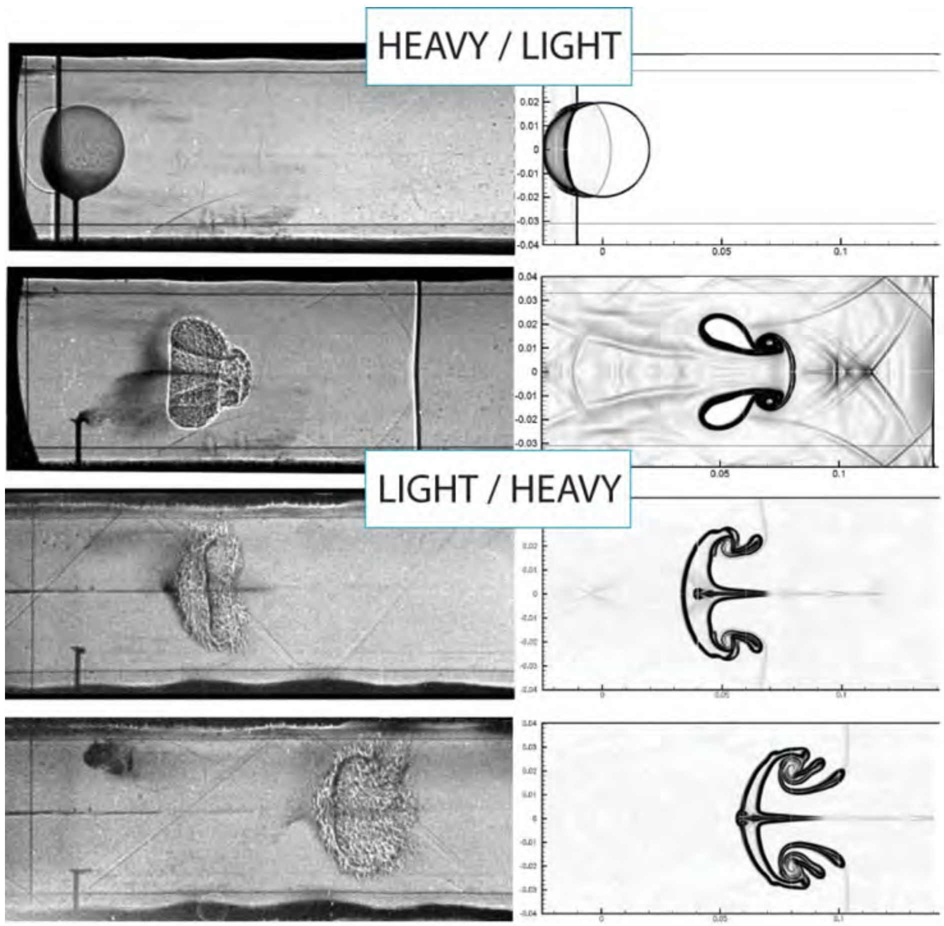
For example, in figure 1 are presented numerical and experimental results concerning heavy/light case (the amplitudes and wavelengths of the initial perturbations are $\lambda = 90\ mm$, $a_0 = -18\ mm$ and $\lambda = 80\ mm$, $a_0 = 14\ mm$ respectively). Compared to the initial perturbation shape, we can observe the classical evolution of a reversed and then convected interface, until the reflected shock arrival. At this time, again perturbed, the deformed and decelerated interface sees its mixing zone increase. In full paper, the physical phenomena will be numerically investigated through a parametric study.

Shock Bubble Interaction - numerical simulations

Jérôme Giordano, Yves Burtschell, Guillaume Layes, Georges Jourdan & Lazhar Houas

Polytech'Marseille DME - IUSTI/UMR CNRS 6595
13453 Marseille Cedex 13, France
jerome.giordano@polytech.univ-mrs.fr

This paper deals with the numerical study of the interaction of a shock wave with different gaseous bubble. Thus, we have simulated the interaction of a shock wave moving in the air with: an *He* bubble (heavy/light), a N_2 bubble (close density), a *Kr* bubble (light/heavy). Our numerical code, named CARBUR, is a finite volume code which describes compressible viscous fluid flows. The solution of Navier-Stokes equations is made by a second order scheme, for both space and time, with the Van Leer slope limiter and an exact Riemann solver.



As we can see on the above pictures, which represent the comparison between experimental and numerical results, different behaviours have been observed. In the heavy/light case the bubble region near its symmetric axis moves faster than the surrounding one, then the bubble reverses from the center. For the light/heavy case, it is the surrounding zone which is faster than the region near the axis, then the bubble reverses from the surrounding zone. In the full paper, including the similar density case, the physical phenomena will be numerically investigated and compared with the experiments.

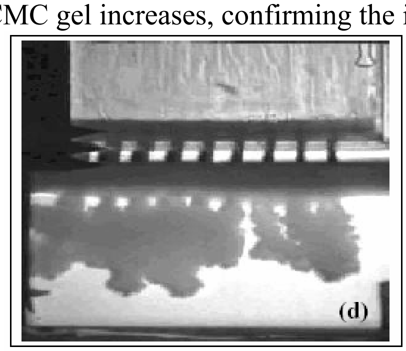
The role of initial conditions on mixing efficiency for convective flows

Pilar L. Gonzalez-Nieto, Carlos Yague, Jose L. Cano & Jose M. Redondo

1 Facultad Ciencias Fisicas. Univ. Complutense, Madrid, Spain
2 Departament Fisica Aplicada, UPC Barcelona, Spain

redondo@fa.upc.es

Mixing is measured by comparing the gain in potential energy with respect to the immiscible situation with the initial available potential energy of a top-heavy brine resting on a gel. The experimental setup generates a discrete number of forced turbulent plumes whose behavior and interaction result in the mixing process. In this experiment our principal aim is the study of the properties of the mixed fluid during the transient turbulent mixing process. The fluid system consists of three homogeneous fluids with different densities that are initially at rest. The fluids are inside a cubic glass container of sides 270 mm (figure 1a). At the bottom of the container there is a fluid with lower density ρ_L making a layer designated as the "light layer" with a height h_L. On top of this layer, a sodiumcarboximethyl celulose gel stratum, or CMC gel, is placed with density ρ_G and a height of h_G. Finally, a system made of two metacrylic boxes, one fitting inside the other is placed at a height Ho from the CMC gel layer. The bottoms of the boxes are pierced with orifices that have apertures that can be regulated. A convective unstable front is generated by the evolution of an array of forced turbulent plumes. The corresponding qualitative conclusions and the quantitative results based on measures of the density field and of the height of the fluid layers are described. The partial mixing process is characterized and analyzed, and the conclusions of this analysis are related to the mixing efficiency and the volume of the final mixed layer as functions of the Atwood number,(Taylor1950, Sharp 1984) which ranges from 0.010 to 0.134. An exponential fit is used for the mixing efficiency versus the Atwood number which explains 98% of the mixing efficiency variability. Similarly, a linear fit is proposed for the mixed volume versus the Atwood number. The mixing efficiency increases with the Atwood number but decreases as the viscosity of the CMC gel is increased. The values of the mixing efficiency are less than 0.30 , slightly lower than in Redondo and Linden (1990) and also tend toward an asymptotic behavior when the Atwood number tends to its maximum experimental value. The mixing efficiency is strongly influenced by the size of the initial plume array and depends directly on the external volume of the mixing cones. The limiting case of RT has to consider that when the stable stratification in the mixed layer increases, more energy is consumed to work against the buoyancy forces. The mixed layer height increases as the Atwood number grows, and also diminishes as the viscosity of the CMC gel increases, confirming the importance of the initial conditions on global mixing efficiencies.



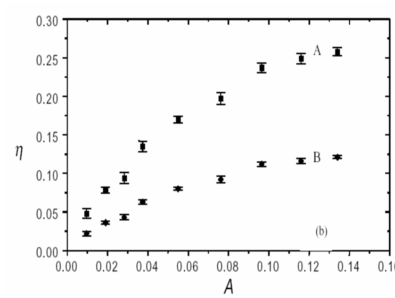


Figure 1. Structure of the Plume array -RT front and the global mixing efficiency for Low A, and high B viscosity gel layers.

References

Taylor G.I.(1950) Instability of superimposed fluids, Proc. Royal Soc.

D.H.Sharp,(1984) "An overview of Rayleigh-Taylor Instability", Physica 12D,3

Redondo J.M. and Linden P.F.(1990) "Mixing produced by Rayleigh-Taylor instabilities" Proceedings of Waves and Turbulence in stably stratified flows, IMA conference. Leeds 18 Dec 1989. Ed. S.D. Mobbs.

Numerical simulations of pulsar wind-sn shell interaction

A.V. Gorodnichev, G.V. Dolgoleva, V.A. Zhmailo, E.A. Novikova & V.P. Statsenko

Russian Federal Nuclear Center - VNIIEF,
Sarov, Russia
yan@md08.vniief.ru

The problem [1,2] of interaction between a pulsar wind and a relatively cold portion (He) of expanding SN shell is being solved.

In 1D, the problem is being solved both with 1D code SNDP [3] and 2D code EGAK [4]. For self-similar conditions the results are compared to approximate analytical solution [1].

SNDP has been also used to calculate turbulent mixing described by the k-ε model. The results of the 1D SNDP computations are compared to 1D and 2D numerical computations [2].

The turbulent mixing has been calculated in the 2D EGAK computations. It appears from evolution of initial random perturbations in two dimensions. A problem is solved, whose setup is closer to Crab conditions than that of ref. [2], that is the pulsar wind, shell and star wind interaction is calculated in the integrated manner. The results averaged using the method of [2] are compared to the relevant data from the 1D computations.

References

1. R. Weawer, R. McCray, J. Castor, P. Shapiro, R. Moore, Interstellar bubbles. II. Structure and evolution, The Astrophysical Journal, 218: 377-395, 1977.
2. Byung-Il Jun, R. A., Interaction of a pulsar wind with the expanding supernova remnant, The Astrophysical Journal, 499, 282-293, 1998.
3. Belkov S.A., Dolgoleva G.V. Mean-ion model for SNDP computation of ionization kinetics, excited level occupancies, and spectral factors of radiation transport // Voprosy Atomnoy Nauki i Tekhniki. Ser. Matematicheskoye Modelirovaniye Fizicheskikh Protsessov. 1992. No.1. P.59-61.
4. Shanin A.A., Yanilkin Yu.V. Program complex EGAK. Gas-dynamic difference schemes in Eulerian variables// Voprosy Atomnoy Nauki i Tekhniki. Ser. Matematicheskoye Modelirovaniye Fizicheskikh Protsessov, 1993. No.1. P. 24-30.

The Richtmyer-Meshkov instability in cylindrical geometry: Experiments and simulation

M. J. Graham Lindquist[1], K. S. Budil[1], J. Grove[2] & B. A. Remington[1]

[1]Lawrence Livermore National Laboratory
lindquist8@llnl.gov

[2] Los Alamos National Laboratory

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.

* This work was performed under the auspices of the U.S. Department of Energy by University of California, Lawrence Livermore National Laboratory under Contract W-7405-Eng-48.

UCRL-JC-143844-ABS

The effect of initial conditions on late time asymptotics and mixing for multimode Richtmyer-Meshov Instability

J.A. Greenough & E.Burke

AX-Division, Lawrence Livermore National Laboratory,
Livermore, CA, USA
greenough1@llnl.gov

In this paper, we investigate the development of a material interface perturbed by a spectrum of modes when subjected to an acceleration by a shock wave. We use the Eulerian Adaptive Mesh Refinement (AMR) code, *Raptor*, for the multi-fluid simulations. In two-dimensions we consider a number of broad-banded initial spectrum over a range of Atwood numbers accelerated by a weak M=1.3 shock wave. For a given realization, we consider decomposing into three cases: 1) the full broad-banded spectrum, 2) the long wavelength modes, and 3) the short wavelength modes. Here long or short is determined by comparison with the transverse dimension, L, of the computational domain. It is found that the subsequent evolution of the overall mixed width reaches an asymptotic t^{θ} scaling for both bubbles and spikes. In the broad-banded and short wave length cases, the spikes and bubbles evolve in an Atwood number independent manner with $\theta = 0.4$, approximately. The long wavelength case exhibits the strong spike Atwood number dependence given previously in the literature (Alon et al. (1995)). In three-dimensions, we reconsider the weak shock case as well as the strong shock (M=5) case. The weak shock case gives, for broad-banded perturbations, an asymptotic scaling for both bubbles and spikes of $\theta = 0.5$ at At=0.6. The evolution of the amount of mixed material also grows with a square root dependence. Including additional accelerations from the incident shock wave reflecting off of a solid end-wall, increases the rate of mixing as well as spike and bubble velocities while maintaining the same power law dependence. Turbulence, as defined by Zhou et al. (2003), appears only after the second acceleration. Simulation results for the high Mach number case will be given. Additional diagnostics such as Fourier spectra within the mixing region and advanced visualizations of the flow fields during the evolution will also be given.

References

Alon, U., Hecht, J., Ofer, D. and Shvarts, D. 1995 Power laws and similarity of Rayleigh-Taylor and Richtmyer-Meshkov mixing fronts at all density ratios; Phys. Rev. Lett., 74, no. 4, 534-537.

Zhou, Y., Robey, H.F., Buckingham, A.C. 2003 Onset of turbulence in accelerated high-Reynolds-number flow; Phys. Rev. E., 67, 056305, 1-11.

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.

Implementation of a turbulent mix model in a 2D ALE code

Brian Grieves

AWE plc,
Aldermaston, UK
brian.grieves@awe.co.uk
http://www.awe.co.uk/

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 in the ALE package 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 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 internal nodes, and this is used to initialise the turbulent mix model calculation.

On implicit large eddy simulation for turbulent flows

Fernando F. Grinstein

IGPP, MS C305, Los Alamos National Laboratory, Los Alamos, NM 87545, USA
fgrinstein@lanl.gov

Large Eddy Simulation (LES) is an effective intermediate approach between DNS and RANS, capable of simulating flow features which cannot be handled with RANS such as significant flow unsteadiness and strong vortex-acoustic couplings, and providing higher accuracy than RANS at reasonable cost but still typically an order of magnitude more expensive. In the absence of an accepted universal theory of turbulence, the development and improvement of subgrid scale (SGS) models has been unavoidably *pragmatic* and based on the rational use of empirical information. Classical approaches have included many proposals ranging from, inherently-limited eddy-viscosity formulations, to more sophisticated and accurate mixed models, e.g., [1]. Their main drawback relates to the fact that *well-resolved* (discretization-independent) LES becomes prohibitively expensive for the practical flows of interest at moderate-to-high Re.

Recently, many researchers have abandoned the classical LES formulations, shifting the focus directly to the SGS modelling *implicitly* provided by non-linear stabilization achieved algorithmically, through use of a particular class of numerical schemes, or based on regularization of the discretization of the conservation laws, [2]. Most numerical discretization schemes can potentially provide built-in or implicit SGS models enforced by the discretization errors if their leading order terms are dissipative. However, not all implicitly implemented SGS models are expected to work: the numerical scheme has to be constructed such that the leading order truncation errors satisfy physically required SGS-model properties, and hence non-linear discretization procedures are required. The analogy to be recalled is that of shock-capturing schemes designed under the requirements of convergence to weak solution while satisfying the entropy condition. Nonoscillatory finite-volume (FV) numerical schemes can likewise be viewed as relevant for *nonlinear* implicit LES (ILES) of turbulent flows [3], if we propose to focus on two distinct inherent *physical* SGS features to be emulated:

the anisotropy of high-Re turbulent flows in the high-wave-number end of the inertial subrange region (characterized by very thin filaments of intense vorticity and largely irrelevant internal structure, embedded in a background of weak vorticity),

the particular nature of laboratory observables (only finite fluid portions transported over finite periods of time can be measured).

We thus require ISSM to be based on FV numerics having a *sharp velocity-gradient capturing capability* operating at the smallest resolved scales. In the Monotonically Integrated LES (MILES) approach [3], the effects of the SGS physics on the resolved scales are incorporated in the functional reconstruction of the convective fluxes using locally-monotonic FV Flux-Corrected Transport methods. The MILES performance has been demonstrated in many fundamental applications ranging from canonical to complex flows; other proposed ILES approaches are discussed in [2].

Challenges for ILES to be addressed in the presentation include developing a common appropriate mathematical and physical framework for its analysis and development, further understanding the connections between implicit SGS model and numerical scheme, and in particular, building physics into the numerical scheme to improve on the implicitly-implemented SGS dissipation & backscatter features. Moreover, additional (explicit) SGS modelling might be needed to address inherently small-scale physical phenomena such as scalar mixing and combustion – which are actually outside the realm of <u>any</u> LES approach: how do we exploit the implicit SGS modelling provided by the numerics, to build efficient "mixed" (explicit/implicit) SGS models ?

[1] Sagaut P.; 2002, “Large Eddy Simulation for Incompressible Flows”,Springer, New York.

[2] Grinstein, F.F. & Karniadakis, G.Em, Editors, Alternative LES and Hybrid RANS/LES; 2002, *J. Fluids Engineering,* 124, 821-942.

[3] Fureby C. & Grinstein F.F.; 2002, "Large Eddy Simulation of High Reynolds Number Free and Wall Bounded Flows", *J. Comp. Physics*, 181, p 68; see also AIAA Paper 2003-4100 (2003).

*Orson Anderson Distinguished Visiting Scholar; on Sabbatical leave from LCP&FD, NRL, Washington DC, USA.

The problem of Kelvin-Helmholtz instability on contact boundary of finite width and ICF applications

S. Yu. Gus'kov[1], A. Caruso[2], V. B. Rozanov[1], R.V. Stepanov[1], C. Strangio[2] & N.V. Zmitrenko[3]

1. P.N. Lebedev Physical Institute of Russian Academy of Sciences,
Moscow, Russia
guskov@sci.lebedev.ru

2. ICF Physics and Technology Laboratory of C.R. ENEA,
Frascati, Italy
caruso@frascati.enea.it

3. Institute of Mathematical Modeling of Russian Academy of Sciences,
Moscow, Russia
zmitrenko@imamod.ru

The statement and analysis of non-stationary Kelvin-Helmholtz instability problem is presented under the conditions when the layer of finite thickness moves along the surface of infinite medium. The layer is oriented perpendicularly to the medium surface and width of contact boundary is limited by the layer thickness. The problem has been investigated for the conditions of spherical and cylindrical fast ignition ICF target (Basov (1992)). In this approach during the period of preliminary compression the layer of thermonuclear fuel moves along a surface of channel which is used to deliver the igniting driver energy inside the target. The Kelvin- Helmholtz instability could lead to the mixing of DT-fuel and heavy material of the channel and deteriorate the ignition conditions (Caruso (2003)).

The results of numerical simulations of the phenomenon by 2D hydrodynamics code are presented and discussed. Simulations were carried out at the different types of the initial spectrum of medium boundary perturbations. Several interesting effects of instability evolution have been found. Among them, there are

-non-stationary dynamics of instability evolution;

-the different time of perturbations growth in the layer and in the medium;

-more large age the perturbations in layer in comparison with the perturbations in medium;

-strong influence of layer front edge on the perturbation evolution;

-the intensive vortexes near the both layer edges and spreading of the layer flatness boundaries.

The work partly supported by ISTC Grant N 1481.

References

Basov N.G., Gus'kov S.Yu., Feoktistov L.P. 1992 Thermonuclear gain of ICF target with direct heating of ignitor; J. Soviet Laser Research, 13(5) 396-399.

Caruso A., Strangio C. 2003 Ignition thresholds for deuterium-tritium mixtures contaminated by high-Z material in cone-focused fast ignition, JETP, 124, 5(11) 1058-1068.

Numerical experiments using high-resolution methods in compressible and turbulent flows

Marco Hahn & Dimitris Drikakis

School of Engineering, Fluid Mechanics & Computational Science Group, Aerospace Sciences Department, Cranfield University, Cranfield, Bedfordshire MK43 0AL, UK
d.drikakis@cranfield.ac.uk
http://www.cranfield.ac.uk

The use of high-resolution methods as an implicit way to model and compute turbulent flows is an evolving area of research. The success of these methods to compute turbulent flows without need to resort to an explicit turbulence model has been demonstrated by a number of studies in the literature, e.g., (Boris 1992; Youngs 2003; Drikakis 2003) and, additionally, there are recent efforts aiming at a theoretical justification (Margolin & Rider 2001).

The desire for understanding better the physics encompassed by numerical methods, high-resolution methods in particular, is motivated by the fact that almost all practical computations in engineering are under-resolved. Numerical methods encompass numerical dissipation which acts to regularise the flow, thereby allowing shock propagation to be captured physically realistically even if it is not fully resolved on the computational mesh. Nonlinear mechanisms (limiters) in high-resolution methods guard the methods from catastrophic failures (due to nonlinear wave steepening or unresolved features) by triggering entropy producing mechanisms that safeguard the calculation when the need arises. The two key questions are: (i) what criteria should be used to design the nonlinear mechanism that triggers the entropy production, and (ii) to what extent numerical dissipation accounts for turbulent flow effects.

In this study, we present numerical studies of flows featuring shock waves and transitional/turbulent mixing, using high-resolution methods. We have performed numerical experiments using Godunov-type and hybrid, total variation diminishing (TVD) schemes, in the context implicit (very) large eddy simulation. By "very large" we imply that the simulation (and thus the flow) is largely under-resolved in terms of grid resolution. This results in magnifying the errors and differences in the results obtained by using variants of high-resolution schemes. The hybrid TVD schemes employed here are based on the combination of first-, second- and third-order non-oscillatory schemes. The schemes adapt the numerical dissipation locally in the flow field through a combination of sensor functions and limiters. We consider the cases of compressible decaying turbulence as well as compressible flow over open cavities to demonstrate some of the numerical effects and differences. Further, we discuss some accuracy and efficiency issues by comparing different Godunov-type methods for the shock-bubble interaction problem.

References

Boris JP, Grinstein FF, Oran ES, Kolbe RJ. Fluid Dyn. Res., 10: 199-228, 1992.

Youngs, D. AIAA-2003-4102.

Drikakis D, Progress in Aerospace Sciences, 39, 405-424, 2003.

Margolin LG, Rider WJ. Int. J. Numer. Meth. Fluids 39: 821-841, 2001.

Interacting thermals

Alison C. Hart & Stuart B. Dalziel

Department of Applied Mathematics and Theoretical Physics
University of Cambridge
a.c.hart@damtp.cam.ac.uk; s.dalziel@damtp.cam.ac.uk
www.damtp.cam.ac.uk/lab/

A thermal is an instantaneous release in a gravitational field of fluid of a density that differs from that of its surroundings. Much work, both experimental and theoretical, has previously been done on the case of a single thermal in both stratified and unstratified environments. Indeed, it is worth noting that the impulsively accelerated equivalent of a shock passing through a bubble or droplet is also of interest to this community. This paper reports preliminary results of a novel study of thermals in the Boussinesq limit, with particular emphasis on the simultaneous release of multiple thermals and their subsequent interaction.

As the thermal propagates it entrains the surrounding fluid which, due to the interior motion of the thermal, becomes mixed throughout. In an array the amount of ambient fluid between each thermal becomes limited and consequently they will either merge or compete for this fluid. We utilise a combination of simple laboratory experiments and numerical modelling in our attempt to understand the dynamics.

This study, motivated in part by an analogy between multiple interacting thermals and Rayleigh-Taylor instability, will help provide insight into the processes of mode coupling and mode competition that appear important for understanding the growth of Rayleigh-Taylor instability.

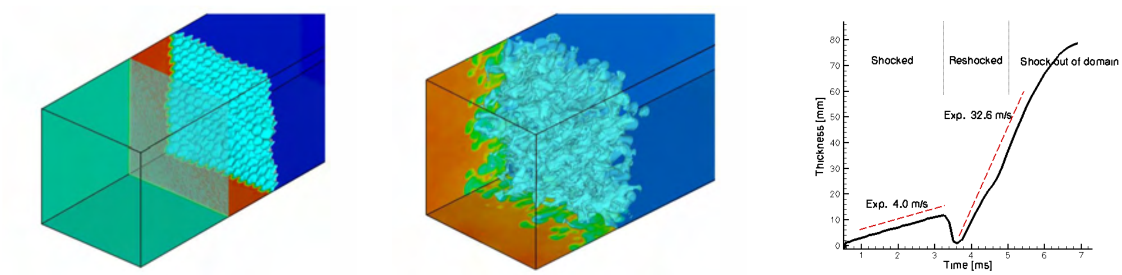
Large-eddy simulation of Richtmyer-Meshkov instability with re-shock

D.J. Hill[1], **D.I. Pullin**[1] **& R.Deiterding**[2]

1. Graduate Aeronautical Laboratories
California Institute of Technology, Pasadena, CA 91125
djh@cacr.caltech.edu

2. Center for Advanced Computing Research
California Institute of Technology, Pasadena, CA 91125

We present results from large-eddy simulations (LES) of three-dimensional Richtmyer-Meshkov (RM) instability in a rectangular tube with reshock off the tube end wall. The subgrid-scale model is the stretched-vortex model of Misra & Pullin (1997). The shock strength, tube geometry and initial interface disturbance were tailored to match the experimental conditions of Vetter and Sturtevant (1995) with shock Mach number $M_s = 1.5$, and density ratio $r = 5$. The numerical method is based on a hybrid WENO (weighted essentially non Oscillatory) scheme, used in thin regions containing shock waves, matched to a tuned centered difference (TCD) scheme in regions of smooth flow, where the SGS model is activated (Hill & Pullin, 2004). The TCD scheme is optimized for good LES performance. Results are presented for both unigrid simulations at 512×256×256 resolution and also for LES using the AMROC (adaptive mesh refinement object-oriented C++) environment. The computed growth rates of the mixing layer, both before and after reshock, are compared with the measurements of Vetter and Sturtevant (1995). To illustrate results, Figure 1 shows images of the center of the mixing layer based on the zero level set of a passive scalar, before and after reshock, and also a comparison of mixing-layer growth rates with experiment.



(a) (b) (c)

Figure 1: Density interface (a) After first shock passage. (b) Post reshock. (c) time-wise growth of mixing layer thickness compared with Vetter and Sturtevant (1995)

References

Hill D.J. & Pullin D.I. 2004 Hybrid Tuned Center Difference - WENO Method for Large Eddy Simulations in the Presence of Strong Shocks. *J. Comp Phys.* In press.

Misra A. & Pullin D.I. 1997 A vortex-based subgrid stress model for large-eddy simulation. *Phys Fluids* **9**, 2443-2454.

Vetter M. & Sturtevant B. 1995 Experiments on the Richtmyer-Meshkov instability of an air/SF6 interface. *Shock waves.* **5**, 247-2524.

Shock tube Richtmyer-Meshkov experiments: inverse chevron and half height

D A Holder & C J Barton

AWE, Aldermaston, UK
david.holder@awe.co.uk
http://www.awe.co.uk/

This paper reports results from two Richtmyer-Meshkov instability (RMI) shock tube experiments. The first features an inverse chevron perturbation and the second consists of a half height dense gas region.

The experiments were conducted on the AWE's 200 x 100 mm shock tube with a shock Mach number of 1.26 (70kPa overpressure). Both configurations involve a three zone test cell arrangement of air / dense gas / air all initially at atmospheric pressure. Using sulphur hexafluoride (SF_6) as the dense gas yields an Atwood number of 0.67.Gas separation was by means of profiled windows and fine wire meshes supporting microfilm membranes. Visualisation of the mixing was by laser sheet illumination of the dense gas seeded with an olive oil aerosol. A pulsed laser allows a drum camera to record over 50 images of the mixing process augmented by an Intensified CCD (ICCD) camera capturing a single image per experiment.

The inverse chevron is on the downstream membrane with a central obtuse angle of 157º and amplitude 20mm. This is complimentary to the chevron presented at the previous workshop (Holder et al., 2001) and is related to the inclined interface experiments initiated at the 5th meeting of this workshop (Bashurov et al., 1995).

The half height experiment is significantly different from our usual experimental configurations involving perturbations on otherwise plane interfaces. In this case the central, dense gas region of the test cell is filled to halfway (100mm high) with seeded dense gas. The interfaces to either side feature microfilm membranes and are plane, whereas the top interface is membraneless and is nominally plane. This then introduces a Kelvin-Helmholtz instability to the experiment.

Sample laser sheet images from each experimental configuration will be compared to corresponding code images from the AWE TURMOIL 3D LES model. A qualitative comparison between experimental and code images will be presented. Quantitative analysis in the form of line-outs through both sets of images will also be shown. Substantial agreement on large scale features will be demonstrated.

A time sequence will be shown for each experiment to allow improved visualisation of the mixing history. These will also be available to view on the linear shock tube pages within the AWE website.

References

Bashurov, V.V., et al., 1995, Experimental and numerical evolution studies for 2-D perturbations of the interface accelerated by shock waves. Proceedings of the Fifth International Workshop on Compressible Turbulent Mixing.

Smith, A.V., et al. 2001, Shock tube experiments on Richtmyer-Meshkov instability across a chevron profiled interface. Proceedings of the Eighth International Workshop on Compressible Turbulent Mixing..00

Spectral characteristics of turbulence driven by Rayleigh-Taylor instability

Joanne M. Holford[1,2], Stuart B. Dalziel[1] & David Youngs[3]

1. Department of Applied Mathematics and Theoretical Physics, University of Cambridge, UK
s.dalziel@damtp.cam.ac.uk
http://www.damtp.cam.ac.uk/lab/

2. BP Institute, University of Cambridge, UK
joanne@bpi.cam.ac.uk
http://www.bpi.cam.ac.uk/

3. AWE plc, Aldermaston, UK
david.youngs@awe.co.uk
http://www.awe.co.uk/

The spectral characteristics of a turbulent flow, such as the flow resulting from Rayleigh-Taylor (RT) instability, can be a useful aid to understanding the fundamental dynamics and energy transfers. In this study, we have investigated the spectral characteristics of RT turbulence in 3D numerical simulations using TURMOIL, a compressible MILES code in which losses of kinetic energy and density fluctuations at the grid scale correspond to a numerical viscosity and diffusivity.

We have studied RT simulations in a domain of size 1×0.8×0.4, with an initially horizontal unstable interface at mid-height, using a grid spacing of 5×10^{-3}. The physical properties of the two fluid layers were chosen so that the effects of compressibility were limited. The initial conditions comprised random perturbations to the interface position, of various spectral distributions and amplitudes, sometimes in association with a 2D velocity perturbation representing the removal of a horizontal barrier at the interface in companion laboratory experiments. The evolving spectra of both density and velocity components were calculated, in the horizontal plane at mid-height, up to non-dimensional time $T = t\sqrt{Ag/H} = 10$, where A is the Atwood number, g the acceleration due to gravity and H the domain height.

For most initial conditions, the concentration fluctuations $\overline{c'^2}$ increased across the spectrum up to $T = 1$, with a smooth profile peaking around $k = 50$ and falling off in the dissipation range as k^{-3}, while $\overline{w^2} \sim k^{-3.7}$ and $\overline{u^2} \sim \overline{v'^2} \sim k^{-4}$. Between $1<T<5$, while the most energetic scales are smaller than the tank dimensions, mid-wavenumber spectra approach $\overline{c'^2} \sim k^{-1.1}$ and $\overline{w^2} \sim k^{-1.3}$, while spectra in the dissipation range steepen to k^{-5}.

A wide range of initial spectra were investigated. The presence of gaps or spikes does not significantly affect the flow, with a smooth spectra attained around $T = 1$ in all cases. Large amplitude perturbations reach this initial spectral shape more quickly, by $T = 0.75$. The simulations with an initial k^{-3} spectrum evolved the most quickly. The 2D perturbation mimicking a laboratory experiment introduced a low wavenumber perturbation (initially around $k = 12$) at about $T = 1$, which also speeded up the flow development.

In this study, the low wavenumber spectra are more sensitive to the initial conditions, and an initial disturbance weighted towards these frequencies evolves more quickly. The high wavenumber spectra and molecular mixing, which occurs at the smallest scales, are less sensitive to the initial conditions.

Study of converging reflected shock waves and Richtmyer-Meshkov instability in spherical geometry

S. H. R. Hosseini, K. Takayama & T. Saito

Interdisciplinary Shock Wave Research Center, Institute of Fluid Science,
Tohoku University, Japan
hosseini@cerers.ifs.tohoku.ac.jp
http://ceres.ifs.tohoku.ac.jp/~coe/indexe.html

The paper describes experimental results of the convergence of a spherical reflected shock wave from a spherical wall and its induced Richtmyer-Meshkov instability. In order to visualize the shock waves and their interaction with gaseous interfaces in spherical geometry, an aspheric lens shaped transparent test section made of acrylic PMMA was designed and constructed. The test section has 300 mm diameter spherical inner wall and 430 mm aspherical shape outer wall. This test section permits the collimated visualization object beam to traverse the test section parallel and emerge parallel. Spherical shock waves were produced at the center of the spherical cavity by explosion of silver azide pellets ranging from 1.0 to 20.0 mg with their corresponding energy of 1.9 to 38 J. The charges were ignited by irradiation of a pulsed Nd:YAG laser beam. Pressures were also measured at two points on the spherical wall surface. To produce uniform diverging spherical shock waves the pellets were simultaneously ignited on two sides and were shaped. Such a spherical diverging shock wave was reflected from the spherical inner wall of the test section to form a converging spherical shock wave. Gaseous spherical interfaces concentric with the explosion center were produced by soap bubbles filled with He, Xe, and SF_6. The shock wave motion and resulted Richtmyer-Meshkov instability at the interfaces were visualized by using double exposure holographic interferometry and time-resolved high speed video recording. The sequence of diverging and converging spherical shock wave propagation and their interaction with explosion products gas and the intensified mixing of the gases at the interfaces were studied.

On the mutual penetrations of two gases submitted to the Richtmyer-Meshkov instability: Part 1 - experiments

Lazhar Houas[1], Georges Jourdan[1], Vincent Filpa[2], Guillaume Layes[1], Jérôme Giordano[1], Clément Amagat[2] & Yves Burtschell[1]

1. Polytech'Marseille DME - IUSTI/UMR CNRS 6595
13453 Marseille Cedex 13, France
Lazhar.Houas@polytech.univ-mrs.fr

2. Ecole de l'Air de Salon,
BA 701, 13661 Salon Air, France

An experimental investigation, based on the laser sheet technique, has been undertaken to study the mutual penetrations of two different density gases, the interface of which is submitted to the Richtmyer-Meshkov instability. Two couples of gases are used to illustrate both heavy/light (air/He) and light/heavy (air/SF_6) cases. The incident shock wave Mach number is of about 1.31 and gases on both sides of the interface (a 0.4 μm nitrocellulose membrane) are at atmospheric pressure. Two different perturbations (positive and negative) are tested. Experiments will be compared with numerical simulations obtained from CARBUR code.

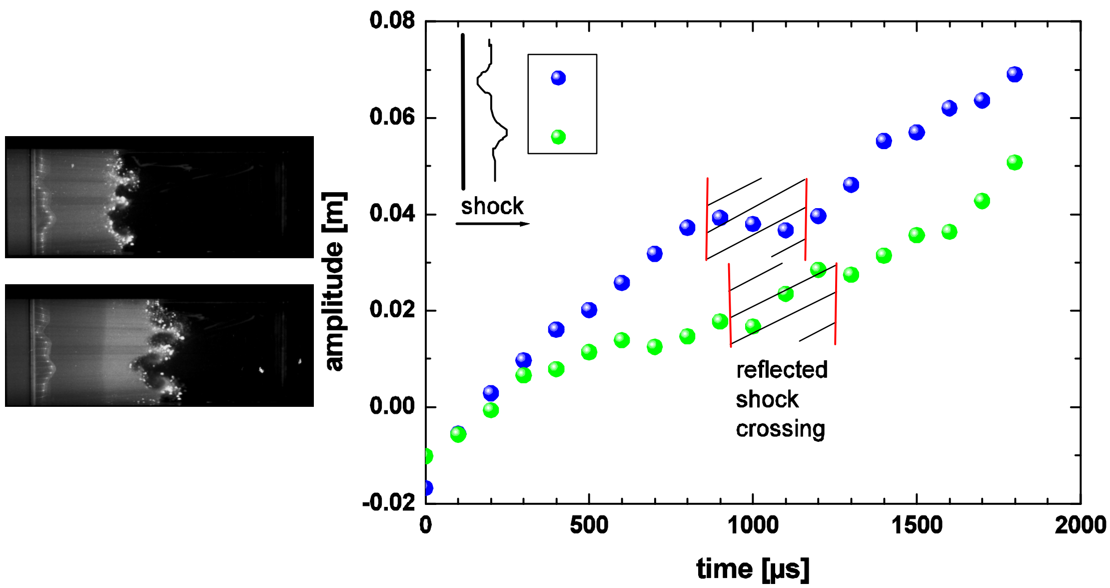


Figure 1: Example of laser sheet typical visualisations of a heavy/light (air/helium) interface submitted to a 1.31 incident shock wave Mach number, moving from left to right first in air (grey) then in helium (black). Frame 0 is taken 22 μs before interaction (100 μs separate two consecutive frames, i.e. 700 μs between frames 0 and 7). The amplitudes and wavelengths of the initial perturbations are $a_0 = 90$ mm and $\lambda = -18$ mm and $a_0 = 80$ mm and $\lambda = 14$ mm, respectively. (b) Evolution of the amplitude of the initial perturbations (the opposite value of the negative perturbation is plotted in order to keep both graphs on the same figure).

Three-dimensional simulations of Richtmyer-Meshkov experiments

R.M. Hueckstaedt[1], S.H. Batha[1], M.M. Balkey[1], N.D. Delamater[1], J.R. Fincke[1], R.L. Holmes[1], N.E. Lanier[1], G.R. Magelssen[1], J.M. Taccetti[1], J.M. Scott[1], C.J. Horsfield[2], K.M. Parker[2] & S.D. Rothman[2]

1. Los Alamos National Laboratory
Los Alamos, NM USA
rmhx@lanl.gov

2. AWE plc
Aldermaston, UK

We measure the growth of Richtmyer-Meshkov instabilities in a convergent plasma (Lanier et al., 2003). Experiments are conducted at the Omega laser facility using cylindrical targets consisting of a low-density foam core and an aluminum marker layer within an epoxy ablator. The targets are directly driven by fifty laser beams and radiographed along the axis. The outer surface of the aluminum layer is machined in order to examine different perturbation spectra. Experiments and simulations study unperturbed (smooth), single-mode, multi-mode (rough), and multi-mode with particular modes accentuated (specified-rough) surfaces. The experimental results vary for rough and specified-rough targets. The rough targets show no marker layer growth beyond that of the smooth targets; whereas, the specified-rough targets (and the single-mode targets) show additional marker growth. Two-dimensional simulations using the RAGE code predict additional marker growth for all perturbed targets and do not explain the lack of observed growth for rough surfaces. We have expanded our simulation efforts to include three-dimensional simulations. At issue is whether the two-dimensional contributions to the specified-rough spectra lead to an enhanced growth of large scale features not generated by the rough spectra. In this paper we present our latest results contrasting the two-dimensional and three-dimensional simulations.

References

Lanier, N.E, Barnes, C.W, Batha, S.H., Day, R.D., Magelssen, G.R., Scott, J.M, Dunne, A.M., Parker, K.W. & Rothman, S.D. 2003 Multi-mode Seeded Richtmyer-Meshkov Mixing in a Convergent, Compressible, Miscible Plasma System, *Physics of Plasmas* **10**, 1816

Exact expansion law for Richtmyer–Meshkov turbulent mixing zone

N.A. Inogamov[1] & A.M. Oparin[2]

1. Landau Institute for Theoretical Physics,
Chernogolovka, Moscow region, Russia
nail@landau.ac.ru

2. Institute for Computer Aided Design,
Moscow, Russia
a.oparin@icad.org.ru

Definition of mixing fronts and turbulent mixing zone

Development of the Richtmyer–Meshkov instability leads to mixing of two substances separated by contact boundary. Let the axis z is perpendicular to a plane of boundary and $z = 0$ corresponds to an unperturbed plane. The turbulent mixing zone is limited by front $z = h_+(t) > 0$ from heavy fluid side and by front $z = h_-(t) < 0$ from light fluid. Mixture of two fluids is confined between these two fronts (layer $h_- < z < h_+$).

Initial conditions

Before pass of a shock wave both liquids were motionless and $z = \eta_0(x,y)$ was perturbed contact boundary. We consider linear (small amplitude) perturbation: $|\nabla\eta_0| \ll 1$. Then the shock wave passes perturbations quickly: $\Delta t << \lambda\dot{\eta}_0$, where Δt is shock wave passage time, λ is typical wavelength (or space scale) of perturbations, and $\dot{\eta}_0$ is typical velocity after shock wave passage, $\dot{\eta}_0(x, y, t = \Delta t)$.

Transition and asymptotic stages

Universal asymptotics follows transition stage at $t >> |\lambda\dot{\eta}_0|$. Functions $h_\pm(t)$ asymptoticaly transform to power law dependences. Mixing is accompanied by cascade of enlarging of dominant scale of a turbulent mixing zone. Under condition $\mu = 0$ exact scaling laws are: $h_+^{2D} \propto t^{2/5}$ and $h_+^{3D} \propto t^{1/3}$, where μ is density ratio, 2D and 3D mark dimension of space. These scalings are calculated in our work. The scaling exponents 2/5 and 1/3 are determined by the mechanism of redistribution of z–component of momentum from small in the large scales. For $\mu \neq 0$ the exponents 2/5 and 1/3 define the bottom limit of a range of possible values for both functions $h_+(t)$ and $h_-(t)$. Our 2D direct numerical simulations at different values $\mu \approx 1$ show that $\dfrac{d \ln h_\pm}{dt} \approx \dfrac{2}{5}$.

This work has been supported by RBRF (grants 02–02–17499, 03–01–00700) and scientific schools (NSh–2045.2003.2, NSh–70.2003.1).

Experiments on the three-dimensional incompressible Richtmyer-Meshkov instability

Jeffrey Jacobs & Patricia Chapman

Department of Aerospace and Mechanical Engineering,
University of Arizona, USA
jwjacobs@u.arizona.edu

Experiments will be presented in which an incompressible system of two miscible liquids is impulsively accelerated to produce Richtmyer-Meshkov instability. The initially stratified liquids (a calcium nitrate/water solution and an isopropyl alcohol/water solution) are contained within a tank mounted to a vertical rail system. A three-dimensional single-mode perturbation of square shape is given to the interface by oscillating a tank of square cross section in the direction of its diagonal. The tank is then released allowing it to fall until it bounces off of a fixed spring giving it an impulsive acceleration. After bouncing the tank travels upward and then downward on the rails in freefall allowing the instability to evolve in the absence of gravity. The resulting fluid flow is visualized using PLIF yielding cross-sectional views of the flow (figure 1). Flood illuminated experiments are also performed in which one of the fluids is made opaque using milk (figure 2). In both cases motion sequences are captured using a video camera that travels with the fluid system. Amplitude measurements taken from these experiments indicate that the three-dimensional instability grows significantly faster in the nonlinear regime (after differences in the linear growth rate are accounted for) than its two-dimensional counterpart. This difference can be attributed to fundamental differences in vorticity distributions of the two flow patterns.

Figure 1: PLIF image.

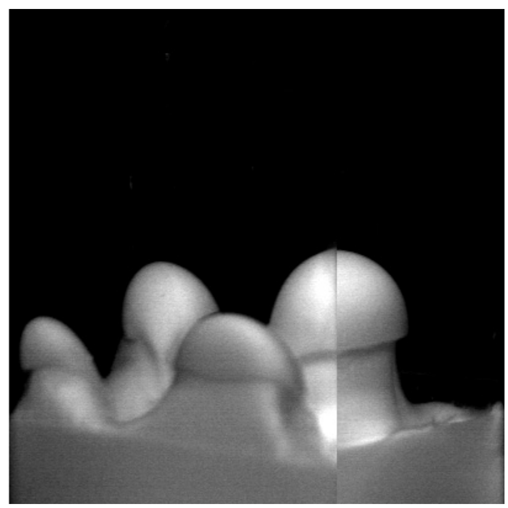


Figure 2: Opaque image.

Interfacial pressures and shocks in a multiphase flow model

Daniel E. Klem

DNT/AX Division
Lawrence Livermore National Laboraotry
klem1@llnl.gov

Multiphase flow models[1] have been proposed for use in situations which have combined Rayleigh-Taylor (RTI) and Richtmyer-Meshkov (RMI) instabilities[2]. This approach works poorly for the case of a heavy to light shock incidence on a developed interface. Such models can be derived and all the approximations made explicit in the same sense that Reynolds Averaged Navier-Stokes (RANS) turbulence models are "derived." Such derivations produce correlations in the RANS sense and also surface terms which are unique to multiphase flow models. These derivations lend insight into the validity of the approximations in the model. The physical original of this difficulty is traced to an inadequate model of the interfacial pressure term as it appears in the momentum and turbulence kinetic energy equations. In this context it is observed that a new constrain on the closures arises. (Such constrains exists on the terms in any model which contains shocks.) This occurs because of the discontinuity within the shock responsible for the RMI. A form is proposed and implemented in a multiphase flow model following the work of Youngs. Comparisons made to the experiments of Vetter and Sturtevant[3] and also of Erez[4]. The proposed model (Shock Scattering) is shown to give useful 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.

References

[1]Drew, D.A.. and Passman, S.L., 1998 Theory of Multicomponent Fluids; Springer-Verlag, New York, Berlin, Heidlberg.

[2]Youngs, D.L., 1989 Physica **D** 37, 270-287.

[3]Vetter, M. and Sturtevant, B., 1995 Experiments on the Richtmyer-Meshkov Instability of an Air/SF6 Interface, 4, 247-252.

[4]Erez, L., et al., 2000 Study of the Membrane Effect on Turbulence Mixing Measurements in Shock Tubes, Shock Waves **10**, 241-251.

UCRL-ABS-201787

The experiment result analysis of turbulent mixing at moderate Reynolds numbers in a gravity field of the Earth.

Alexander Kozlovskih, Vadim Anisimov & Sergey Baban.

RFNC–VNIITF,
Snezhinsk, Russia
a.s.kozlovskih@vniitf.ru

Kucherenko's group explored the turbulent mixing of different density gases [1] in "OSA" – facility experiments in 2001. Explored gases were placed in a multifunctional shock tube and were separated by a "spectre-membrane". There was a grid from micro conductors. A fluid soap film was superimposed on this grid. The specter-membrane was destroyed into small-scale fragments by the external force. The contact boundary of gases was accelerated by means of a compression wave, which was formed in the shock tube. The zone of the gravitational turbulent mixing appeared at the contact boundary. Acceleration of the contact boundary was about $g \approx 40000$ m/s^2. The constant of gravity turbulent mixing (α_b=0.04) was found as a results of these experiments.

The same experiments were carried out in the gravity field of the Earth also [2]. Turbulent mixing zone appeared in the field with g=9.81 m/s^2 when a membrane was destroyed. Estimated value of constant α_b=0.078 approximately twice exceeded the values determined in experiments with a compression wave.

We suggested the interpretation of the apparent difference of the turbulent mixing constant. All experimental data, both in the shock tube and in the field of gravity, are described by uniform dependence in variables $\overline{Re} = \left(S^{3/2} g^{1/2}\right)/\tilde{\nu}$ and $\varphi\left(\overline{Re}\right) = \frac{3L_b}{2A}\left(\frac{\tilde{\nu}^2}{g}\right)^{1/3}$. It allows us to surmise that a self-similar growth rate of the turbulent zone depends on turbulent Reynolds numbers. There is shown, that α_b decreases when turbulent Reynolds number increases, and dependence of turbulent zone width passes to a standard $L=\alpha Agt^2$. Opposite, the value α_b increases at moderate values of $Re_t=10^2$ - 10^3 and the dependence of turbulent zone width becomes nonlinear and self-similar law of turbulent zone growth does not carry out.

References

1. Yu.A. Kucherenko et al. 2001. "Experimental investigation into the evolution of turbulent mixing of gases by using the multifunctional shock tube". Proceedings of the IWPCTM 8, Pasadena, USA.
2. Yu.A. Kucherenko et al. 2001, "Experimental investigation into the self-similar mode of mixing of different density gases in the earth's gravitational field". Proceedings of the VI Zababakhin Scientific Talks, Snezhinsk, Russia.

About the opportunity of use of the color photo for visualization of the zone of turbulent mixing in experiments on the shock tube with the GEM-driver

V. Kozlov[1], A. Levushov[1,2] & E. Meshkov[1,2]

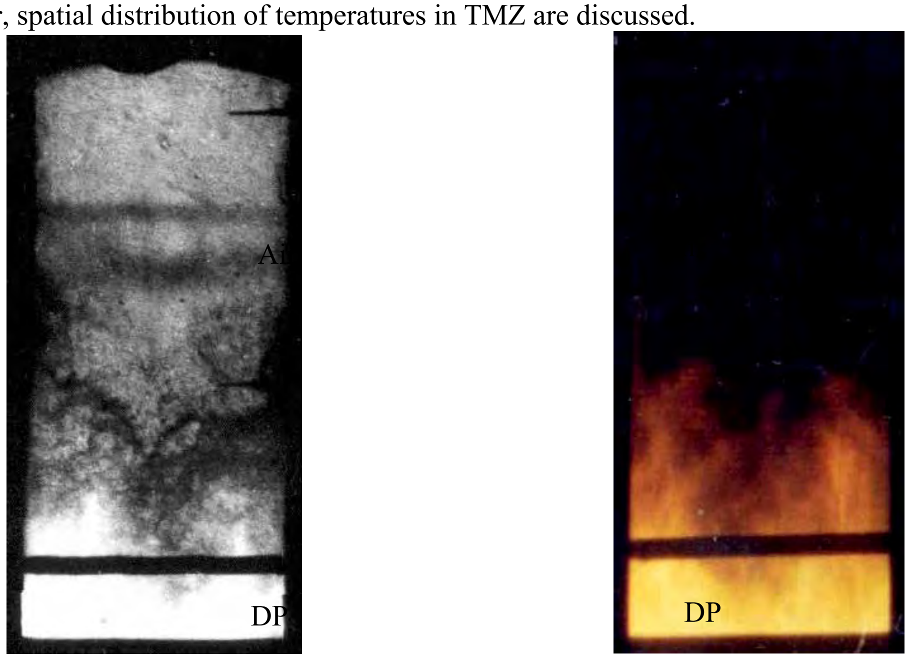
[1]Russian Federal Nuclear Center - VNIIEF, Sarov, Russia

[2]Sarov Physical-Technical Institute
meshkov@sarfti.sarov.ru

A zone of turbulent mixing (TMZ) on the interface of two gases in experiments on shock tubes (see f.e. [1]) is invisible without visualization and photoregistration tools, so apply various shadow methods are used.

In experiments with the TMZ using gas explosive mixtures (GEM) [2] products of a detonation of a mix of acetylene with oxygen possess high temperature (~4000^{o}) and shining bright enough for registration of current on a color film (see figure). The outcome of the experiments in a shock tube with the GEM-driver illustrate opportunities of similar registration of TMZ on interface between products of detonation GEM and air.

Opportunities to study the structure of TMZ in similar experiments with the help of a color photo and, in particular, spatial distribution of temperatures in TMZ are discussed.



(a) (b)

Zone of turbulent mixing on interface: a detonation products (DP) of mixture of acetylene with oxygen - air (Air) in experiments on the shock tube working under the method [2] a) Shadow black-and-white photo of a zone of mixing and b) a color photo of own luminescence of products of a detonation

References

1. Andronov V.A. *et al.* **.** Sov.Phys.JETP, т.71, вып. 2(8), 1976. C. 806. (in Russian)**.**

2. Meshkov E.E. One Approach to the Experimental Study of Hydrodynamic Instabilities:Creation of a Gas-Gas Interface Using the Dynamic Technique.The Proc of the 5th IWPCTM, Stony Brook, USA, **1995**, p.237.

Recovery of Rayleigh-Taylor mixing from unstably stratified flow past a cylinder

Wayne N. Kraft & Malcolm J. Andrews

Department of Mechanical Engineering
Texas A&M University, College Station, Texas, USA
wkraft@tamu.edu, mandrews@mengr.tamu.edu

An experimental investigation has been performed to study the non-equilibrium development of small Atwood number Rayleigh-Taylor mixing. Specifically, the recovery of a Rayleigh-Taylor mixing layer due to a disruption of its equilibrium by a cylindrical obstruction.

A water channel, previously used to investigate the development of Rayleigh-Taylor mixing, has been modified to include an obstruction. A splitter plate initially separates parallel streams of hot and cold water. With cold above hot, a buoyancy driven mixing layer develops. Downstream a cylindrical obstruction is located at the centerline of the mixing layer. A turbulent wake formed by the obstruction disrupts the equilibrium of the buoyancy driven mix. As a result the equilibriums of the Rayleigh-Taylor mix and plane wake interact.

Recovery of buoyancy dominated turbulence from a plane wake is characterized through measurements of velocity and density fluctuations at the centerline of the mixing layer. These measurements are acquired through particle image velocity (PIV) and a thermocouple system. These diagnostics are utilized to document the transition, and recovery to equilibrium, of the Rayleigh-Taylor mixing layer. To investigate the effects of density differences and cylinder diameter on the response of the buoyancy driven mixing layer, measurements have been taken for different Atwood and internal Froude numbers. This has led to the development of a model for the initial decay of centerline velocity fluctuations behind the cylinder.

This work has been funded by the U.S. Department of Energy from DOE Grant # DE-FG03-99DP00276/A000.

Visualization of Rayleigh-Taylor instability

Wayne N. Kraft & Malcolm J. Andrews

Department of Mechanical Engineering
Texas A&M University, College Station, Texas, USA
wkraft@tamu.edu, mandrews@mengr.tamu.edu

Rayleigh-Taylor instability (R-T) occurs when a density gradient is accelerated by a pressure gradient such that when a heavy fluid rests above a light fluid under the influence of gravity. As a result the density interface is unstable to infinitesimal perturbations. This poster presents a visualization overview of our statistically steady R-T mixing experiment. Photographs from dye visualization, PIV, PIV-S, and PLIF are shown. Apart from the intrinsic scientific and engineering interest, the images reveal the beauty and art of buoyancy driven fluid mixing.

Experimental study of the late-time evolution of single-mode Richtmyer-Meshkov instability

Vitaliy Krivets, John Stockero & Jeffrey Jacobs

Department of Aerospace and Mechanical Engineering,
University of Arizona, USA
vkrivets@email.arizona.edu

A vertical shock tube is used to study the Richtmyer-Meshkov instability of an Air/SF_6 interface. The two gases flow from opposite ends of the shock tube driven section to form the interface which is given a sinusoidal perturbation is by oscillating the tube in the lateral direction. PLIF is used to visualize the flow. New experimental results will be presented in which initial perturbations with shorter wavelength and larger amplitude are used to produce significantly increased dimensionless evolution time kv_0t, where k is the perturbation wave number and v_0 is the initial growth rate. These late-time results show the transition to turbulence of the vortex cores (figure 1) which is triggered by an instability on the vortex spirals. Once turbulent, the vortex cores rapidly grow in size and begin to erode the remainder of the mushroom caps. At the latest times the interface is characterized by flat-topped bubbles separated by thin strips of heavy gas which are remnants of the mushroom stems. When reshocked, this late-stage interfacial pattern results in a decreased growth rate when compared with that observed when earlier stages of evolution are reaccelerated by the reflected shock wave.

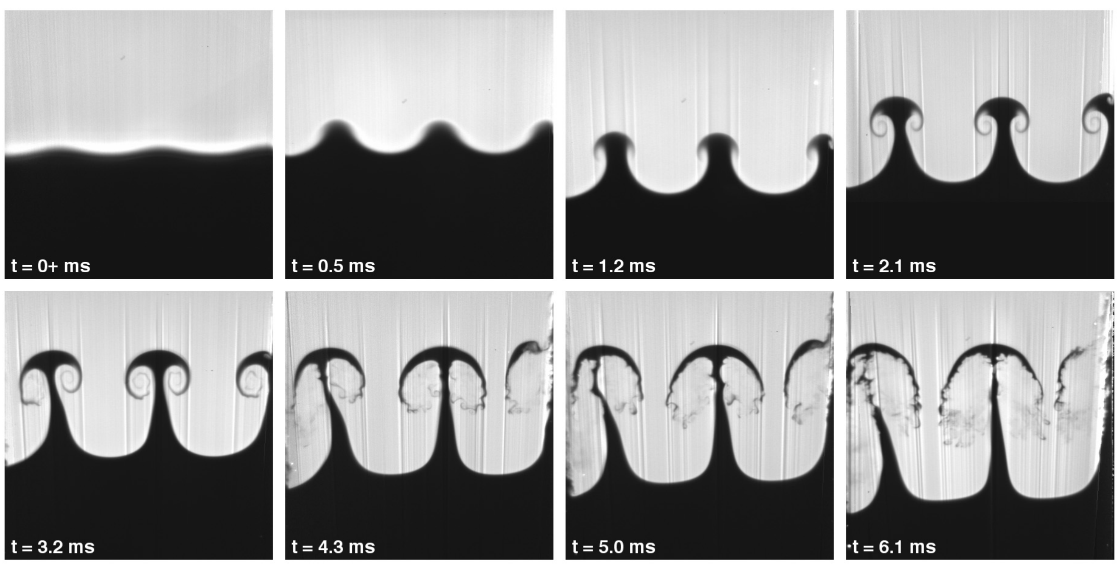


Figure 1: PLIF images assembled to form a time sequence of the instability resulting from shock-acceleration by an $M_s = 1.27$ incident shock wave.

Experimental study into the turbulent mixing transition to a self-similar regime at constant acceleration of the interface of gases

Yu.A. Kucherenko, O.E. Shestachenko, Yu.A. Piskunov, E.V. Sviridov, V.M. Medvedev & A.I. Baishev

Academician E. I. Zababakhin Russian Federal Nuclear Center
All-Russian Research Institute of Technical Physics
kucherenko@five.ch70.chel.su

Experiments on study of the transition to a self-similar regime of different density gases mixing in the Earth's gravity field have been carried out at the OSA facility. A heavy gas was imposed upon a light one. Gases were separated with the Specter-diaphragm. At some moment of time the Specter-diaphragm was destroyed into small-scale fragments by an outer force. The Rayleigh-Taylor instability arose at the formed interface of two different density gases, and a non-stationary zone of turbulent mixing developed. Experiments were performed for two Atwood numbers 0.54 and 0.94. In the experiments there were determined the front mixing trajectories in both the light gas and the heavy one. As a result of the experiments the constant alpha characterizing the non-dimensional velocity of mixing was determined.

On possibility of experimental determination of integral characteristics of molecular component of mixing by means of X–ray technique

Yu.A. Kucherenko, S.I. Balabin, R.I. Ardashova, O.E. Kozelkov, A.V. Dulov & I.A. Romanov

Academician E. I. Zababakhin Russian Federal Nuclear Center
All-Russian Research Institute of Technical Physics
kucherenko@five.ch70.chel.su

In the present work there was made the first attempt of experimental determination of integral quantity of substances, which were mixed molecularly, over the time in experiments with the Rayleigh-Taylor turbulence. There were used mutual soluble liquids in the experiments. There was determined the averaged density of matter in the zone of the Rayleigh-Taylor turbulence at the separation stage by means of X-ray technique. The density distribution of matter conditioned by the molecular component was measured at the moment of finishing of the total separation of heterogeneous structures.

On possibility of experimental determination of molecular component of non-stationary turbulent mixing

Yu.A. Kucherenko, A.P. Pylaev, V.D. Murzakov, A.V. Belomestnih, V.N. Popov & A.A. Tyaktev

Academician E. I. Zababakhin Russian Federal Nuclear Center
All-Russian Research Institute of Technical Physics
kucherenko@five.ch70.chel.su

It has been studied a possibility of using of chemical indicator phenolphthalein for determination of molecular component of mixing. Phenolphthalein is inserted into one of two different density miscible liquids of the same refraction indexes. Using of the mentioned indicator is based on its property to vary its colour in presence of alkali. In contrast to an analogous method proposed in the work by P. F. Linden, J. M. Redondo, and D.L. Youngs (1994) pH values of the liquids are chosen in such a way that coloring power of a certain volume of molecular mixture would depend on concentration of phenolphthalein molecules only. The total volume of the mixing area occupied by molecular mixture, at validity of certain conditions, can be determined by measuring of intensity of transmitted light through the area.

Experimental study into the initial perturbation spectrum influence upon the delay of the turbulent mixing evolution in systems with transitional layers

Yu.A. Kucherenko, S.I. Balabin, R.I. Ardashova, O.E. Kozelkov, A. V. Dulov & I.A. Romanov

Academician E. I. Zababakhin Russian Federal Nuclear Center
All-Russian Research Institute of Technical Physics
kucherenko@five.ch70.chel.su

Results of experimental study into influence of the spectrum of the initial perturbations that were generated in the middle of the transitional layer upon the Rayleigh-Taylor turbulent mixing evolution are presented. In the experiments there were used mutual soluble liquids with different ratios of densities. The transitional layer with continuous distribution of density formed in the region of the contact boundary of liquids owing to molecular diffusion. Dependence of the mixing fronts coordinates on parameter g_1t^2 was determined in the experiments. It was shown the influence of the initial perturbation spectrum upon the turbulent mixing evolution delay.

Experimental study into the Rayleigh-Taylor instability evolution in a continuous distribution density layer

Yu.A. Kucherenko, A.P. Pylaev, V.D. Murzakov, A.V. Belomestnih, V.N. Popov & A.A. Tyaktev

Academician E. I. Zababakhin Russian Federal Nuclear Center
All-Russian Research Institute of Technical Physics
kucherenko@five.ch70.chel.su

Experimental results concerning growth of perturbations being generated in the middle of a continuous distribution density layer at different initial and boundary conditions under action of the Rayleigh-Taylor instability have been obtained by the SOM facility. The layer of certain width forms owing to mutual diffusion of two different density miscible liquids through a flat contact boundary for a certain time. The liquids of different refraction indexes are located in an ampoule of square cross section with transparent windows for recording by a light-shadow technique. The Rayleigh-Taylor instability arises owing to acceleration of the ampoule along a vertical measuring channel equipped with horizontally placed light channels of certain spacing for the process recording. Experiments have been performed for density ratios of liquids $\boldsymbol{n} = 1.5, 2.0, 3.0$. The results are compared with values of the Rayleigh-Taylor turbulent mixing zone width obtained for miscible liquids with a density jump at the contact boundary.

An experimental study of the interaction of three Richtmyer-Meshkov-unstable gas cylinders

Sanjay Kumar[1], Peter Vorobieff[2], Greg Orlicz[1], Christopher Tomkins[1], Cherie Goodenough[1] & Robert Benjamin[1]

1. Hydrodynamics Group, DX-3
Los Alamos National Laboratory, USA
sanjay@lanl.gov

2. Department of Mechanical Engineering
University of New Mexico, USA

We report an experimental investigation of the interaction of three shock-generated vortex pairs. The vortex pairs are generated by the simultaneous interaction of a planar Mach 1.2 shock wave with three heavy gas (SF_6) cylinders in air. The gaseous cylinders are formed by letting the heavy gas fall under gravity from three circular holes in a nozzle at the top of shock tube. The cylinders are separated laterally across the width of the shock tube with spacing S/D = 1.5, where S is the spacing between the cylinder centers and D = 3.1 mm is the cylinder diameter at the nozzle exit. The simultaneous interaction of the planar shock with three gaseous cylinders results in vorticity deposition at the cylinder surface. This vorticity rolls up resulting in three counter-rotating vortex pairs. The interaction of these vortex pairs is studied experimentally using planar laser induced fluorescence (PLIF) of an acetone tracer pre-mixed with SF_6. It is found that four distinct post-shock flow morphologies (shown below in figure 1) result from nominally identical initial conditions. Each frame of figure 1 shows two time sequence PLIF images taken at t = 418 and 583 μs, where t = 0 is the instance when the shock first interacts with the gaseous cylinders. Because we observe multiple complex flow features, we surmise that the shock/three-cylinder-configuration interaction is highly nonlinear. We attempt to explain these complex morphologies with careful analysis of initial conditions. The variation of the overall integral width of these structures with time is reported. Recent experimental images capturing the time evolution of shock propagation through the initial cylinder configuration will also be presented.

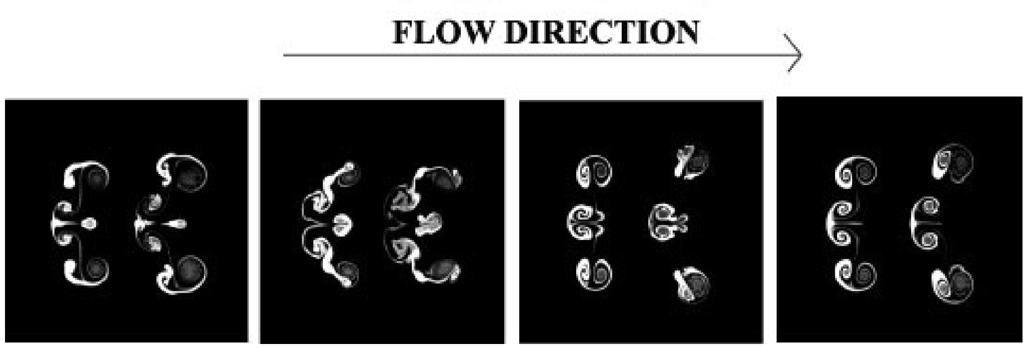


Figure 1. Distinct flow morphologies (PLIF images).

Time dependent mix in a converging burning capsule

G.A. Kyrala[1], D.A. Haynes[1] , M.A. Gunderson[1] , D.C. Wilson[1], C. Christensen[1], F.J. Marshall[2], V.Yu. Glebov[2], C. Stoeckl[2], C.K. Li[3], F.H. Séguin[3], R.D. Petrasso[3], J. Frenje[3] , S.P. Regan[2], V.A. Smalyuk[2] & J.R. Rygg[3]

1 Los Alamos National Laboratory,
P.O.Box 1663, MS E-526
Los Alamos, NM 87544
kyrala@lanl.gov

2. Laboratory for Laser Energetics,
U. of Rochester, USA

3. Plasma Science and Fusion Center,
Massachusetts Institute of Technology, USA

We use time dependent spectroscopy and imaging techniques to gather data, which will constrain the different mix models. The data is collected from implosions as a new tool to measure the mixing of material in an imploding shell with a very thin Ti layer on the inside of the capsule. The interior of the capsule is filled with deuterium gas. During the implosion some of the titanium mixes with the burning deuterium fuel and emits radiation. The present study measures the emission from the titanium material. The titanium that mixes with the fuel reaches a higher temperature compared to the titanium at the edge of the core that is in contact with the pusher shell. Using filter gated x-ray cameras, we are able to distinguish between the hot titanium that mixes and emits the hydrogenic lines and the colder titanium that mostly emits the He-like lines. Similarly, by measuring the time dependent spectrum using streak cameras, we are able to measure the time history of this mix.

We performed such an experiment at the Omega facility using 860 micron OD CH micro baloons filled with deuterium at a pressure of 3 or 15 Atm gas fill and a 0.1-µm thick doped Ti layer. We expect that one of the two fills will in one case be mixed due to the faster implosion of the shell; while for the other case the mix will be minimal. We will discuss the measurement and the spectroscopic techniques that we used. An image of one of the capsules is displayed in Figure 1, where the implosion, burn, and explosion phases have been captured in one shot.

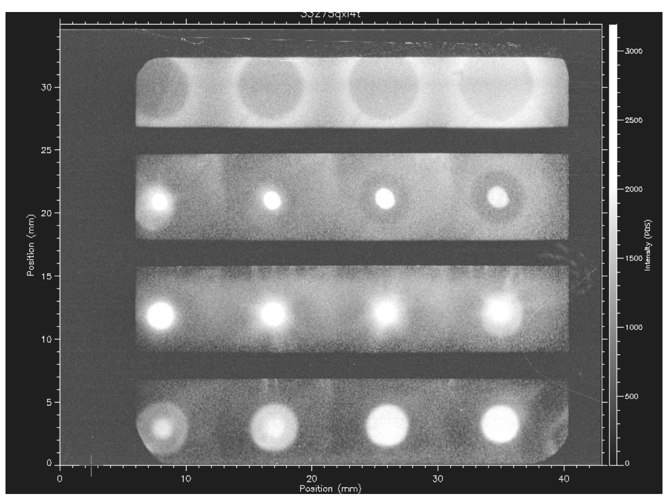


Figure 1. Time gated x-ray images of one imploding burning capsule captured in one shot.

Experimental investigation on the behaviour of a shock accelerated spherical gas inhomogeneity

Guillaume Layes[1], **Georges Jourdan**[1], **Lazhar Houas**[1], **Denis Souffland**[2] & **François Renaud**[2]

1. Polytech'Marseille DME - IUSTI/UMR CNRS 6595
13453 Marseille Cedex 13, France
Guillaume.Layes@polytech.univ-mrs.fr

2. CEA / DAM,
BP 12 91680 Bruyères-le-Châtel, France

An experimental investigation of the interaction of a plane shock wave and a single gaseous bubble has been conducted in a shock tube, in order to better understand the Richtmyer-Meshkov instability process in spherical geometry and the generated turbulent mixing. Different gaseous bubbles, i.e. helium, nitrogen and krypton, were introduced in air at atmospheric pressure within the experimental chamber. Those configurations correspond to negative (H/L), close to zero (CD) and positive (L/H) initial density jumps across the interface. The shock tube is coupled with a high speed rotating camera shadowgraph system synchronized with a stroboscopic Nanolite flash lamp (one flash each 70 μs) which allows to record about 100 frames per run. Thus, we reconstruct the experimental history of the gaseous inhomogeneity motion and deformation and then measure different inhomogeneity characteristic sizes (length, height vortex pair spacing...). Fig.1b is an example of results which will be presented during the workshop.

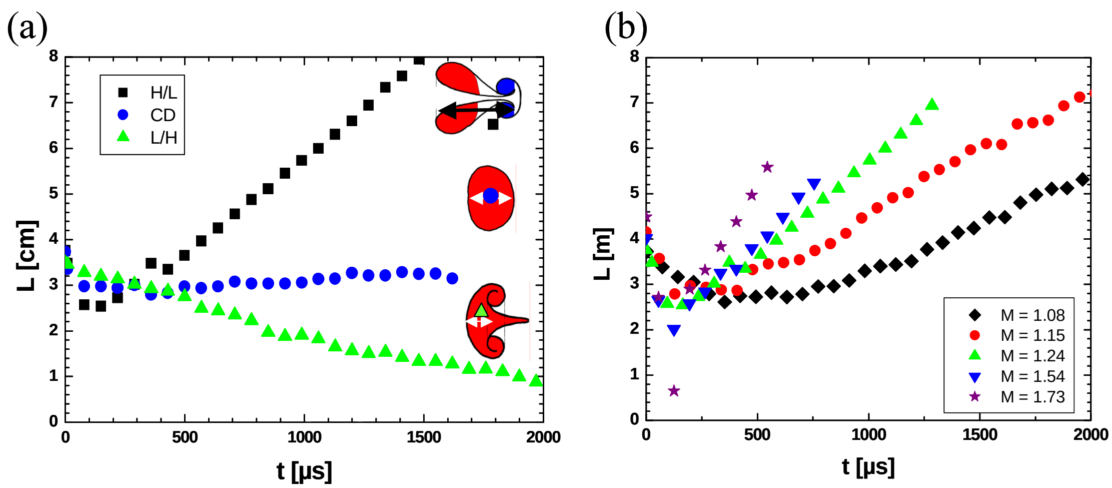


Figure 1: Evolution of the inhomogeneity length with time (a) for the H/L, Cd and L/H cases for a similar shock wave Mach number (≈1.2) and (b) for different shock wave Mach number for the H/L configuration

References

Layes, G., Jourdan, G. and Houas, L. 2003, Distortion of a Spherical Gaseous Interface Accelerated by a Plane Shock Wave *Phys. Rev. Letters* **91**, Issue 17.

Haas, J.F. and Sturtevant, B. 1987, Interaction of weak shock waves with cylindrical and spherical gas inhomogeneities. *J. Fluid Mech*, **181**, 41-76.

Laser shock tube. Research & development.

Ivan Lebo[1,2] & Vladimir Zvorykin[2]

1. Department of Cybernetics,
Technical University-MIREA, Moscow, Russia
lebo@mirea.ru

2. Lebedev Physical Institute of RAS,
Moscow, Russia
zvorykin@sci.lebedev.ru

Abstract.

A concept of laser-driven shock tube (LDST) is developed. (Zvorykin (2000)). Research & Development of LDST, selection of necessary sizes and materials has been performed, different diagnostic methods are developed and tested.

The experimental and numerical investigations (using 2D "ATLANT_C-code (Iskakov (]) of shock wave propagation in air (the initial pressure being within 0.1-2 bar) were made using KrF-laser GARPUN (Zvorykin (1999)) for the irradiation of targets made of different materials (Al, polyethylene, iron etc.). Good agreement between the calculated and experimental data was reached. It was shown that the shock wave velocity is defined mainly by the laser intensity and initial pressure of the surrounding atmosphere, and weakly depends on the target material.

The experimental study and numerical modelling of thin polymer film acceleration were made. The maximum velocities about 4 km/s were reached. The good agreement of the calculated and experimental data was obtained.

The development of hydrodynamic instabilities at the contact boundary "film-erosion plasma" and "film rear side-compressed air" were experimentally studied. The initial perturbations were given with the help of a metal grid placed between the laser and the film. We obtained dynamic characteristics of broadening of a matter cluster formed after passing of a SW through the film and the development of jets. It should be noted that at later time moments the jets came in front of enveloping SW.

These studies were support by INTAS, project 01-0846

References

Iskakov A.B., Lebo I.G., Tishkin V.F.: J. of Russian Laser Research, (2000),21, 247-263

Zvorykin V.D., Lebo I.G.: Laser and Particle Beams, (1999), 17, 69-84.

Zvorykin V.D., Lebo I.G.; Quantum Electronics, (2000), 30(6), 540-544.

Radiatively induced Richtmyer-Meshkov instability

Michel Legrand & **Georges Fiorèse**

Commissariat à l'Energie Atomique/DAM, France
michel.legrand@cea.fr

Laser induced Richtmyer-Meskov (RM) instabilities have previously been described. A classical RM instability can be generated using X-rays produced in a hohlraum (Mikaelian (1991)). The target is a double layer pill about 1 mm in diameter and 300 µm thick: 100 µm Be on 200 µm of SiO_2 foam (ρ = 0.2 g/cc). The drive generates a Mach 25 shock in the Be ablator whose initial density is about 2g/cc. The shock reaches the Be/SiO_2 interface in about 4 ns and generates a classical RM instability at this interface.

More recently Goncharov (1999) and Aglitskiy (2002) describe a RM-like instability, commonly known as "ablative RM instability". The authors are interested in the stability of the ablation front in the ablator of a direct drive ICF target. In the case of a corrugated ablation front, ablation pressure generates a rippled shock which induces a pressure perturbation leading to an instability of the ablation front. The features of the ablative RM instability are very different from those of the classical RM instability. In particular, the ablation front perturbation amplitude does not grow linearly with time but presents decaying oscillations.

We are interested here in a third situation. The target is similar to Mikaelian's, except that in Mikaelian setup the X-rays irradiates the ablator and generates a shock. In our setup, the X-rays irradiates the foam which is nearly transparent with respect to the ablator. This lead to a violent release of the ablated plasma into the foam plasma. The acceleration of the ablated plasma/foam plasma interface is an impulsion similar to the interface acceleration in a classical RM instability. Numerical simulations carried out with our FCI2 code show that the amplitude of a perturbation of the ablator/foam interface grows linearly in time with a growth rate similar to RM instability one. Another well known feature of the classical RM instability is the phase reversal of the perturbation which occurs when the velocity jump is directed from the heavy fluid to the light fluid. In our situation the phase reversal seems to be sensitive to the nature of the ablator.

References

Mikaelian, K.O. Design calculations for a NOVA mix experiment; Proceedings of the 3rd International Workshop on the Physics of Compressible Turbulent Mixing (Royaumont, France, June 17-19, 1991) 137-144

Goncharov, V.N. Theory of the ablative Richtmyer-Meshkov instability; Phys. Rev. Let. **82**, 2091 (1999)

Aglitskiy, Y *et al.* Direct observation of mass oscillations due to ablative Richtmyer-Meshkov instability and feedout in planar plastic targets; Physics of Plasmas **9**, 2264 (2002)

Investigation of the hydrodynamic instability induced by multi-acceleration of a contact surface between two fluids

E. Leinov[1], A. Formaozo[1], O. Sadot[1,2], E. Sarid[1,2], A. Yosef-Hai[1,2], D. Cartoon[2], Y. Elbaz[2], A.L. Levin[1,2], D. Shvarts[1,2] & G. Den-Dor[1]

1. Pearlstone Center for Aeronautical Engineering Studies, Mechanical Engineering Department,
Ben-Gurion University of the Negev Beer-Sheva, Israel
sorens@bgumail.bgu.ac.il

2. Physics Department, Nuclear Research Center Negev, Israel.

Abstract

The hydrodynamic instability, which develops on the contact surface between two fluids, has crucial importance in achieving ignition condition in inertial confinement fusion (ICF), and better understanding astrophysical phenomena. In those applications acceleration waves pass across a material interface and initiate and enhance unstable conditions in which small perturbations grow dramatically. During the past decade efforts have been made to develop understanding on the instability evolution in the single wave situation. However, in those applications the contact surface experiences several acceleration waves.

In the present study a multi-acceleration condition has been created in a shock tube apparatus in order to mimic experimentally, in more convenience measurement conditions, the hydrodynamic instability. To achieve the multi-accelerate waves, different gas configurations were used. In shock tube experiments the incident shock wave initiate the Richtmyer-Meshkov instability; the reflected shock hits again the contact surface and enhances the mixing process. The passage of the reflected shock through the contact surface creates a secondary reflected wave, which can be either a refraction wave or a compression wave (a shock wave) depending on the gas combination. This wave hits the unstable contact surface once again after reflecting from the end-wall. The end-wall distance from the initial contact surface position controls the duration of the above-described interaction with waves.

In the present study the experimental technique will be described, it will be followed by the experimental results in the multi-mode initial conditions and single-mode initial conditions. A comparison of the experimental results with numerical simulations and analytical models will be presented.

Application of Ronchi method for visualization of a turbulent mixing zone in shock tube experiments

A. Levushov[1,2], A. Logvinov[1,2], E. Meshkov[1,2] & V. Popov[1]

[1]Russian Federal Nuclear Center - VNIIEF, Sarov, Russia

[2]Sarov Physical-Technical Institute
meshkov@sarfti.sarov.ru

Usually, to visualize a turbulent mixing zone (TMZ) on the interface of two gases in experiments on shock tubes [1], is applied a shadow method. In experiments with gas explosive mixtures (GEM) [2] there are difficulties of TMZ visualization connected with heterogeneity of stream in the area adjoining to interface between detonation products (DP) of GEM both air, and self-luminescence of DP. The presented results of experiments illustrate opportunities of application of Ronchi method [3] for flow visualization in a similar shock tubes.

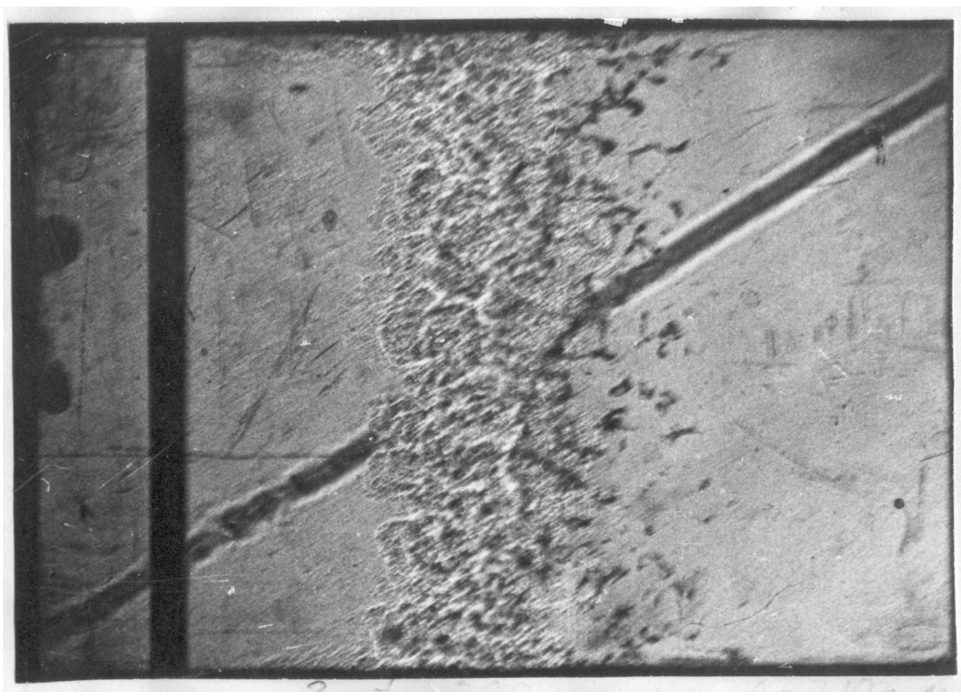


Photo of *turbulent mixing* zone on air - helium interface in experiments such as [1], received by a *Ronchi* method at the moment of time *t=890* мкс after the beginning of movement of interface. Designations: TMZ-zone ТП; F-.shadow of string, size of a defocusing *Δ* =210 mm,

References

1. Andronov V.A. *et al.* **.** Sov.Phys.JETP, т.71, вып. 2(8), 1976. C. 806. (in Russian)
2. V.I.Dudin, E.V.Gubkov, E.E.Meshkov *et al.* The Proc. of the 6th IWPCTM, Marseille, France, 1997. P.152.
3. M.Skotnikov. Shadow quantitative methods in gasdynamik. M.,Nauka,1976 (in Russian)

Study on the shock-bubbles interaction in the two bubbles case

K. Levy[1,2], O. Sadot[1,2], E. Sarid[1,2], A. Yosef-Hai[1,2], D. Cartoon[2], Y. Elbaz[2], D. Shvarts[1,2] & G. Den-Dor[1]

1. Pearlstone Center for Aeronautical Engineering Studies, Mechanical Engineering Department, Ben-Gurion University of the Negev Beer-Sheva, Israel
sorens@bgumail.bgu.ac.il

2. Physics Department, Nuclear Research Center Negev, Israel.

The interaction of a shock wave with a spherical bubble, and the consequent formation of a vortex ring, has been studied thoroughly. It was shown that the vortex ring posses a constant velocity which can be scaled according to the initial parameters of the problem.

In the present study, theoretical and experimental research was performed on the interaction of two bubbles arranged in series, after the passage of a shock wave. The main goal was to investigate the limiting distance separating the interaction into two cases: the first of a significant interaction between the two bubbles, or resultant vortex rings, and the second of no mutual effect, i.e. the dynamics of one bubble is totally independent of the other. This distance was mapped in the parameter space of bubble size ratio and the distance of the centers of the bubbles. This was done by conducting full numerical simulations, together with suitable experiments performed in a shock tube.

The results show that the existence of one bubble is evident on the evolution of the other in two possible mechanisms. One is the alteration of the incident shock wave by the first bubble. The encounter of a curved shock wave on the second bubble will alter its evolution into a vortex ring. The second mechanism is the influence of the spiral velocity field surrounding the first vortex ring on the second bubble. It was seen that the effect of a curved shock wave has a closer range since the shock wave tends to retain its planar form in a short time. The interaction of the first vortex ring with the second bubble is more gradual and the effect can only be seen at latter time than that of the curved shock wave. An example for the limiting ranges in the case of a two bubbles of the same initial size, is that the curved shock wave mechanism is relevant up to an initial distance of 2.5 diameters (the bubble diameter was taken as 2cm) and that there is no interaction when the initial distance is 4 diameters.

Volume fraction profiles of transport structures in Rayleigh-Taylor turbulent mixing zone: evidence of enhanced diffusion processes

Antoine Llor[1], Pascal Bailly[2] & Olivier Poujade[2]

1. CEA/Siège,
31-33, rue de la Fédération, 75752 Paris Cedex 15, France
antoine.llor@cea.fr

2. CEA/DAM,
BP12, 91680 Bruyères le Châtel, France
pascal.bailly@cea.fr, olivier.poujade@cea.fr

Using (a) general mass conservation equations, (b) simple volume fraction and density profiles provided by experimental and numerical data, and (c) basic first-gradient constraints on mass flux and mass exchange closures, it is possible to deduce the normalized strength of the flux and exchange terms in a turbulent mixing zone (TMZ) for incompressible fluids and vanishing Atwood number. Some physical consistency properties are also obtained.

This approach shows that, in contrast to more common turbulent shear layers, the Rayleigh-Taylor TMZ must contain an enhanced diffusion process, which is about 25 fold higher than $C_\mu k^2/\varepsilon$, the usual estimate of the turbulent diffusion coefficient. The relative weakness of the usual turbulent diffusion reflects the small integral length scales which were previously reported [Llor 2003]. However, the turbulence relaxation rate is still correctly and consistently captured as ε/k.

The findings support some recent and important evolutions of the 2SFK modelling concept [LLor & Bailly 2003] as presented in this conference [LLor, Bailly & Poujade 2004].

References

LLor, A. 2003 Bulk turbulent transport and structures in RT, RM and variable acceleration instabilities; *Laser Part. Beams* ,305.

LLor, A. & Bailly, P. 2003 A new turbulent 2-field concept for modelling RT, RM and KH mixing layers; *Laser Part. Beams* ,311.

LLor, A., Bailly, P. & Poujade, O. 2004 The modelling of turbulent mixing in gravitationally induced instabilities based on the 2-Structure, 2-Fluid, 2-turbulence (2SFK) concept; (in preparation).

Derivation of a minimal 2-structure, 2-fluid and 2-turbulence (2SFK) model for gravitationally induced turbulent mixing layers.

Antoine Llor[1], Pascal Bailly[2] & Olivier Poujade[2]

1. CEA/Siège,
31-33, rue de la Fédération, 75752 Paris Cedex 15, France
antoine.llor@cea.fr

2. CEA/DAM,
BP12, 91680 Bruyères le Châtel, France
pascal.bailly@cea.fr, olivier.poujade@cea.fr

A new modelling concept for the statistical description of gravitationally induced turbulent mixing layers was previously introduced in a preliminary communication [Llor & Bailly 2003]. Central to this concept, called 2SFK which stands for 2 Structures (meaning: turbulent structures), 2 Fluids and 2 turbulent fields (K), is the fact that the observed average geometrical (Dimonte 2000) and turbulent (Llor 2003) length scales are astonishingly similar in a Rayleigh-Taylor mixing zone. The relevant transport entities to consider in describing its evolution are not only the fluids themselves but the turbulent structures as well. This similarity was taken as a general basic assumption for modelling.

Within the same general framework, we here outline a more systematic, consistent and parsimonious model. First, the turbulent kinetic energy is analysed and decomposed into canonical contributions (in a sense to be defined) which participate in the definition of the Lagrangian of the physical system. Then, Hamilton's least action principle is applied to get a conservative set of equations. And finally, an extension of the thermodynamics of irreversible processes is used to complete the model.

This new approach (Llor, Bailly & Poujade 2004) conforms to some essential physical features in addition to those previously mentioned: (i) it takes into account a consistent buoyancy-drag balance between structures thanks to mass exchange terms; (ii) it captures the four basic mean self-similar parameters (bubble and spike growth coefficients, and for vanishing Atwood numbers, mean effective Knudsen number of turbulent transport, mean molecular mixing fraction and mean Reynolds tensor anisotropy); (iii) it is hyperbolic; (iv) and it is minimal. A sample of graphic materials are shown and a more extensive illustration will be presented at the poster session.

References

LLor, A. & Bailly, P. 2003 A new turbulent 2-field concept for modelling RT, RM and KH mixing layers; *Laser Part. Beams* (in press).

Dimonte, G. 2000 Spanwise homogeneous buoyancy-drag model for RT mixing and experimental evaluation; *Phys. Plasma* **7**(6), 2255.

LLor, A. 2003 Bulk turbulent transport and structures in RT, RM and variable acceleration instabilities; *Laser Part. Beams* (in press).

LLor, A., Bailly, P. & Poujade, O. 2004 The modelling of turbulent mixing in gravitationally induced instabilities based on the 2-Structure, 2-Fluid, 2-turbulence (2SFK) concept; (in preparation).

1D numerical simulations of various self similar accelerated turbulent mixing layers using the 2SFK model.

Antoine Llor[1], Pascal Bailly[2] & Olivier Poujade[2]

1. CEA/Siège,
31-33, rue de la Fédération, 75752 Paris cedex 15, France
antoine.llor@cea.fr

2. CEA/DAM,
BP12, 91680 Bruyères le Châtel, France
pascal.bailly@cea.fr, olivier.poujade@cea.fr

The turbulent mixing zone (TMZ), arising from gravitationally induced instabilities at the interface of two stratified fluids, is modelled and evolved using the 2 Structures, 2 Fluids and 2 turbulent fields (2SFK) concept (Llor & Bailly 2003; Llor, Bailly & Poujade 2004) summarized in an oral presentation at this conference. The full model is here given explicitly without extensive justifications.

This model has been implemented in a 1D simulation code (fully explicit, bi-Lagrange and remap, second order in space and time) and we present, on this poster, the numerically simulated self similar evolution of the TMZ under the influence of various kinds of acceleration fields (SSVARTs; Llor 2003). After a transient period, the profile of any physical quantity reaches a self similar regime.

Two types of quantities are presented for different Atwood numbers: global, which are time dependant and space averaged over the whole TMZ; and local, which depend on time and position and are often plotted as a function of position in the TMZ at a given time during the self similar evolution. The global quantities are the four basic mean self-similar parameters: the bubble and spike growth coefficients, and for vanishing Atwood numbers, the mean effective Knudsen number of turbulent transport, the mean molecular mixing fraction and the mean Reynolds tensor anisotropy. They are found to be in good agreement with experimental and numerical (DNS, LES) results. The local quantities are the volume fraction profiles of fluids and structures, and for each structure, the velocity, the integral length scale, the different energy reservoirs and production terms. These profiles reproduce qualitative behaviours as given by accepted buoyancy-drag models, and they are consistent with numerical (DNS, LES) results.

References

LLor, A. & Bailly, P. 2003 A new turbulent 2-field concept for modelling RT, RM and KH mixing layers; *Laser Part. Beams* (in press).

LLor, A., Bailly, P. & Poujade, O. 2004 The modelling of turbulent mixing in gravitationally induced instabilities based on the 2-Structure, 2-Fluid, 2-turbulence (2SFK) concept; (in preparation).

LLor, A. 2003 Bulk turbulent transport and structures in RT, RM and variable acceleration instabilities; *Laser Part. Beams* (in press).

Large eddy simulations of miscible Rayleigh-Taylor instability

T.W. Mattner[1], D.I. Pullin[2] & P.E. Dimotakis[2]

1. Department of Applied Mathematics,
The University of Adelaide, Australia
tmattner@maths.adelaide.edu.au

2. Graduate Aeronautical Laboratories,
California Institute of Technology, USA
dale@galcit.caltech.edu, dimotakis@caltech.edu

This paper describes some results from large eddy simulations (LES) of miscible Rayleigh-Taylor (RT) instability at density ratios up to 7. We consider a high-density fluid located above a low-density fluid subject to a constant downward acceleration field. The fluids are assumed to be incompressible and miscible. Fluid motion is governed by the Favre-filtered continuity, species-transport, and Navier-Stokes equations. The subgrid-scale (SGS) scalar flux and stress are estimated using the stretched-vortex mixing (Pullin 2000) and stress (Misra & Pullin 1997) models. A compact filter and a circular spectral filter are applied in the the inhomogeneous direction and homogeneous directions, respectively. These filters damp wavenumbers larger than the model cut-off wavenumber.

Performance of the model is assessed by comparison of coarse-resolution (64×64×256) LES against fully resolved (256×256×1024) direct numerical simulations (DNS) at three density-ratios: 5/3, 3, and 7. The initial conditions for the LES are obtained by filtering the DNS data at a time when the mixing-zone has grown sufficiently thick to be represented on the coarse LES grid. LES mixing-zone widths, as well as scalar and kinetic energy spectra, are in satisfactory agreement with the DNS results. DNS resolution limitations limit the comparison to Reynolds numbers (based on mixing-zone width and growth-rate) of less 4000. As a result, SGS scalar and model dissipation is less than 10% of the total dissipation.

We use the stretched-vortex model to obtain predictions of RT unstable flow at Reynolds numbers as large as 0.5–2 $\times 10^6$, on 128×128×256 grids, at three density ratios: 5/3, 3, and 7. Mixing-zone growth is approximately quadratic in time and mean mole-fraction profiles are approximately self-similar. Resolved-scale kinetic-energy spectra exhibit an approximate $k^{-5/3}$ dependence, whereas the scalar-energy spectra decay more sharply than this approaching the cut-off wavenumber. The mole-fraction field exhibits unphysical excursions (over/undershoots of the initial scalar maximum/minimum) of up to 6%.

References

Misra, A. & Pullin, D. I. 1997 A vortex-based subgrid stress model for large-eddy simulation. *Phys. Fluids* **9**, 2443–2454.

Pullin, D. I. 2000 A vortex-based model for the subgrid flux of a passive scalar. *Phys. Fluids* **12**, 2311–2319.

Large-eddy simulation of Rayleigh-Taylor turbulence with compressible miscible fluids

Juan Pedro Mellado[1], Sutanu Sarkar[1] & Ye Zhou[2]

1. Department of Mechanical and Aerospace Engineering,
University of California, San Diego, USA
mellado@mae.ucsd.edu, sarkar@ucsd.edu

2. Lawrence Livermore National Laboratory,
University of California, Livermore, USA
zhou3@llnl.gov

Large-eddy simulation (LES) of the *three-dimensional* Rayleigh-Taylor problem using the *compressible* equations for the case of two *miscible* fluids with a density ratio of 3 is presented. The motivation is twofold. First, to study the behavior of the dynamic mixed subgrid model in this type of flow. In addition, numerical simulations allow the study of the Reynolds stresses and their transport equations in detail. Second, to analyze the effect of the intrinsic compressibility, that is, the Mach number of the fluctuations, M_t.

Results

LES predictions of the growth of the mixing depth and the evolution of mixing parameters compare well with the available literature (Cook *et al.*, 2001). Anisotropy of the Reynolds stresses also agree with reported values (Linden *et al.*, 1994). Simulations confirm the result predicted theoretically *a priori* by us that the turbulent Mach number cannot become large enough ($M_t < 0.3$, figure below). In other words, intrinsic compressibility effects cannot become important in a pure Rayleigh-Taylor problem. This is due to the link between the initial thermodynamic state of the flow and the level of turbulent fluctuations achievable from it. This link can be broken in the Richtmyer-Meshkov problem, so that, in contrast, M_t can increase substantially.

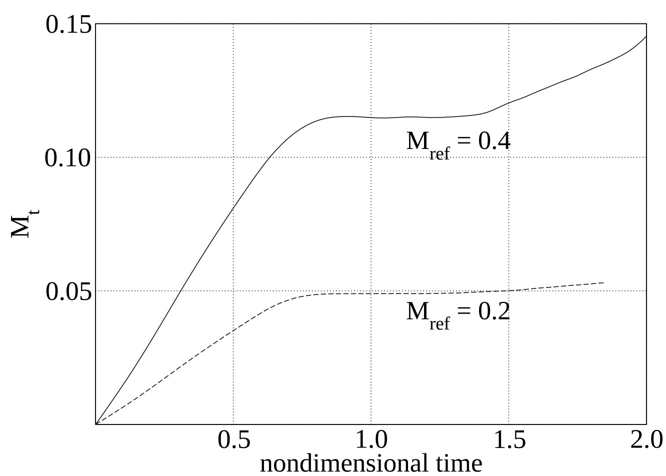


Figure 1: Temporal evolution at the center plane of the turbulent Mach number, $M_t = u_{rms}/\bar{c}$.

References

Cook, A. W. & Dimotakis, P. E. 2001 Transition stages of Rayleigh-Taylor instability between miscible fluids, *J. Fluid Mech.* **443**, 69-99.

Linden, P. F. & Redondo, J. M. and Youngs, D. L. 1994 Molecular mixing in Rayleigh-Taylor instability, *J. Fluid Mech.* **265**, 97-124.

On new possible directions of hydrodynamical instabilities and turbulent mixing investigations for the solution some practical problems

E. Meshkov[1,2]

[1]Russian Federal Nuclear Center - VNIIEF, Sarov, Russia

[2]Sarov Physical-Technical Institute
meshkov@sarfti.sarov.ru

Hydrodynamic instability and turbulent mixing play the important role in a problem of inertial confinement fusion (ICF) and astrophysics; it, first of all, also defines interest to the given problem. In the ICF problem hydrodynamic instability and turbulent mixing are the factors *interfering* achievement of ignition of thermonuclear fuel. Meanwhile, there are some other practical problems at which hydrodynamic instability and turbulent mixing are the factors *promoting* the solution of a problem. At the solution of similar problems results lead before researches and the developed methods can be used. And, if till now these development were conducted from the point of view of the solution of a problem of suppression of instabilities or reduction of their nocuous action now these "harmful" properties can be used address various practical problems.

In the report the review of new possible directions of researches hydrodynamic instabilities and turbulent mixing with regard to applied problems is presented.

The phenomena of turbulent mixing can be under certain conditions used for creation of atomized liquids [1,2] and others media [3]. Similar aerosuspensions can find of wide application:

Suppression of fires [2,4];

Reduction in explosive loadings [5,6];

Localization of harmful (radioactive) aerosols and a dust;

Preparation of fuel-air mixtures in engines of internal combustion [2,7];

Hydrodynamic instability and turbulent mixing can play an essential role at explosive suppression of forest fires [8,9].

The powerful explosive short-term light source in which fast cooling of luminous explosive plasma is carried out due to turbulent mixing [10,11] is developed.

References

1. E.Meshkov, N.Nevmerzhitskii. Turbulent Mixing Development in a Thin Liquid Layer Acclerated by a Compressed Air in Closed Volume. *Technical Physics Letters. Vol.28, N4, 2002, pp.323-324*.
2. Yu.Alekhanov, A.Levushov, A.Logvinov, S.Lomtev, E.Meshkov. About possibility receiving of atomized liquid mix with gas by means of a piston machine. *Alternative power and ecology. №5, 2002, c.54-57 (in Russian)*.
3. M.Bliznetsov, I.Zhidov, E.Meshkov, N.Nevmerzhitskii, E.Sen`kovskii, E.Sotskov. Development of the Rayleigh-Taylor Instability at the Boundary of a Friable Medium Layer Acclerated by a Compressed Air Flow. *Technical Physics Letters. Vol.28, N1, 2002, pp.80-81*
4. Yu.Alekhanov, M.Bliznetsov, Yu.Vlasov, V.Dudin, A.Levushov, A.Logvinov, S.Lomtev, E.Meshkov. Interaction of Dispersed Water with Flame. *Technical Physics Letters. Vol.29, N3, 2003, pp.218-220*
5. V.Gorodnichev, E.Meshkov, N.Nevmerzhitsky, V.Rogachev, Yu.Yanilkin, I.Zhidov. The Effect of Turbulent Mixing on Operation of Liquid Protective Walls. *Proc. of the 7th IWPCTM, St.-Petersburg, Russia, 5-9 July 1999, pp.472-477.*
6. V.Afanas`ev, L.Belovodsky, I.Zhidov et al. A method of reduction in explosive loading in closed volume…*Patent RF #2215983, 2003.*

7. E.Meshkov, N.Nevmerzhitsky. A method of receiving of a mix atomized liquids with gas. Patent RF #2220009, 2003.

8. E.E.Meshkov. On Possible Role of Hydrodynamic Instabilities at Explosive Method for Extinguishing Forest Fires. *Proc. of the 7th IWPCTM, St.-Petersburg, Russia, 5-9 July 1999, pp.477-478.*

9. M.Bliznetsov, V.Dudin, S.Gerasimov, L.Houas, G.Jourdan, A.Logvinov, E.Meshkov, Yu.Vlasov. Development of a Method for Studying the Interaction between Shock Wave and a Flame. *Abstracts of 8th IWPCTM, Pasadena, USA, 9-14 December 2001, p.12.*

10. S.Gerasimov, E.Meshkov, N.Mischenko, S.Kholin. Mixing Light Source. *Proc. of the 7th IWPCTM, St.-Petersburg, Russia, 5-9 July 1999, pp.469-471.*

11. Gerasimov S., Meshkov E. *Patent RF 215 26 65, 2000*

Potential role of scaling factor in turbulent mixing problem

E.E. Meshkov[1,2], N.V. Nevmerzhitskii[1],V.G. Rogachev[1] & Yu.V. Yanilkin[1]

[1] Russian Federal Nuclear Center - VNIIEF

[2]Sarov Physics & Engineering Institute
meshkov@sarfti.sarov.ru

The paper presents the arguments in favor of hypothesis that for the RT mixing at gas-fluid interface, one can expect the deviation from the steady-state history pattern of gas bubbles penetrating the fluid at the turbulent mixing zone front with the zone growth.

Experimental scenarios are proposed to verify the hypothesis of potential scaling factor impact on the growth pattern of the turbulent mixing zone.

2D CALE Simulations of Directly Driven Shaped Implosions

K.O. Mikaelian[1], H.-S. Park[1], H.F. Robey[1], R.E. Tipton[1], D.P. Rowley[1], R.J. Wallace[1], C.K. Li[2], R.D. Petrasso[2], J.A. Frenje[2], F.H. Seguin[2], R. Rygg[2], V.Yu. Glebov[3] & F.J. Marshall[3]

1. Lawrence Livermore National Laboratory
mikaelian1@llnl.gov

2. Plasma Science and Fusion Center, MIT

3. Laboratory for Laser Energetics, U. of Rochester

We present direct numerical simulations of directly-driven capsule experiments at the LLE OMEGA laser. DHe^3 and He^3 gas capsules were imploded in symmetric and asymmetric configurations with laser energies ranging from 16 to 24 kJ. In addition to the detected neutrons and protons we imaged each implosion in x-rays. We use the two-dimensional hydrocode CALE to simulate these experiments. The purpose is to correlate the shape of the implosion (via x-rays) with the amount of mix (via neutrons and protons), and to test the dynamic, two-dimensional turbulent mix model K-L in the code.

* Work performed under the auspices of the US DOE at the U. of California LLNL under Contract No. W-7405-Eng-48, and supported by the US DOE Contract DE-FG03-99SF21782 and US DOE Office of Inertial Confinement Fusion under Cooperative Agreement No. DE-FC03-92SF19460.

Effect of initial conditions on compressible mixing for multimode systems driven by a strong blast wave

A.R. Miles[1,2], M.J. Edwards[2], J.A. Greenough[2] & H.F. Robey[2]

1. University of Maryland at College Park, USA

2. Lawrence Livermore National Laboratory, USA

miles15@llnl.gov
edwards39@llnl.gov
greenough1@llnl.gov
robey1@llnl.gov

Perturbations on an interface driven by a strong blast wave grow in time due to a combination of Rayleigh-Taylor, Richtmyer-Meshkov, and decompression effects. In this paper, we present results from a computational study of such a system under drive conditions to be attainable on the National Ignition Facility. Using the multi-physics, AMR, higher order Godunov Eulerian hydrocode, Raptor, we consider the late nonlinear instability evolution for multiple amplitude and phase realizations of a variety of multimode spectral types. We show that compressibility effects preclude the emergence of a regime of self-similar instability growth independent of the initial conditions by allowing for memory of the initial conditions to be retained in the mix-width at all times. The loss of transverse spectral information is demonstrated, however, along with the existence of a quasi-self-similar regime over short time intervals. The initial conditions are shown to have a strong effect on the time to transition to the quasi-self-similar regime. For high Mach number systems, nonlinear interactions between spikes can drive anomalously-fast generation of large scales that dominate the late-time growth. Results from both 3D and 2D calculations are presented, and 3D verses 2D effects are discussed.

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

UCRL-ABS-201768

Study of short-wavelength perturbation growth on a NIF double-shell ignition target design

Jose Milovich, Peter Amendt, Michael Marinak, Harry Robey & Robert Tipton

Lawrence Livermore National Laboratory,
University of California, USA
milovich1@llnl.gov
http://www.llnl.gov/

Achieving ignition with the National Ignition Facility is a major goal of the US-ICF program. To maximize the prospects of accomplishing this objective an improved non-cryogenic double-shell target was recently proposed as a complement to the cryogenic baseline design [Amendt *et al*, Phys. Plasmas **9**, 2221 (2002)]. Notwithstanding the advantage of non-cryogenic preparation, double shells pose a major challenge in controlling instabilities seeded by unavoidable interface perturbations. During implosion, these perturbations become unstable as they are subjected to impulsive (Richtmyer-Meshkov) and time-dependent (Rayleigh-Taylor) accelerations. The inner surface of the inner shell is unstable at deceleration onset leading to mix of the dense high-Z pusher and the DT gas with the consequent cooling of the fuel and possible quenching of ignition. Furthermore, irregularities in the outer surface of the pusher are unstable during most of the implosion phase. If uncontrolled, the growth of these perturbations may feed-through to the inner surface, further contributing to dangerous fuel-pusher mix. In order to understand and therefore control these instabilities, we have undertaken an ambitious program of simulating short-wavelength perturbations (Legendre mode numbers up to a few thousand) on the surfaces of the pusher. To study the non-linear RT evolution for such a large range in modes we use the parallel 3-D rad-hydro code HYDRA. Our approach consists of introducing perturbations (from measured surrogate spectra) on all surfaces of the capsule and systematically studying the effects on ignition. Our results have indicated that the growth of perturbations on the inner surface of the pusher give rise to a mix-width well below the minimum radius with only a slight degradation in yield. However, we have encountered a new pathway for RT instability of the pusher's outer surface perturbations that may lead to shell disruption (well-before peak compression). L-band radiation (>8 keV) from the laser-irradiated high-Z hohlraum wall passes through the outer shell and ablates the outer surface of the high-Z inner shell, promoting a large outward expansion (to nearly twice its original radius), which is subsequently recompressed by the converging outer shell. During recompression, low density material (foam) pushes onto high density (inner shell) material, giving rise to the classic conditions for RT instability. We show that this phenomenon can be controlled by tamping of the inner shell with a low-Z material. However, the instability is not entirely suppressed and we find that the pusher/tamper interface becomes turbulent at late time with high Reynolds number. The mix-width that develops follows closely Young's bubble-spike late time behaviour. Our simulations are unable to resolve the smallest scales that evolve during the turbulent flow, but we are confident that the larger scales are well modelled. To avoid the onset of turbulence, and therefore gain more confidence on the simulations, we have introduced a new design with a manufactured density gradient scale length in combination with a high-Z supporting foam. The benefits of reducing the Atwood number during implosion have been assessed through DNS that show little growth of perturbations and near 1D performance.

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

Experimental and computational investigations of shock-accelerated gas bubbles

B. Motl[1], J. Niederhaus[1], D. Ranjan[1], M. Anderson[1], J. Greenough[2], J. Oakley[1], R. Bonazza[1] & L. Smith[1]

1.Department of Engineering Physics, University of Wisconsin – Madison
bonazza@engr.wisc.edu

2.Lawrence Livermore National Laboratory

A new experiment is being developed to study shock-induced motions and mixing at a gas interface. The experiments take place in a vertical, square shock tube, of large internal cross section (25 × 25 cm); the test gas is contained in a soap bubble (with diameter varying between 4 and 8 cm), either supported by an injector or freely moving (upwards or downwards, depending on the test gas density) inside the shock tube (shock-accelerated bubbles were first studied by Haas and Sturtevant (1987)). The initial interface is therefore three-dimensional, with axial symmetry being a reasonable assumption for a free rising (or falling) bubble. The strength of the accelerating shock is in the range $2 \leq M \leq 4$. The interface is imaged once immediately before shock arrival and twice after interaction with the shock wave, so that the initial conditions are known and growth rates can be calculated for each experiment. Planar Mie scattering and planar laser induced fluorescence are utilized to diagnose the flow.

Concurrently, the *Raptor* code is being used to numerically simulate the shock tube runs for the purpose of optimizing the design of the experiments and for comparing the experimental to the numerical results. The code solves the compressible Navier-Stokes equations using a piecewise linear method (PLM) combined with adaptive mesh refinement (AMR).

An example of calculation and experimental results are shown in Fig. 1 and we will report growth and mixing rates for different values of the Atwood and Mach numbers.

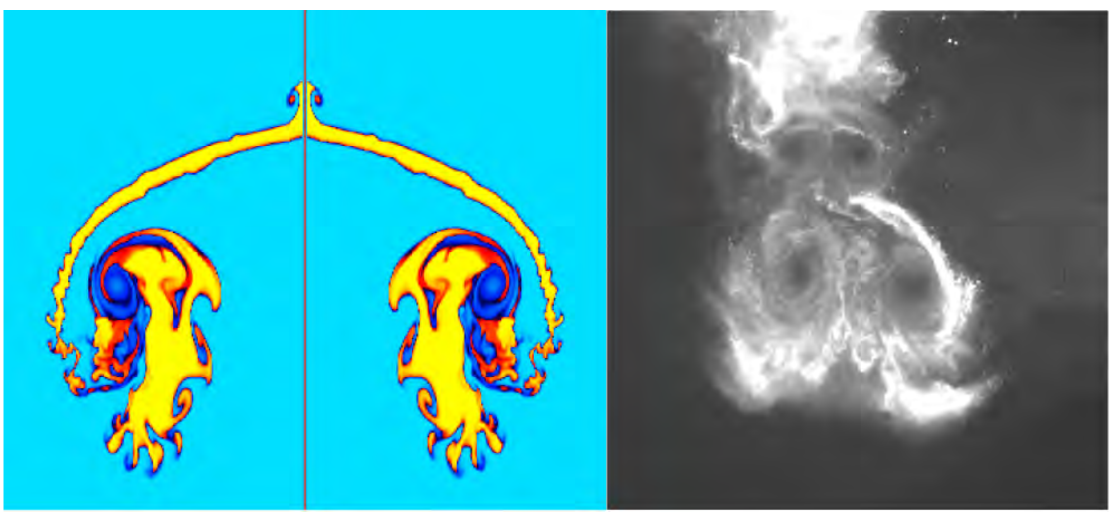


Figure 1: Ar bubble in air; $M = 2.14$; $t = 1.2$ ms after shock-bubble interaction. Left: computational air mass fraction. Right: planar Mie scattering image.

Reference References

J.F. Haas and B. Sturtevant, Interaction of weak shock waves with cylindrical and spherical gas inhomogeneities. JFM 41-76, 1987.

Convective instability of self-similar gravitational collapse with radiative transfer

M. Murakami

Institute of Laser Engineering, Osaka University
Yamada-oka 2-6, Suita, Osaka 565-0871, Japan
mym@ile.osaka-u.ac.jp

Convective instability of spherical implosions of gaseous sphere under both self-gravity and radiative diffusion is investigated, where the diffusivity is modelled by a power-law with respect to density and temperature. The reduced two-dimensional eigenvalue problem is solved to show that there is a unique quantitative relation between the two physical effects for the self-similar motion. The resultant spatial and temporal behavior are determined also uniquely, once the opacity mechanism is specified. Persistent entropy emission via radiation plays an important role in the stability.

The analysis of experiments and calculations for determination of intensity of turbulent mixing on the basis of turbulent mixing model of diffusion type

V.E. Neuvazhayev

Russian Federal Nuclear Center – VNIITF,
Snezhinsk, Chelyabinsk region, Russia
v.e.neuvazhayev@vniitf.ru

The analysis and comparison of known experimental and calculated (direct numerical simulation) results of research of gravitational turbulent mixing is carried out from uniform positions on the basis of semi-empirical model of turbulent mixing of diffusion type. The value of a basic constant of mixing α_1 was determined which described the intensity of penetration of easy substance into heavy.

In presented paper together with simple test problems the experiments are attracted, where complex non self-similar modes were performed. Due to presence of an exact solution these complex flows can be handled and the constant α_1 can be determined from them.

At first experimental results for incompressible liquids are analyzed. Three cases are considered: 1) a self-similar problem about mixing of two adjoining liquids with densities ρ_1 and ρ_2, that are in gravitational field g, 2) the same problem, but liquids are inter-soluble, therefore at the initial moment the interface is diffusion, that introduces the specificity in the problem, 3) mixing of a finite layer that is located in an infinite medium of other density. For these three problems there are experimental results, and also exact analytical solutions are constructed within the framework of lv-model, that allows determining the value of constant α_1.

Also the handling and analysis of experiences with compressible gases are carried out.

The results of three-dimensional numerical simulation of gravitational turbulent mixing are analyzed.

Unfortunately, a scatter in definition of turbulent mixing intensity α_1 remains significant. Most probably, a reason of it is the slow outcome on a developed self-similar turbulence and thus the initial data are remembered rather long.

For now, probably, it is necessary to count, that the constant of mixing has the following indeterminacy $\alpha_1 = 0.02 \sim 0.08$.

Study into Development of Turbulent Mixing at Gas-Liquid Interface with accelerations from 10^2 g_0 to 10^5 g_0

N.V. Nevmerzhitsky, E.A. Sotskov & M.V. Bliznetsov

RFNC-VNIIEF, Russia, Sarov
postmaster@gdd.vniief.ru

The paper presents the results of the experimental study into development of turbulent mixing arising in Rayleigh-Taylor instability at the interface of a liquid layer accelerated by compressed gas.

We used water as liquid and helium compressed to the pressures 1-400 atm as gas. In experiments we varied the value of liquid layer acceleration from $\approx 10^2 g_0$ to $\approx 10^5 g_0$ (g_0=9.81 m/s^2). The layer mixing was about 20 mm.

The following is obtained: when increasing acceleration of a liquid layer within the given range, the rate of gas front penetration into liquid is decreased approximately a factor of two. The authors connect this phenomenon with changing the turbulent mixing zone structure resulted from the increasing pressure and acceleration.

Emergence of detonation in the flowfield induced by Richtmyer-Meshkov instability

Nikos Nikiforakis & **Kevin R. Bates**

Department of Applied Mathematics and Theoretical Physics
University of Cambridge, UK
n.nikiforakis@damtp.cam.ac.uk, k.r.bates@damtp.cam.ac.uk
http://www.damtp.cam.ac.uk/user/lcd

Combustible mixtures of gases can support two steady modes of combustion, namely deflagration and detonation. Under certain conditions a relatively low speed deflagration can accelerate to form a supersonic detonation wave, a process referred to as *deflagration to detonation transition* (DDT). Whilst the behaviour of steady deflagrations and detonations is reasonably well understood, there are many gaps in our understanding of the nature of the transition mechanism.

The aim of this research is to investigate the transition process, i.e. the reasons behind the change of propagation mechanism from the advection/reaction/diffusion mode of a deflagration, to the coupled shock/reaction system of a detonation wave and in particular the role of interfacial instabilities. To this end, the effect of the Richtmyer-Meshkov instability arising from the interaction of a shock wave with a flame has been studied by means of Implicit Large Eddy Simulations. Transition to detonation is shown to take place in the neighbourhood of localised temperature perturbations (hot-spots). Finally, the character of the interim combustion-driven waves arising from these hot-spots is analysed.

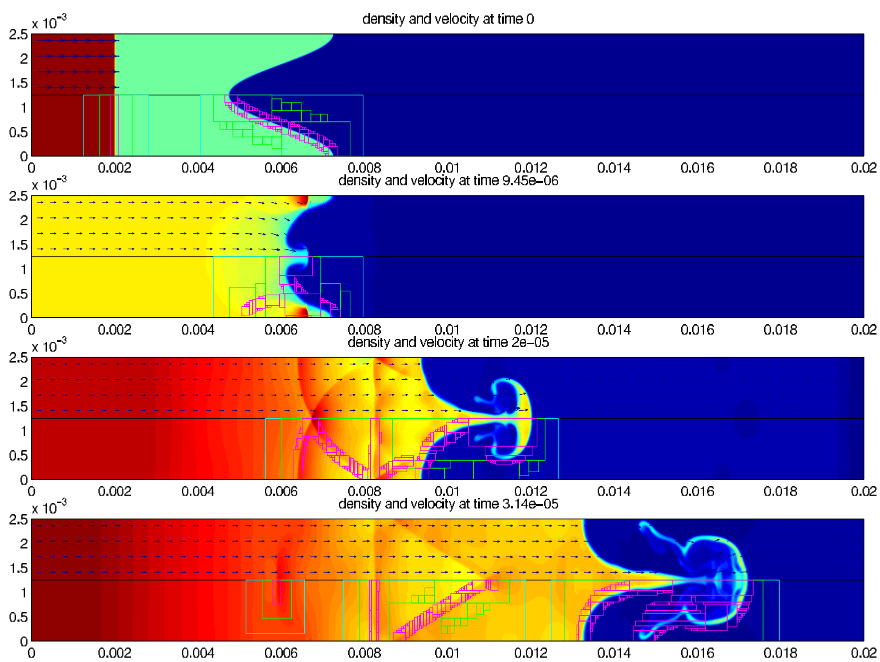


Figure 1: Richtmyer-Meshkov instability induced by the acceleration of a deflagration by a weak shock wave; density and velocity vectors shown. Numerical results using a TVD scheme coupled with adaptive mesh refinement; the boxes denote levels of refinement.

Linear and nonlinear evolution of Richtmyer-Meshkov instability

Katsunobu Nishihara[1], Chihiro Matsuoka[2], Gustavo J. Wouchuk[3] , Snezhana I. Abarzhi[4] & Vasilii V. Zhakhovskii[1]

1. Institute of Laser Engineering,
Osaka University, Japan
nishihara@ile.osaka-u.ac.jp

2. Deaprtment of Physics,
Ehime University, Japan
matsuoka@phys.sci.ehime-u.ac.jp

3. E. T. S. I. Industrials-UCLM-(13071) Campus,
Universitario s/n Ciudad Real, Spain
gwouchuk@ind-cr.uclm.es

4. Center for Turbulence Research,
Stanford University, USA
snezha@summer8.Stanford.edu

The Richtmyer-Meshkov instability (RMI) develops at a corrugated interface separating two fluids for following two cases, a shock wave traverses the interface (for example, Dimonte (1996)), and the interface is accelerated in impulsive form during short time (Jacobs (1996)). We here present analytical solutions for linear and nonlinear evolution for both cases, which agree very well with those experiments (Dimonte (1996) and Jacobes (1996)). In a shock-driven environment, the linear theory (Wouchuk (1997)) indicates that the instability is driven by the nonuniform velocity shear left by transmitted and reflected rippled shocks at the interface. The instability is also governed by compressibility effects which are more important as stronger are the shocks involved (Wouchuk (2001)). In later case, on the other hand, no shock wave has been used to accelerate the interface and therefore compressibility of the fluids can be ignored. Based on a weakly nonlinear theory (Matsuoka (2003)), we can describe the instability evolution for any Atwood number at the interface and the asymmetry of the bubble and spike structures. In this work, the nonlinear evolution of the interface has been investigated as a self-interaction of a nonuniform vortex sheet with a density jump. The theory developed shows the importance of the finite density jump and the finite initial corrugation amplitude of the interface. The vorticity on the interface for a finite density jump is not conserved in the nonlinear regime. Our results suggest that the spiral structure of the spike is due to local increase and decrease of the vorticity on the interface. Nonlinear analysis shows that the large initial amplitude of the corrugation results in rapid increase of the vorticity, which may also explain the fast roll up motion of the spiral for large amplitudes. We have also developed a theory (Abarzhi (2003)) that yields a non-trivial dependence of the bubble velocity and curvature on the density ratio and reveals an important qualitative distinction between the dynamics of Rayleigh-Taylor and RM bubbles.

References

Abarzhi, S. I., Nishihara, K and Glimm, J., 2003, Phys. Lett. A, **317**, 470.

Dimonte, G., Frerking, C. E., Schneider, M. and Remington, B., 1996, Phys. Plasmas **3**, 614.

Jacobs, J. W. and Shelly, J. M., 1996, Phys. Fluid **8**, 405.

Matsuoka, C., Nishihara, K. and Fukuda, Y., 2003, Phys. Rev E **67**, 036301.

Wouchuk, J. G. and Nishihara, K., 2003, Phys. Plasmas **4**, 1028.

Wouchuk, J. G. 2001, Phys. Rev. E **63**, 056303.

The multiparametric statistical analysis of hydrodynamic instabilities, based on wavelet preprocessing and neuronetwork classification

Anton Nuzhny, Vladislav Rozanov, Roman Stepanov & Alexander Shumsky

P.N. Lebedev Physical Institute of RAS,
Moscow, Russia
nuzhny@mail333.com, rozanov@sci.lebedev.ru

The present work demonstrates a new method of studying the RT-instability, which is based on the analysis and generalisation of a large amount of numerically simulated data. Initially these data (for different sets of initial conditions: hereinafter - processes) had been organised into time series of 2D distributions of physical values. Discrete wavelet-transform of these distributions has led to stable (in time) representation, namely to one, for which the proximity of states for early time moments (i.e. proximity by Euclidean distance between wavelet-images) is followed by proximity of late states of the processes. This feature of wavelet-representation allows one to perform probabilistic prediction of the Rayleigh-Taylor mixing evolution in time by comparison of an initial state with ones of the processes picked from database.

The analysis of DNS results, which have been visualised in the space of wavelet-components, discovered two important characteristics of the processes, which depend linearly on coefficients of wavelet-decomposed density fields. First of these characteristics correlates with "age" (time of evolution) of a process, mixed mass, mixing zone width, *etc.* Second one depends on time weakly, and its presence indicates that motion integrals are likely to exist for the problem of RT-induced mixing.

The research is supported by ISTC, Project #1481.

Investigation of mix after reshock in a cylindrical geometry.

Kenneth Parker[1], C.J. Horsfield[1], S.D. Rothman[1], M.M. Balkey[2], S.H. Batha[2], N.D. Delamater[2], J.R. Fincke[2], R. Hueckstaedt,[2] N.E. Lanier[2], G.R. Magelssen[2] & M. Taccetti[2]

1. AWE plc,
Aldermaston, Berkshire, UK
Kenneth.W.Parker@awe.co.uk
http://www.awe.co.uk/

2. Los Alamos National Laboratory,
Los Alamos, NM, USA
http://www.lanl.gov/

Abstract

Simulations of double cylinder implosions are presented. In these experiments the targets, consisting of concentric cylinders and having a buried, RM unstable aluminium marker layer, are imploded. Late in time, the aluminium layer is subjected to a second, counter-propagating shock. The effect of reshock on a turbulent mixing region is explored.

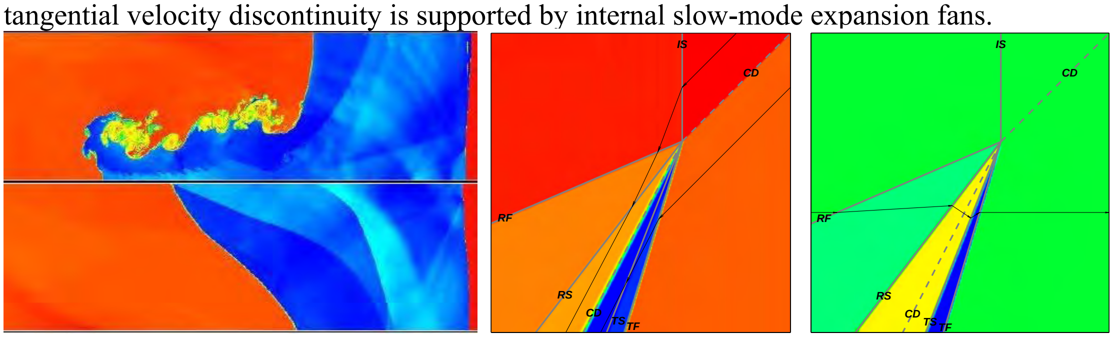
Suppression of the Richtmyer-Meshkov instability in the presence of a magnetic field

Dale Pullin[1], Ravi Samtaney[2] & Vincent Wheatley[1]

1. Graduate Aeronautical Laboratories,
California Institute of Technology, Pasadena, CA, USA
vincentw@galcit.caltech.edu

2. Princeton Plasma Physics Laboratory,
Princeton University, Princeton, NJ, USA

We present numerical evidence that the Richtmyer-Meshkov (RM) instability of an interface separating conducting fluids of different densities may be suppressed in the presence of a magnetic field. An example of this is shown in Figure 1(a) (Samtaney 2003). An explanation for this phenomena can be developed by considering the problem of regular refraction of a shock at an oblique, planar contact discontinuity. We show that in the presence of a magnetic field, the shock refraction process produces a system of from five to seven plane waves that may include MHD shocks, compound waves, 180° rotational discontinuities, and expansion fans that intersect at a point. In these solutions, the shocked contact is vorticity free and hence Kelvin-Helmholtz stable. The set of equations governing the structure of these multiple-wave solutions are obtained in which fluid property variation is allowed only in the azimuthal direction about the wave-intersection point. A numerical method of solution is described and examples are compared to the results of numerical simulations, as shown in Figure 1(b)-(c). Solutions in the limit of vanishingly small magnetic field are examined. These correspond to the hydrodynamic triple-point with the shocked contact replaced by a singular wedge whose angle scales with the applied field strength. Within the singular wedge the magnetic field strength is finite, the MHD contact remains vorticity free, and the tangential velocity discontinuity is supported by internal slow-mode expansion fans.



(a) (b) (c)

Figure 1: (a) Density fields from RM simulations with (bottom) and without (top) a magnetic field present. (b) Density contours, and (c) vertical magnetic field contours from simulations compared to computed shock angles. Sample streamlines and field lines are shown in (b) and (c) respectively.

References

Samtaney, R. 2003 Suppression of the Richtmyer-Meshkov instability in the presence of a magnetic field; *Phys. Fluids* **15**(8), 53-56.

Numerical simulation of influence of turbulent mixing zone on local perturbation growth under Rayleigh-Taylor instability conditions

V.A. Raevsky, S.N. Sinitsyna, A.L. Stadnik & Yu.V. Yanilkin

RFNC-VNIIEF, Sarov, the Nizhniy Novgorod region
postmaster@gdd.vniief.ru

It is known that in case of the turbulent mixing zone absence the self-similar local perturbation growth occurs according to the law

$$R_l \cong \beta\left(\frac{\rho_h-\rho_l}{\rho_h+\rho_l}\right)\cdot\frac{gt^2}{2},$$

and the growth constant β is approximately three times as much than the self-similar turbulent mixing zone growth constant α. According to two-dimensional and three-dimensional numerical simulations by Euler code EGAK it was revealed that when at initial time the local perturbation (R_{l0}) and perturbations (R_{turb0}) determining turbulent mixing zone later on were existed at interface, the continuous continuum of self-similar solutions was realized, in which β is function of the relation R_{l0}/R_{turb0} and $\alpha < \beta < N\alpha$ ($N = 3$ and $N = 6$ according to the two-dimensional and three-dimensional cases). Thus the turbulent mixing zone does not absorb the local perturbation, but decrease the self-similar growth constant β depending on initial conditions.

The numerical simulation results agree with the jelly substance experiments.

An overview of Rayleigh-Taylor experiments at Texas A&M University

Praveen Ramaprabhu[1] & Malcolm J. Andrews[2]

[1]Los Alamos National Laboratory
Los Alamos, New Mexico, USA
ramaprabhu@cnls.lanl.gov

[2]Department of Mechanical Engineering
Texas A&M University, College Station, Texas, USA
mandrews@mengr.tamu.edu

We present a summary of results obtained from the small Atwood number ($A_t \sim 7.5 \times 10^{-4}$) Rayleigh-Taylor (RT) experimental facility at Texas A&M University over the past 10 years. The conditions for RT instability are created by admitting cold water over a stream of hot water in a water channel facility. A splitter plate initially separates the two streams. As the fluid streams leave the edge of the splitter plate, an unstable interface is formed that results in a RT mix. The experiment allows for long data collection times, short transients, and is statistically steady. Over the past 10 years a variety of quantitative and qualitative flow measurement methods have been used or developed. In particular, velocity and density measurements have been made using the Particle Image Velocimetry technique, and high-resolution thermocouples respectively. In addition, a novel technique to simultaneously measure velocity-density fields was developed. The results to be presented include mean density profiles through the mix, and up to two decades of velocity spectra development, and four decades of temperature spectra. Consistent with the statistics, the velocity spectra also exhibit anisotropy between the vertical and horizontal velocity fluctuations, and a more isotropic dissipative range. The net kinetic energy dissipation, as the flow evolves from an initial state to a final self-similar state, was measured to be 49% of the accompanying loss in potential energy, and is in close agreement with values obtained from 3D numerical simulations. We will close with a description of a new high Atwood number RT mix experiment currently under development.

Multifractal structure and intermittent mixing in Rayleigh-Taylor driven fronts

Jose M. Redondo & German Garzon

Departament Fisica Aplicada, UPC Barcelona, Spain
redondo@fa.upc.es german@fa.upc.es

The advance of a Rayleigh-Taylor mixing front such as that described in Linden & Redondo (1991), may be shown to follow a dependence with time such that the average mixing region is described as $h = 2cgAt^2$ where h is the width of the growing region of instability, g is the gravitational acceleration and A is the Atwood number. The detailled structure of the front will afect the overall mixing as well as the transport properties between the fluids of different densities subject to gravitational acceleration. A Large Eddy Simulation numerical model using FLUENT as well as a dedicated code is used to predict some of the features of the experiments, (Figure 1) different models on the interaction of the bubble generated buoyancy flux and on the boundary conditions are compared with the experiments. The aspect ratios of the bubble induced convective cells are seen to depend on the boundary conditions applied to the enclosure. In the context of determining the influence of structure on mixing ability, multifractal analysis is used to determine the regions of the front which contribute most to molecular mixing and relating intermittency to the structure functions and to the maximum local fractal dimension.

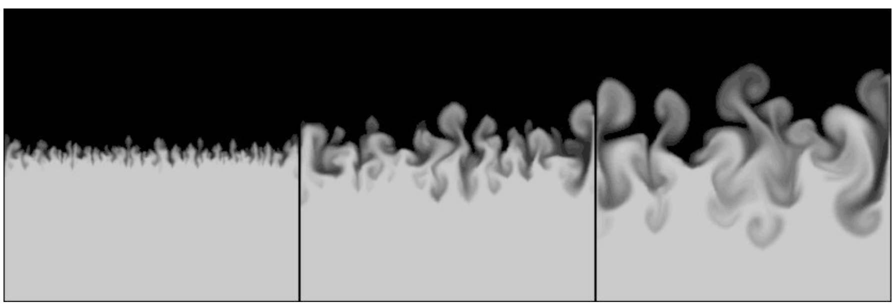


Figure 1. Structure of the RT front at times t/T=1,2 and 3.

Figure 2, shows the evolution of the multifractal dimension (calculated performing the box-counting algorithm) for each level of velocity modulus (a) and volume fraction (b). Much more relevant information can be extracted from these evolutions than from the maximum value presented by Linden et al.(1994), furthermore it is of great interest to study independently the fractal properties of velocity, volume fraction and vorticity fields for the different regions and thus determine the relative local mixing efficiencies during the transient mixing process.

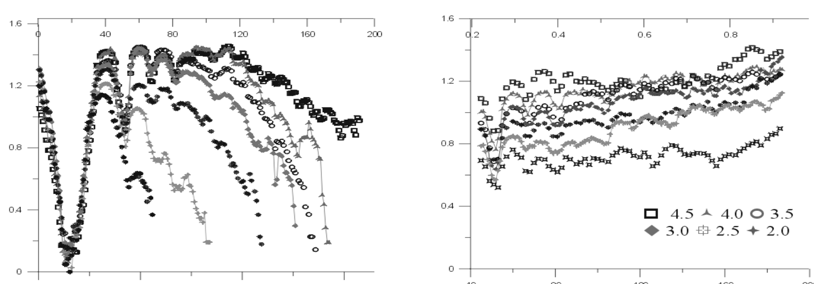


Figure 2. Evolution of the multifractal dimension RT fronts for the velocity and for the volume fraction at non dimensional times t/T=0.5, 1, 1.5, 2, 2.5, 3 and 3.5 for every level of intensity (normalized 0/1)

References

Linden P.F. & Redondo J.M. (1991) “Molecular mixing in Rayleigh-Taylor instability. Part 1. Global mixing”. Phys. Fluids. 5 (A), 1267-1274.

Linden P.F., Redondo J.M. and Youngs D. (1994) “Molecular mixing in Rayleigh-Taylor Instability” Jour. Fluid Mech. 265, 97-124.

MEDIC-2F: A one-dimensional diffusive mixing model. Application to LMJ target simulations.

François Renaud & Denis Souffland

CEA/DIF,
B.P. 12, 91680 Bruyères-le-Châtel, FRANCE
francois.renaud@cea.fr
http://www-dam.cea.fr

In laser-driven implosion experiments, a degradation of the single shell capsule yield could be observed due to mixing between the fuel and shell. This mixing is obtained by the growth of hydrodynamic instabilities at the interface between the fuel and the shell. These processes have various origins (inner and outer shell roughness, laser drive perturbations, ...) and evolve through different ways (Rayleigh-Taylor Instability, Richtmyer-Meshkov Instability, "Feed-Through", ...). The numerical simulations of these intrinsically three-dimensional phenomena, are still costly in term of cpu-time. We thus need an one-dimensional mixing model if we want to asses the impact of variation in the definition of the target, the holraum or the laser drive with a moderate cpu-time cost.

The main hypothesis for our mix-model is that the interpenetration is multifluid and that mass fraction and thermal exchanges could be modelled by the meaning of diffusive processes. Each fluid is in its own volume in an isothermal and a quasi-isobaric balance with the other. An additional diffusive equation calculate the mass fraction evolution of one component of the mixing. The diffusion coefficient is proportional to the length of the mixing zone and its time derivative. The thickening of the interpenetration zone is, indeed, supposed to be known from experimental data or from post-processing of two-dimensional computations results. One part of the thermal exchanges are due to the enthalpy exchanged by mass transport. Another part is due to electronic and ionic thermal conduction. All others thermal homogenization phenomena (energy loss by transverse thermal conduction, 1D average, ...) are modelled by an effective thermal conduction.

We will discuss examples of application of our model to LMJ target simulations. We focused on comparison between our one-dimensional computation results using MEDIC-2F and the corresponding 1D-averaged two-dimensional computation results obtained with the CEA hydrocode FCI2.

References

Souffland, D. and Renaud, F. 2001, A Mix-Model for One-Dimensional Simulations of Laser-Driven Implosion Experiments, *in proceedings of the eighth International Workshop on the Physics of Compressible Turbulent Mixing*, Pasadena, CA, USA.

Galmiche, D. and Cherfils, C. 2002, Hydrodynamic Stability of Indirect-Drive Targets, *in proceedings of the 27th European Conference for Laser Interaction with Matter*, Moscow, Russian Federation, in press.

Juraszek, D. 1993, FCI par laser : Physique de l'implosion, *La fusion thermonucléaire inertielle par laser* **2**, edited by R. Dautray and J.P. Watteau (Eyrolles, Paris, 1994), 275.

The relative effectiveness high-resolution methods in simulating compressible mixing

William J. Rider[1], **Jeff Greenough**[2] **& James R. Kamm**[1]

1. Los Alamos National Laboratory, Los Alamos, NM 87545 USA
rider@lanl.gov

2. Lawrence Livermore National Laboratory, Livermore CA, 94550, USA

High-resolution methods are necessary for the effective computation of compressible mixing. A large number of methods are available, but there is relatively little guidance on which methods are more appropriate or efficient under which circumstances. Some of the more popular methods available are PLM and PPM, (Woodward & Colella 198e) and the weighted ENO method (Jiang & Shu 1996). We will also consider more recent monotonicity preserving methods that can be applied to either the above formulations to achieve greater accuracy and efficiency per unit mesh (Rider, Greenough & Kamm 2003). We examine this question using the results computed for several standard problems at several comparable meshes and including a comparison with experimental data. We will use a number of measures. We will evaluate method convergence and produce accuracy estimates. This works springboards from a recent evaluation of WENO and PLM for 1-D shock physics problems where the PLM method was demonstrated to be more computationally efficient than WENO for these problems.

We will also examine the development of a cylindrical column(s) of SF6 accelerated by a shock wave resulting the Richtmyer-Meshkov instability. The idealized problem was constructed in order to compare compute codes and consists of a single Gaussian cylinder of SF6 accelerated by a Mach 1.2 shock and a very similar flow has been studied experimentally. Finally, the performance on the Taylor-Green vortex problem shows the ability of the method to compute three dimensional vortex dynamics ultimately leading to turbulence. In Table 1 we show a comparison at early time and late time using the entropy as the metric. Our calculations were conducted on two meshes, 32^3 and 64^3. We see that the WENO method is outperformed at both early and late time by either of the PLM or PPM methods. This advantage grows as the flow becomes more nonlinear at late times and the newer xPLM and xPPM methods.

T=2						T=10				
Grid	PLM	PPM	WENO	xPLM	xPPM	PLM	PPM	WENO	xPLM	xPPM
32^3	4.0e-04	1.5e-04	9.e-04	2.6e-04	5.0e-04	0.030	0.029	0.039	0.029	0.026
64^3	4.4e-05	1.2e-05	7.4e-05	3.7e-05	7.0e-06	0.024	0.022	0.030	0.023	0.021
CPU	1.00	0.93	17.00	1.30	1.45	15.35	14.21	261.0	19.93	22.22

Table 1. Error comparison for the Taylor-Green problem in terms of entropy and relative CPU time.

References

G.S. Jiang & C.-W. Shu, Efficient Implementation of Weighted ENO Schemes, J. Comp. Phys. 128, 202-228, 1996.

W.J. Rider, J. Greenough & J. Kamm, Extrema, Accuracy and Monotonicity Preserving Methods for Compressible Flows, AIAA-2003-4121, 16th AIAA CFD Meeting Orlando Florida.

P. Woodward & P. Colella, The Numerical Simulation of Two-Dimensional Fluid Flow with Strong Shocks, J. Comp. Phys., 54, 115-173, 1984.

The effects of viscosity and mass diffusion in hydrodynamically unstable plasma flows

H.F. Robey

Lawrence Livermore National Laboratory, Livermore, California, USA
robey1@llnl.gov

Hydrodynamically unstable plasma flows driven by intense laser radiation are described in which an interface between two materials of dissimilar densities is subjected to a very strong shock and then decelerated over a longer time scale. Pre-imposed perturbations on this interface are unstable to a combination of the Richtmyer-Meshkov (RM) and Rayleigh-Taylor (RT) instabilities. Overall target dimensions for these experiments are of the order of 1 mm, and length scales of the unstable perturbations of interest are as small as a few microns. At such small spatial scales, the effects of dissipative processes such as viscosity, thermal conductivity, and mass diffusion begin to affect instability growth rates.

In this study, estimates are presented of the spatial scale at which viscosity and mass diffusion begin to affect the growth of a perturbation due to the RM and RT instabilities. Time dependent values for the plasma kinematic viscosity and interfacial binary mass diffusivity are estimated for the conditions occurring in laser-driven instability experiments recently conducted on the Omega laser. These are used together with several models in the literature for estimating the reduction in the growth rate dispersion curves of the Rayleigh-Taylor and Richtmyer-Meshkov instabilities due to the presence of these small-scale dissipative effects.

Work performed under the auspices of the Department of Energy by the Lawrence Livermore National Laboratory under contract number W-7405-ENG-48.

Growth rate of mixing zone in a direct numerical simulation of Rayleigh-Taylor multimode instability development

Vladislav Rozanov[1], Roman Stepanov[1], Mikhail Anuchin[2], Yury Yanilkin[3], Nadezhda Proncheva[4] & Nikolai Zmitrenko[4]

1. P.N. Lebedev Physical Institute of RAS,
Moscow, Russia
rozanov@sci.lebedev.ru

2. Russian Federal Nuclear Center – All-Russia Scientific Research Institute of Technical Physics,
Snezhinsk, Russia
m.g.anuchin@vniitf.ru

3. Russian Federal Nuclear Center – All-Russia Scientific Research Institute of Experimental Physics,
Sarov, Russia
yan@md08.vniief.ru

4. Institute of Mathematical Modelling of RAS,
Moscow, Russia
zmitrenko@imamod.ru

On the base of many 2D numerical simulations of Rayleigh-Taylor instability development, which have been performed in the framework of ISTC Project #1481, the approximate formula was suggested to describe a mixing zone width variation with time. The initial perturbation is a sum of different modes with wavelength and amplitude, which are defined by certain law, and a random phase. The proposed formula has an asymptotic, corresponding to a spike movement with a constant velocity. Contributions of different modes to a zone width is described by the weights, depending on time and simulating the destruction of a given spike due to Kelvin-Helmholtz instability (Zmitrenko et al.(1997)). Different models of mixing zone growth are discussed.

The research is supported by ISTC, Project #1481.

References

Zmitrenko, N.V., Proncheva, N.G., Rozanov, V.B., 1997 The evolution model of a turbulent mixing layer; Preprint FIAN #65, Moscow.

Investigation of the large-scale and statistical properties of Richtmyer-Meshkov instability-induced mixing

Oleg Schilling[1], Marco Latini[2], Wai-Sun Don[3] & Barna Bihari[1]

1. Lawrence Livermore National Laboratory, Livermore, California, USA
schilling1@llnl.gov

2. Applied and Computational Mathematics
California Institute of Technology, Pasadena, California, USA
mlatini@caltech.edu

3. Division of Applied Mathematics
Brown University, Providence, Rhode Island, USA
wsdon@mail.cfm.brown.edu

The weighted essentially non-oscillatory method (Jiang & Shu 1996; Shu 1999) is applied to study the evolution of single- and two-mode Richtmyer-Meshkov instability-induced mixing. The numerical method is validated using two-dimensional simulations of the Mach 1.21 air/SF_6 shock tube experiments of Collins and Jacobs (2002) that include reshock of the evolving interface. The flow structure and perturbation amplitude growth obtained from the simulations are shown to be in very good agreement with the corresponding experimental data. The amplitude growth is also compared to the growth predicted by several nonlinear analytical models.

High-resolution, three-dimensional simulations are performed to study the spatial structure, spectra, and statistics in the Mach 1.5 air/SF_6 shock tube experiment of Vetter and Sturtevant (1995). The interfacial perturbation, including the embedded wire mesh, is modeled following the two-scale representation of Cohen et al. (2002). The mixing layer width is compared to the experimental data. The time-evolution of the kinetic energy spectra corresponding to velocity fluctuations in both the streamwise and spanwise directions and the density variance spectra are investigated. The balance of terms in the kinetic energy and enstrophy evolution equations is studied to provide insight into the baroclinic production and vortex stretching mechanisms that drive the instability and turbulence. Simulations using different orders of spatial accuracy are compared at different grid resolutions to investigate the dependence of quantities on the resolution.

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.

References

Cohen, R. H., Dannevik, W. P., Dimits, A. M., Eliason, D. E., Mirin, A. A., Zhou, Y., Porter, D. H. & Woodward, P. R. 2002 Three-dimensional simulation of a Richtmyer-Meshkov instability with a two-scale initial perturbation; Phys. Fluids 14, 3692-3709.

Collins, B. D. & Jacobs, J. W. 2002 PLIF flow visualization and measurements of the Richtmyer-Meshkov instability of an air/SF_6 interface; J. Fluid Mech. 464, 113-136.

Jiang, G.-S. & Shu, C.-W. 1996 Efficient Implementation of Weighted ENO Schemes; J. Comp. Phys. 126, 202-228.

Shu, C.-W. 1999 High Order ENO and WENO Schemes for Computational Fluid Dynamics; *High-Order Methods for Computational Physics*, edited by T. J. Barth and H. Deconinck, 439-582, Springer-Verlag.

Vetter, M. & Sturtevant, B. 1995 Experiments on the Richtmyer-Meshkov Instability of an Air/SF_6 Interface; Shock Waves 4, 247-252.

UCRL-ABS-201724

Direct numerical simulations of miscible, small Atwood number Rayleigh-Taylor instability-induced mixing

Oleg Schilling[1], Nicholas Mueschke[2] & Malcolm Andrews[2]

1. Lawrence Livermore National Laboratory, Livermore, California, USA
schilling1@llnl.gov

2. Department of Mechanical Engineering
Texas A&M University, College Station, Texas, USA
mueschke@tamu.edu, mandrews@mengr.tamu.edu

Experimental and numerical investigations have been conducted to investigate the effects of initial conditions on the evolution of the large- and small-scale dynamics of an incompressible, miscible, statistically-stationary, small Atwood number Rayleigh-Taylor mixing layer. Experiments were performed at Texas A&M University on an existing water channel facility (Snider & Andrews 1994; Wilson & Andrews 2001; Ramaprabhu & Andrews 2004). Density and velocity fluctuations were measured using a high-resolution thermocouple system and particle image velocimetry (PIV). Quantities in both the streamwise and spanwise directions were measured to determine the initial conditions of the mixing layer in two-dimensional space. The temporal evolutions of various velocity and density statistics were also recorded for comparison with simulation results.

High-resolution two- and three-dimensional direct numerical simulations (DNS) of the experiment were performed using the MIRANDA spectral/compact difference code (Cook & Dimotakis 2001) at Lawrence Livermore National Laboratory. The simulation parameters were chosen to match as closely as possible the experimental values of the densities, viscosities, diffusivities, physical dimensions, and gravitational acceleration. The experimentally measured initial density and velocity fluctuations were used to provide the initial perturbations for the DNS. Comparisons of statistical turbulent and mixing quantities inferred from the experimental measurements and from the DNS are presented. Differences in the evolution of statistics and spectra between the two- and three-dimensional DNS are discussed, including the dependence upon initial conditions of the late-time transition to an αAgt^2 mixing layer width. It is shown that DNS using experimentally determined initial velocity *and* density perturbations yields spectra and statistics in very good agreement with the corresponding quantities obtained from the experimental data.

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 work has also been supported by the Department of Energy as a part of the High Energy Density Science Grant Program under Contract No. DE-FG03-02NA00060.

References

Cook, A. W. & Dimotakis, P. E. 2001 Transition stages of Rayleigh-Taylor instability between miscible fluids; J. Fluid Mech. 443, 69-99.

Ramaprabhu, P. & Andrews, M. J. 2004 Experimental investigation of Rayleigh-Taylor mixing at small Atwood numbers; J. Fluid Mech. (in press).

Snider, D. & Andrews, M. J. 1994 Rayleigh-Taylor and shear driven mixing with an unstable thermal stratification; Phys. Fluids 6, 3324-3334.

Wilson, P. N. & Andrews, M. J. 2001 Spectral measurements of Rayleigh-Taylor mixing at small Atwood number; Phys. Fluids 3, 938-945.

UCRL-ABS-201725

Measurements of turbulent mixing within an air/SF_6 shocked and reshocked interface

Laurent Schwaederlé, Jean-François Haas, Philippe Montlaurent, Claude Rayer & Guillaume Seguin

Commissariat à l'Énergie Atomique,
Bruyères le Châtel, France
jean-francois.haas@cea.fr

We observe in a vertical shock tube the behaviour of an air/SF_6 mixing zone induced by the Richtmyer-Meshkov instability and excited by two subsequent waves reflected from the upper end wall: a shock and a rarefaction. The 1 m long driver and 3.058 m long driven sections are filled with air, and are followed by the 250 or 300 mm long measurement section filled with SF_6, at local atmospheric pressure (1 bar). The nominal Mach numbers are 1.20, 1.06, 1.304 and 1.297 for the incident, reflected in air (from the interface), the transmitted into SF_6 and reflected in SF_6 (from the end wall) shock waves respectively. Here, the shock wave propagates upwards from air into SF_6. The discontinuous interface between the test gases air and SF_6, which after shock acceleration leads to the mixing zone, is materialized by a thin (0.5 μm) nitrocellulose film sandwiched between two stainless steel wire grids. The upper (respectively lower) grid has a wire spacing of 1.8 (1.0) mm, with a wire diameter of 0.23 (0.07) mm. The lower grid is needed to support the membrane. The role of the upper grid is to impose a non-linear three dimensional perturbation of fundamental wave length 1.8 mm in the transverse directions. The perturbation amplitude in the axial direction is estimated between 0.1 and 0.3 mm. This wavelength and amplitude combination leads to an early transition to turbulence. After incident shock (reflected shock) the mixing zone moves upwards (downwards) at 69.4 (-24.7) m/s with an Atwood of 0.70 (-0.72). We measure the mixing thickness and velocity variance evolution for comparison with calculated quantities from turbulent mixing models imbeded in one-dimensional hydrodynamic codes [1]. The mixing thickness evolutions obtained from Schlieren visualisation for two initial SF_6 lengths (300 and 250 mm) exhibit power law dependence on time with exponent θ equal to 0.23±0.05 before reshock, 0.60±0.32 and 0.83±0.15 after reshock, for 250 mm and 300 mm respectively. The measurements of the axial and transversal components of the velocity will be performed for 250 mm using a DANTEC two components laser doppler velocimeter [2] at the three axial locations: 30, 88 and 146 mm.

References

[1] D. Souffland et al. 1997 Measurements and Simulations of the Turbulent Energy Levels in Mixing Zones Generated in Shock Tubes, Proceeding of the 6th IWPCTM, Marseille, June 1997, G. Jourdan and L. Houas eds., Caractère Press, Marseille.

[2] F. Poggi et al. 1999 Turbulence intensity measurements of shock-induced mixing using laser Doppler anemometry, Proceedings of ISSW22, Imperial College, London, July 1999, Ball, Hillier & Roberts eds., CD or book, Imperial College Press.

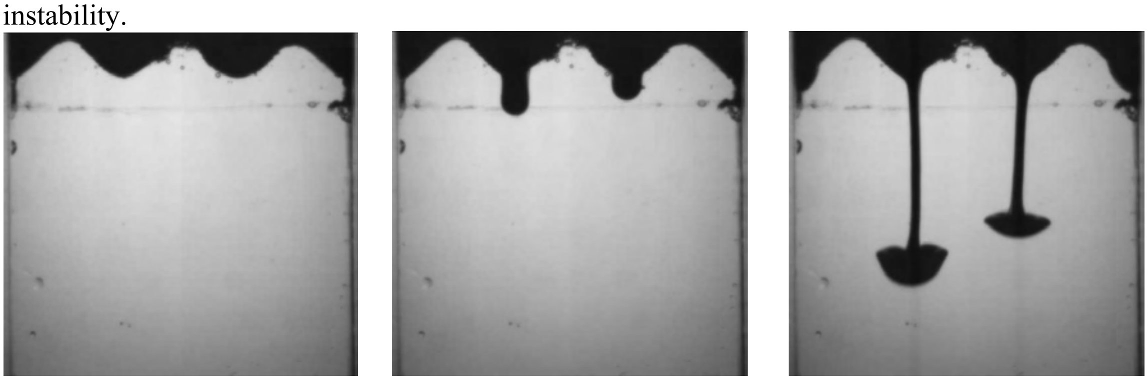
Experimental investigation of the Rayleigh-Taylor instability using a magnetorheological fluid

C. Selig, J. White, M. Anderson, J. Oakley & R. Bonazza

Department of Engineering Physics, University of Wisconsin - Madison
bonazza@engr.wisc.edu

A new experiment has been developed for the study of the Rayleigh-Taylor (RT) instability. It is centered on the use of a magnetorheological (MR) fluid as one of the two fluids at a perturbed interface. The property of the MR fluid that makes it ideal for a RT experiment is that the fluid can be “frozen" into any shape by applying a sufficiently large magnetic field; the fluid’s behavior is very nearly Newtonian in the absence of a magnetic field. One can therefore impose an arbitrary shape on the free surface of a MR fluid, then apply an external magnetic field thus forcing the MR fluid to retain the imposed shape; the “frozen" MR fluid can now be coupled with a different fluid (*e.g.* water) thus forming a pair of fluids of different densities separated by a perturbed interface; when the magnetic field is removed, gravity drives the RT instability. Use of an MR fluid thus allows for the preparation of interfaces of any desired shape (in particular, with any superposition of sinusoidal modes) and ensures that the experiment begins with both fluids at rest.

The new experiment uses a Plexiglas test section, 6.3 cm wide, 1.3 cm thick, 13 cm tall. The MR fluid in use is a dispersion of Fe particles (average diameter 4.5 μm) in mineral oil (75 % weight of Fe), with a small addiction of a surfactant (oleic acid) to prevent coalescence of the Fe particles. The “shaped" MR fluid sits on top of water (the interface Atwood number is 0.48) and it is held in place by two sets of five permanent magnets each mounted in two Plexiglas holders. The magnets each have a strength of 1.2 T, large enough to freeze the MR fluid into shape from a distance of about 15 cm. To start the experiment, the magnet holders are retracted away from the test section by two pneumatic cylinders. The interface is illuminated with diffuse, white light and it is imaged using a 512 × 512 pixel CCD camera, operating at 230 fps. Sample images from an experiment with a single mode interface (initial conditions: η = 2.7 mm; λ = 21.5 mm) are shown below. We will present results from experiments with both single-mode and multi-mode initial conditions and compare them to some of the proposed non-linear theories for the RT instability.



(a) (b) (c)

Figure 1:Rayleigh-Taylor instability at a magnetorheological fluid/water interface. (a) 0^- ms, (b) 150 ms, (c) 300 ms.

Numerical simulation of an experiment to study turbulent mixing on multiple shock wave passage through interface

O.G. Sin’kova, V.P. Statsenko, Yu.V. Yanilkin & A.R. Guzhova

Russian Federal Nuclear Center - VNIIEF,
Sarov, Russia
yan@md08.vniief.ru

The paper summarizes results of the direct numerical simulation of the turbulence generated at gas interface in a shock tube in interaction with shock waves. The computations have been performed with parallel 3D gas-dynamic code TREK using $3*10^6$ cells.

The computed data was processed (averaged) in order to estimate evolution of the mixing zone width and mean-square velocity component fluctuations.

The computed data is compared to the predictions by phenomenological turbulence models (Nikiforov’s and k-e models) as well as to well-known experimental data [1-2].

A good agreement between the computed data and with the experimental data is observed.

References

1. Francoise Poggi, Marie-Helene Thorembey, Gerard Rodriguez. Velocity measurements in gaseous mixtures induced by Richymyer-Meshkov instability/ Phisics of Fluids, v.10, n. 11, 1998, pp. 2698-2700.
2. D. Souffland, O. Gregoire, S. Gauthier, F. Poggi, J.M. Koenig. Measurements and simulation of the turbulent energy levels in mixing zones generated in shock tubes. 6th International Workshop on the Physics of compressible turbulent mixing (Marseille, France), 1997, pp. 486-491.

Direct 3d numerical simulation of shear turbulent mixing

O.G. Sin'kova, V.P. Statsenko, Yu.V. Yanilkin & V.A. Zhmailo

Russian Federal Nuclear Center - VNIIEF,
Sarov, Russia
yan@md08.vniief.ru

The paper considers one of the simplest shear flows that is a 1D time-dependent plane mixture layer. A variety of more complex flows – a time-independent plane mixture layer, initial sections of plane and circle jets, mixing process in a cylindrical vortex in its initial phase, etc. – are similar to it under certain conditions.

Earlier, we carried out numerical studies of the problem by direct numerical simulation using 2D and 3D codes.

In the given paper, the problem of shear turbulent mixing on a plane interface between two incompressible fluids of the fixed density is also studied by direct numerical simulation using 3D hydrodynamic code TREK, however, computations were carried out using a more fine computational grid (up to $16*10^6$ cells).

Numerical arrays of hydrodynamic quantities from 3D computations are used to find the moments for these quantities. Velocity pulsations in the turbulent mixing zone have been analyzed spectrally, its approximation to Kolmogorov spectrum has been studied

Some 3D computation results are compared to the results of measurements, as well as the data of the semi-empirical theory of turbulence considering the Reynolds tensor anisotropy. Good agreement between computational and experimental data is observed.

Direct numerical simulation of shear-gravitational turbulent mixing

O.G. Sin'kova, V.P. Statsenko, Yu.V. Yanilkin & V.A. Zhmailo

Russian Federal Nuclear Center - VNIIEF,
Sarov, Russia
yan@md08.vniief.ru

The paper addresses the problem of turbulent mixing at a plane interface of two different-density incompressible fluids in gravitational field with a velocity shear at the interface. This flow type occurs, for example, in the upper or lower part on the initial area of plane or circular jets, whose density is other than that of the surrounding jet.

The paper studies the problem with a stable gravitational acceleration direction using direct numerical simulation with 3D gas-dynamic code TREK [1]. The computations were conducted on a fine computational grid with parallelization to several tens of processors.

Moments of the quantities are found using numerical arrays of hydrodynamic quantities from 3D computations. The spectral analysis of the velocity fluctuation in TMZ has been performed: its approximation to Kholmogorov spectrum has been studied.

Some results of the 3D computations are compared to those of measurements [2-4] as well as to the data of semi-empirical theory of turbulence [5] that regards for Reynolds tensor anisotropy.

References

1. Stadnik A.L., Shanin A.A., Yanilkin Yu.V. Eulerian code TREK for computing 3D gas-dynamic multi-material flows //Voprosy Atomnoy Nauki i Tekhniki, Ser. Matematicheskoye Modelirovaniye Fizicheskikh Protsessov, 1994, No.4.
2. Spenser B.W., Jones B.G. Statistical investigation of pressure and velocity fields in the turbulent two-stream mixing layers . -AIAA Paper, 1971, P.613.
3. Browand F.K., Latigo B.O. Growth of the two-dimensional mixing layer //Phys.Fluids. 1979. Vol. 22, N 6, P.1011.
4. Rodi W.A. Review of experimental data of uniform density free turbulent boundary layers. -Studies in convection, Acad. Press, London, 1975, Vol. 1, P.79-166.
5. Statsenko V.P. Testing the model of turbulence with Reynolds tensor anisotropy //Voprosy Atomnoy Nauki i Tekhniki, Ser. Teoreticheskaya i Prikladnaya Fizika, 1996, P.43-51.

Turbulent mixing of multiphase flows in a gravitational field

Edward Son

Department of Physical Mechanics,
Moscow Institute of Physics and Technology, Russia
son@son.rector.mipt.ru
http://www.fizteh.ru

Turbulent mixing of stratified multiphase flows in a gravitational field is considered. Examples of multiphase flows are the flow of gas-oil-water in channel or pipe inclined to the horizon, convective gas flow of different densities, etc. At given pressure drop along the horizontal channel velocities of fluids of different densities give the result of slip velocities at the interfaces between layers and as result the Kelvin-Helmholtz instability. In the case of stable stratification this instability suppresses by gravity field (inverse Rayleigh-Taylor instability) and we can observe linear and then nonlinear stages of mixing layer development. At high Reynolds numbers turbulent mixing arises and the mixing layer in the gravity field is stabilized at some level. Experimental investigations for gas convective flow has been published Harlow (2001) and for multiphase flows Theron&Unwin (1996). In the present report we have developed linear theory of combined Kelvin – Helmholtz instability Inogamov et all (1999) in multiphase laminar viscous flows suppressed by gravity fields, nonlinear development of this instability, transition to the turbulence and turbulent models Onuphriev et all (2003) for high Reynolds numbers. Some preliminary LES and DNS results are also presented. For the simple case of two stratified fluids of very different densities like gas and liquid the solution for both the liquid and the gas regions can be obtained satisfying matching conditions at the interface. Such a solution will be applicable only to smooth surfaces, for the case of instability or turbulent flows it will be quite complex. Some essential results for mixing turbulent layers achieved in experiments and computations in accelerating shock waves and in ocean wind surface have been used for formulating turbulent models.

Acknoledgements. This work has been partially supported by Schlumberger and Joint CRDF and Russian Ministery of Education REC-011 Grant. Many thanks F.Harlow from Los Alamos and Chris Besson and Chris Lenn from Schlulberger for fruitful discussions. I also thank N.Inogamov, A.Demianov, V.Konovalov, A.Kostine, V.Sobololevsky, A.Zibarov and P.Zubkov for discussions and their valuable contibution to the computational work.

References

Inogamov N.A., Demianov A.Yu., Son E.E., 1999 Hydrodynamics of mixing. Periodical structures. Subharmonics generation. MIPT Publishing House, 464 p.

Son E.E. 2003 Multiphase Hydrodynamics, MIPT Conf. Invited Lecture.

Onuphriev A.T., Sapharof R.A., Son K.E., Son E.E. 2003 Semiempirical models of Turbulence. Theory and Experiment. Moscow, Science Publisher House (NAUKA) 346 P.

Theron B.E.&Unwin T. 1996 Stratified Flow Model and Interpretation in Horizontal Well, SPE 36560, SPE Conference USA, Denver, Colorado.

Harlow F. 2001 Los Alamos Report.

Joint growth of local perturbation and zone of turbulent mixing at gas-jelly interface

E.A. Sotskov, N.V. Nevmerhzitsky, M.V. Bliznetsov & E.D. Sen'kovsky

RFNC-VNIIEF, Russia, Sarov
postmaster@gdd.vniief.ru

The authors present results of experimental study of joint growth of local perturbation (LP) and zone of turbulent mixing occurred at Rayleigh-Taylor instability at interface of low-strength layer of jelly accelerated by compressed helium.

Local perturbation was a cavity of hemispherical shape with radius varied from R=0.5 mm to R=3 mm. On the free surface of the layer without local perturbations, background perturbations were specified as small cavities of square section having sizes of 2×2×0.2mm.

Pressure of compressed helium was varied from 13 to 300 atm. Acceleration of the layer was changed from $\approx 10^3 g_0$ to $10^5 g_0$ (g_0=9.8 m/s^2).

It was obtained that:

a) with increase of LP size, velocity of its growth into jelly layer is growing;

b) local perturbation with R=0.5 mm actually coincides with the zone of turbulent mixing, LP with R≥1 mm has velocity more than 2 times higher than velocity of the turbulent mixing growth;

c) at acceleration of layer $g \approx 10^5 g_0$, the internal surface of LP becomes instable.

Statistical properties of 2D RT-induced mixing at nonlinear and transient stages for 6-modes ensemble

Roman Stepanov[1], Vladislav Rozanov[1] & Nikolai Zmitrenko[2]

1. P.N. Lebedev Physical Institute of RAS,
Moscow, Russia
roman_an@mail.ru

2. Institute of Mathematical Modelling of RAS,
Moscow, Russia
zmitrenko@imamod.ru

Present work introduce the results of statistical analysis of specially chosen ensemble of RT-unstable flows. Initial perturbations have been set up as sum of six subharmonics (on computation domain) corresponding to first six prime numbers with randomly chosen initial phases. Ensemble-averaged distributions of physical values show spatial complexity with different typical structures for different analyzed fields. Observed inverse cascade principally accords to Layzer-type models, but time laws which govern dominant scales are likely to differ depending on the direction (along or orthogonal to gravity acceleration direction); deviation of temporal dependence of averaged TMZ width from t^2 law can be interpreted as evidence in favor of this difference. This behaviour can be explained in terms of long-living memory about pecularities of initial conditions, especially about combinations of proxime thin spikes. This circumstance may indicate that it is not correct to use Layzer-type evolution law to describe bubbles and spikes dynamics simultaneously.

The research is supported by ISTC, Project #1481.

3D numerical simulation of gravitational turbulent mixing with regard to molecular viscosity

A.L. Studnik, V.P. Statsenko & Yu.V. Yanilkin

Russian Federal Nuclear Center - VNIIEF,
Sarov, Russia
yan@md08.vniief.ru

Turbulent mixing under Rayleigh-Taylor instability is a classic problem. There is a lot of experimental data concerning the laws of TMZ growth, however, this date give significantly different values of the zone growth coefficient in the area which is assumed to be self-similar ($0.04 < \alpha < 0.35$).

We earlier showed in our previous papers that there was initial non-self-similar phase of turbulent mixing, both in 3D computations by TREK parallel code without consideration of molecular viscosity and in experiments. The corresponding area width depends both on the difference scheme in use and the number of computational cells and indicates that the scheme viscosity essentially affects the resultant solution.

The paper presents the results of 3D computations with regard to molecular viscosity for which simulation a code for solving Navier-Stokes equations has been developed within TREK code complex. A series of computations by the code has been carried out with $N=2\cdot10^6$ computational cells.

The computation results are compared to similar results without viscosity that allows us to estimate both its influence on the solution and the scheme effects. Computations show the increased duration of the initial non-self-similar area under large enough values of the molecular viscosity coefficients.

Numerical simulation of turbulent stage of Richtmyer-Meshkov instability with multishock interaction

V.F. Tishkin, M.Ye. Ladonkoina & N.V. Zmitrenko

IMM RAS, Moscow
zmitrenko@imamod.ru

In present work the investigation of Richtmyer-Meshkov instability development is fulfilled under the experiment [1] conditions. The calculations were carried out by means of an original parallel hydrodynamic code.

A good agreement of experimental and calculated dynamics of a turbulent mixing zone growth was obtained. An analysis of an influence of initial perturbations and comparison of experimental and computation intensity of velocity pulsation was fulfilled. The spectral characteristics of an arising turbulent flow are presented also.

Reference

[1] F.Poggi, M.-H.Thorembey, G.Rodriguez. Velocity measurements in turbulent gaseous mixtures induced by Richtmyer-Meshkov instability. // Physics of Fluids, 1998, Vol.10, No.11, pp.2698-2700.

Visualizing the onset and growth of secondary instabilities in Richtmyer–Meshkov-unstable flows

Chris Tomkins[1], Sanjay Kumar[1], Peter Vorobieff[2], Mark Marr-Lyon[1], Cherie Goodenough[1] & Robert Benjamin[1]

1. Hydrodynamics Group, DX-3,
Los Alamos National Laboratory, USA
ctomkins@lanl.gov

2. Department of Mechanical Engineering
University of New Mexico, USA

We report high-resolution concentration measurements of secondary instabilities developing along shock-accelerated material interfaces at intermediate and late times (~300-700 μs after shock passage) for the case of a shock interacting with a cylinder of heavy gas in air. The cylinder is formed by steadily flowing the heavy gas (SF_6) through a 5-mm circular nozzle under the influence of gravity; the cylinder is then impacted with a planar, Mach-1.2 shock. A recently implemented quantitative planar laser-induced fluorescence (PLIF) diagnostic is used to capture the concentration field of the heavy gas at several instances after shock passage, and the technique reveals fine details of the structure. Of particular interest in the present study is the development of secondary instabilities. Evident in the visualizations are two types of secondary instabilities, apparently distinct, with different characteristic length scales: one appears along the outer edge of the structure, and the other is manifest within the vortex cores (see Figure 1).

The nature of the mechanisms driving the secondary instabilities is also investigated. Particle image velocimetry (PIV) measurements, which provide 2-D velocity field data in a plane with high resolution (187um vector spacing), are performed at late time. These data are analyzed to identify the regions of the flow that may be expected to have the highest receptivity to the secondary instability mechanisms in question.

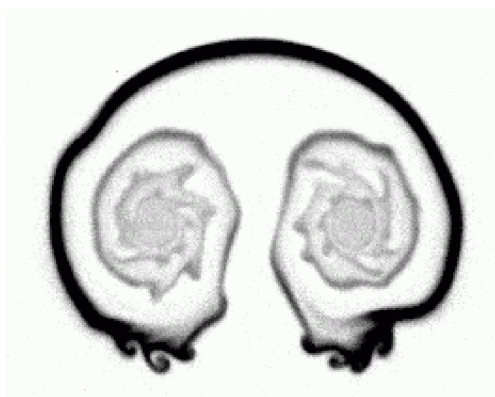


Figure 1: PLIF measurement of a single shock-accelerated gas cylinder at 680 μs after shock passage. Flow direction is top to bottom.

Turbulent diffusion of a passive scalar in a bidimensional flow: Astrophysical application.

Nathalie Toqué[1], François Lignières[2] & Alain Vincent[1]

1. Dynamiques des Fluides Astrophysiques,
LATT, FR
nathalie.toque@ast.obs-mip.fr
http://webast.ast.obs-mip.fr/latt/dfa/

2. Dynamiques des Fluides Astrophysiques,
LATT, FR
francois.lignieres@ast.obs-mip.fr
http://webast.ast.obs-mip.fr/latt/dfa/

3. Université de Montréal, QC
vincent@astro.umontreal.ca

We study the evolution of a passive scalar in a two-dimensional flow, highly sheared and stratified in temperature. The simulations are realised with a two-dimensional spectral code without subgrid model. In the physical space, the grid is supplied with 6×256^2 squared meshes. The flow is turbulent ($Re_{turb} \approx 120$) and anisotropic ($\sqrt{\frac{<u_x{}^2>}{<u_z{}^2>}} > 1$). The Richardson number of each simulated flow is less than ¼. The Peclet number of the passive scalar is $Pe_{turb} \approx 100$.

The purpose of this study is to find a relation between the diffusion coefficient of the scalar and the velocity components of the flow. This relation is designed as follows : $\frac{D_L}{lv} \propto A^{-\alpha}$.

★ D_L is the diffusion coefficient. It is calculated with Lagrangian particles which are advected by the flow.

★ lv is the product between the length scale and the velocity scale of the flow. The mean value slightly grows with the Richardson number.

★ A is defined as follows : $A = \sqrt{\frac{<u_x{}^2>}{<u_z{}^2>}}$ and belongs to the interval : $1 < A < 40$.

★ For the set of simulated flows, the exponent α is found in the interval: $0.912 < \alpha < 1.069$.

The contribution of this study is to improve the results of Vincent *et al.* It is double :

● The flow is calculated with the Navier-Stokes equations and is stratified. In Vincent & al, the velocity field is generated with the Ornstein-Uhlenbeck process.

● The law : $\frac{D_L}{lv} \propto A^{-1}$ is not valid for any anisotropy value. This limitation is not detected in the simulations of Vincent *et al.*

With such a relation, the Standart Evolution Model of Solar-type stars could take into account the influence of the differential rotation on abundances.

References

Vincent, A., Michaud, G and Meneguzzi, M. 1996 On the turbulent transport of a passive scalar by anisotropic turbulence; *Phys. Fluids* **8**, 1312-1320.

Michaud, G and Vincent, A. 1997 Abundance Anomalies and Anisotropic Turbulent Tranport in Stars; *Procc. ClarkeWest97*.

Analytic model for the single-mode Richtmyer-Meshkov instability from the linear to the nonlinear regime

Marc Vandenboomgaerde

1. Commissariat a l'Energie Atomique, Bruyeres-Le-Chatel,
Commissariat a l'Energie Atomique, Bruyeres-Le-Chatel,
BP 12, 91680 BRUYERES-LE-CHATEL, FRANCE
marc.vandenboomgaerde@cea.fr

The Richtmyer-Meshkov instability (IRM) is involved in several physical phenomena such as, for example, inertial confinement fusion (ICF). This instability can break the symmetry of the implosion and reduce the fusion gain. The nonlinear regime of the IRM has been studied by numerous authors (A.L. Velokovich *et al.* 1996, Q. Zhang *et al.* 1997, M. Vandenboomgaerde *et al.* 2002), but algebraic solutions have a limited range of validity. They exhibit a secular behavior.

This study is an attempt to solve this problem by describing the non-linear growth of the IRM with ordinary differential equations. The equations which describe the dynamics of a single-mode Richtmyer-Meshkov instability are simplified using a change of variable. The shape of the interface and the velocity potentials are expressed as Fourier series. These series are introduced in the system, and the following technics are used:

assumptions about the order of some expressions are made;

as the IRM saturates with time, the analytic solution must not diverge. So, the expressions leading to divergent solutions are assumed to be cancelled by infinite sums of smaller order terms.

At first order, this leads to an differential equation for the growth of the fundamental. Other orders can be taken into account leading to a set of differential equations. The saturation of the linear growth of the IRM is found. Comparisons with experimental data and 2D numerical simulations are presented.

References

Velokovich A.L. and Dimonte G., Phys. Rev. Let , 3112 (1996).

Zhang Q. and Sohn S-I., Phys. Fluids , 1106 (1997).

Vandenboomgaerde M., Gauthier S. and Mügler C., Phys. Fluids , 1111 (2002).

Experimental study of initial stage of instability development on gases interface under influence of shock wave front acceleration

A.V. Vasilenko

Russian Federal Nuclear —
Center Zababakhin Institute of Technical Physics,
Snezhinsk, Russia
vasilenko@gdd.ch70.chel.su

Results of experimental study in instability development on flat interface of noble gases under influence of shock wave front acceleration are described in the paper. Instability development was observed after strong decelerating shock wave with M = 3.3 – 4.5, generated in electromagnetic shock tube (EST) passed through the interface. The phenomenon was recorded by schlieren system of shadow imager IAB-451.

Analysis of experimental data was performed by 1D numerical simulation of flow dynamics in EST with preset stable interfaces.

It has been demonstrated that under experimental conditions in EST thin nytrocellulose membranes originally separating gases were burning under effect of heat irradiated by shock compressed gases prior to shock wave arrival to investigated interface.

It has been demonstrated that the width of disturbance zone in initial stage of instability development increases proportionally to $t^{1/2}$.

Empirical equation of disturbance zone dependence versus time and parameters of gases flow on the interface has been drawn up. This equation describes development of disturbance zone up to turbulization of flow.

Compressible aspects in simulations of multi-mode Rayleigh-Taylor mixing

Erik L. Vold

Los Alamos National Laboratory
elv@lanl.gov

Compressible aspects of the Rayleigh-Taylor mixing layer are explored in 2-D (x-y) multi-mode IC resolved scale simulations solving the multi-fluid Euler equations with interface reconstruction. R-T mix layer growth rates are computed in an 'incompressible limit' and found to be in agreement with experimental data across the range of Atwood numbers (0.04-0.96) for bubbles and for spikes. Fluctuation contributions to mixing are examined in contour plots, profiles of transverse averaged quantities, and in spectra of pressure and pressure components, momentum components, and the advection and compressible terms in the density and energy equations.

Results show pressure fluctuations are driven by density fluctuations with a comparable contribution from the energy fluctuations omitted in incompressible formulations. Transverse planar averaged magnitudes of fluctuations for density over that for internal energy are less than unity in the bubble growth region and greater than unity in the spike growth region, implying fluctuations are dominated by different contributions in each region. The magnitudes of compressible terms compared to the incompressible advection terms in the density and in the energy equations show significant trends averaged across the mix layer. Compressible contributions to fluctuations are most important for density in the bubble growth region and for internal energy in the spike growth region. Long wave length modes in the initial conditions, which have been proposed by others as a mechanism for enhanced mix layer growth rates, are seen to be inescapable in the present multi-fluid compressible formulation. Vorticity and other fluctuating components play key roles in dissipating the instability acceleration into the transverse plane and thus establishing the characteristic gradient scale lengths across the mix layer and the effective mix layer growth rates within each fluid region.

The results together show that density and internal energy fluctuations, including the compressibility terms, are significant contributions to the dynamics. This supports the concept that mix layer growth is driven by interface physics which depends upon discontinuities in both density and in internal energy. It is hypothesized that this physics must be properly represented in a multi-fluid simulation in order to match multi-mode growth rates in experiments even in the 'incompressible limit'.

Rayleigh-Taylor and Richtmyer-Meshkov aspects of interface deceleration mixing

Erik L. Vold

Los Alamos National Laboratory
elv@lanl.gov

Resolved scale simulations using a 2-D (r-z) compressible multi-fluid Eulerian code with interface reconstruction are used to study the mixing layer produced in interfacial fluid deceleration. The fluid interfacial deceleration (normal to the interfacial plane) is driven by transient stagnating pressure as flow is reflected from an impenetrable boundary in planar geometry or at an axis of symmetry in cylindrical geometry. Several driver conditions are evaluated and the cylindrical convergent case is related to ICF experiments currently underway. For the cases driven with a shock at the outer boundary, R-M instability growth occurs at early times prior to any deceleration and agrees with the linear impulse model. The total R-M mixing over the duration of cylinder convergence prior to deceleration is insignificant compared to later time deceleration mixing. Results show deceleration mixing can be approximated with an initial rapid growth rate and a slower late time growth rate after the acoustic transit time when pressure gradient reversals occur in the fluids. Each growth rate is characterized by a power law in time with the exponent of the initial rapid mix growth proportional to the energy into the system, and ranging from less than 1 to over 10 in the cases studied. The exponent matches the R-T growth rate scaling (~ t^2 for constant acceleration, g) only for a small energy into the system which is too small for significant convergence in the cylindrical system. The interface deceleration mix layer differs from classic R-T mix in several respects with growth rates varying in time, including phases of de-mixing and 'mode doubling' in some regimes, smaller scales and less vortical structures. An interfacial area $A_{12}(t)$, important in diffusive atomic mixing, is seen to grow faster in time than the mix layer width. The deceleration mix layer grows after the main acceleration peak has decayed to small values, and as such, interface deceleration mix more closely resembles R-M mix than R-T mix. We conclude with preliminary efforts to represent the mix layer growth dynamics and the evolution of the atomically mixed components simultaneously in an unresolved (sub-grid scale) simulation.

A NIF 3-D high Mach number feature experiment*

Stephen Weber, S. Gail Glendinning, Harry Robey, Peter Stry & D. Tod Woods

Lawrence Livermore National Laboratory
Livermore, CA, USA
svweber@llnl.gov
glendinning@llnl.gov
robey1@llnl.gov
pstry@llnl.gov
todw@llnl.gov

Some ICF ignition capsule designs for the National Ignition Facility (NIF) require localized features such as fill tubes, holes, and waist joints, which break the ideal spherical symmetry of the capsule. Simulations have been employed to explore the robustness of capsules to perturbations from such features. An experiment using the first four beams of NIF experiment has been designed to test modeling of features. This experiment examines the hydrodynamic response of a pusher void to a high Mach number shock in a mini-shock tube. The shock is generated by direct illumination of a CH ablator by a 5 kJ 1.5 ns NIF laser pulse. The pressure of the ablator drives a blast wave through a 250 μm thick planar aluminium pusher into density 0.1 g/cm^3 carbon foam enclosed in a CH tube. The shock pressure in the Al is 20-60 Mb, the lower value applying at breakout into the foam. The Mach number of the shock in the Al at breakout is about 8. We will compare the behavior of a 2-D axisymmetric feature to a 3-D feature. The 2-D feature is a cylindrical void of 160 μm diameter and 150 μm depth penetrating into the Al from the interface with the foam. Shock passage over the void launches a jet of Al into the foam, which will be diagnosed with x-ray backlighting. We have considered 3-D feature options including a void of square cross-section and a tilted cyclinder. The final 3-D design has not been chosen at the time of submission of this abstract. We shall present 3-D simulations using the ALE code Hydra and early experimental data.

* 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.

Validating the FLASH code: Two- and three-dimensional simulations of shock-cylinder interaction

Greg Weirs[1], Tomek Plewa[1], Todd Dupont[1], Vikram Dwarkadas[1], Chris Tomkins[2] & Mark Marr-Lyon[2]

1. ASCI Flash Center, University of Chicago
Chicago, IL
weirs@flash.uchicago.edu
http://flash.uchicago.edu

2. Los Alamos National Laboratories,
Los Alamos, NM
http://www.lanl.gov

We describe validation tests of the FLASH code for flows dominated by vorticity deposition and vortex dynamics. An experiment at Los Alamos National Laboratory is the the reference for comparison. In the experiment, a column of sulfur hexafluoride is introduced into the test section of a shock tube, otherwise filled with air. A weak shock is generated and passes through the column. Baroclinic torques produce vorticity at the interface as the shock crosses it, leading to the formation of a vortex pair. The interface is distorted as the vortex pair rolls up, and secondary instabilities develop along the interface. The experiment is valuable for validating simulation codes in weakly compressible regimes driven by vorticity dynamics. Our validation tests focus on two-dimensional simulations, but three-dimensional effects are also examined.

Turbulent jets?

B.H. Wilde[1], P.A. Rosen[2], J.M. Foster[2], T.S. Perry[3], R.F. Coker[1], P.A. Keiter[1], G.R. Bennett[4], D.B. Sinars[4], M.J. Steinkamp[1], B.E. Blue[3], H.F. Robey[3], A.M. Khokhlov[5], M.L. Gittings[1], J.P. Knauer[6], R.P. Drake[7], R.B. Campbell[4], A. Frank[6], & T.A. Mehlhorn[4]

1. Los Alamos National Laboratory, X-2, MS T087, Los Alamos, NM, 87545, USA
bhw@lanl.gov, FAX: 505-665-2227

2. AWE, Aldermaston, UK

3. Lawrence Livermore National Laboratory, Livermore, USA

4. Sandia National Laboratory, USA

5. University of Chicago, USA

6. Laboratory for Laser Energetics, U. of Rochester, USA

7. University of Michigan, USA

Over the last few years we have fielded numerous supersonic jet experiments on the NOVA and OMEGA lasers and Sandia's pulsed-power Z-machine in collaboration between Los Alamos National Laboratory, the Atomic Weapons Establishment, Lawrence Livermore National Laboratory, and Sandia National Laboratory. These experiments are being conducted to help validate our radiation-hydrodynamic codes, especially the newly developing ASC codes. One of the outstanding questions is whether these types of jets should turn turbulent given their high Reynolds number. Recently we have modified our experiments to have more Kelvin-Helmholtz shear, run much later in time and therefore have a better chance of going turbulent. In order to diagnose these large (several mm) jets at very late times (~1000 ns) we are developing point-projection imaging on both OMEGA and at NIF. We are also developing large field-of-view imaging on Z using a monochromatic-curved-crystal imager at 6.15 keV. Since these jets have similar Euler numbers to jets theorized to be produced in supernovae explosions, we are also collaborating with the astrophysics community to help in the validation of their new codes. This talk will present a review of the laser and pulsed-power experiments and a comparison of the data to simulations by the codes from the various laboratories. We will show results of simulations wherein these jets turn highly 3-dimensional and show characteristics of turbulence. With the new data, we hope to be able to validate the sub-grid-scale turbulent mix models (e. g. BHR) that are being incorporated into our codes.

This work is performed under the auspices of the U. S. Department of Energy by the Los Alamos National Laboratory Laboratory under Contract No. W-7405-ENG-36, Lawrence Livermore National Laboratory under Contract No. W-7405-ENG-48, the Laboratory for Laser Energetics under Contract No. DE-FC03-92SF19460, Sandia National Laboratories under Contract No. DE-AC04-94AL85000.

Shock propagation through multiphase media

R.J.R. Williams & D.L. Youngs

AWE plc,
Aldermaston, UK
robin.williams@awe.co.uk
http://www.awe.co.uk/

Multiphase media are found in a wide range of natural and technological systems. Examples include clouds, foams, and sprays, with applications such as diesel engines and fluidized beds, as well as ICF capsules. In astrophysics, the interstellar medium is a multiphase system, primarily due to the form of the thermal equilibrium curve, through which strong shocks are driven by stellar wind bubbles and supernovae.

In this paper, we study the propagation of strong shocks through multiphase media using two and three dimensional simulations. The presence of inhomogeneities seeds strongly turbulent flows, which have significant effects on shock structure and the mixing of flow components. We test the applicability of one dimensional turbulent mixing models by comparison with these detailed simulations.

3D modelling of cylindrical implosion experiments

R.J.R. Williams, D.L. Youngs & K.W. Parker

AWE plc,
Aldermaston, UK
robin.williams@awe.co.uk
http://www.awe.co.uk/

AWE has been involved in a series of experimental campaigns to study shock-induced mixing in a convergent geometry. We have studied the flows in these simulations using a three-dimensional hydrodynamic code, Turmoil3D. In this paper, we compare these adiabatic results with more physically detailed two-dimensional simulations and the results of turbulence models, as well with experimental results. We also consider geometries which may be of interest for future experimental work.

Mixing in thick-walled and pulse-shaped directly driven ICF capsule implosions.

D.C. Wilson[1], F.J. Marshall[2], P.W. McKenty[2], V.Yu. Glebov[2], C. Stoeckl[2], C.K. Li[3], F.H. Séguin[3], D.G. Hicks[3], R.D. Petrasso[3], C.W. Cranfill[1], G.D. Pollak[1] & W.J. Powers[1]

1. Los Alamos National Laboratory
Los Alamos, New Mexico, USA
dcw@lanl.gov

2. Laboratory for Laser Energetics,
U. of Rochester, USA

3. Plasma Science and Fusion Center,
Massachusetts Institute of Technology, USA

The mult-fluid interpenetration mix model of Scannapieco and Cheng (Phys. Lett A, 2002) has been applied to X-ray driven inertial confinement fusion capsules (ICF) (Wilson *et al*., Phys. Plamas, 2003), to double shell ICF capsules (Wilson *et al*. 2004a), and to directly driven capsules with a 20 μm wall thickness using a 1ns square laser pulse with both symmetric (Wilson *et al*., 2004b) and asymmetric illumination (Christensen *et al*., 2004). In general it was found that using atomic mixing the single mixing parameter could fit almost all the data with a value of 0.05 ±0.02. In this paper the model is tested against data from a wider range of directly driven capsules with wall thicknesses up to 40 μm, and with square, moderate (PS26) and extreme (low adiabat) pulse shapes (Marshall *et al*., 2000a,b, 2004). In addition to yield, burn temperature, and burn history, model simulations are post-processed to compare with X-ray image profiles, secondary neutron yields, and shell rho-r measurements.

References

Christensen, C. R. et al. 2004, The influence of asymmetry on mix in direct-drive ICF experiments, accepted for Phys. Plasmas, May, 2004.

Scannapieco, A. J. and Cheng, B. 2002, A multifluid interpenetration mix model; Phys. Lett. A, 299, 49-64.

Marshall, F. J. *et al*. 2000a, Direct-drive, hollow-shell implosion studies on the 60-beam; UV OMEGA laser system; Phys. Plasmas, **7**, 1006-1013.

Marshall, F. J. *et al*. 2000b, Direct-drive high-convergence-ratio implosion studies on the OMEGA laser system; Phys. Plasmas, **7**, 2108-2113.

Marshall, F. J. *et al.* 2004 Direct-drive-implosion experiments with enhanced fluence balance on OMEGA; Phys. Plasmas, **11**, 251-259.

Wilson, D. C. et al. 2003, Degradation of radiatively driven inertial confinement fusion capsule implosions by multi-fluid interpenetration mixing, Phys. Plasmas 10, 4427-4434.

Wilson, D. C. et al. 2004a, Mixing in double shell capsules, proceedings of IFSA 2003, to be published by the American Nuclear Society.

Wilson, D. C. et al. 2004b. Multi-fluid interpenetration mixing in directly driven inertial confinement fusion capsule implosions, accepted for Phys. Plasmas, May, 2004.

Spontaneous acoustic emission in a non ideal gas in the presence of a piston

J.G. Wouchuk & J. Lopez Cavada

E.T.S.I.Industriales, University of Castilla La Mancha,
Campus Universitario s/n
(13071) Ciudad Real
Spain
gwouchuk@ind-cr.uclm.es

An analytic model to study the perturbation evolution in the space between a corrugated shock and the piston surface is presented. The exact Laplace transform of the pressure perturbations is derived for an arbitrary equation of state and its limits of validity are discussed. The conditions for stable oscillation patterns are obtained by looking at the poles of the Laplace transform. The D'yakov-Kontorovich (DK) criterion for the spontaneous acoustic emission of a corrugated shock wave is generalized. It is seen that besides the standard DK mode of oscillation, the shock surface can exhibit an additional set of discrete frequencies. The additional eigenmodes are excited when the shock is launched at $t = 0+$, due to the piston that reflects normal waves toward the shock. The first eigenmode (the DK mode) is always present, assuming that the Hugoniot curve has the correct slope in the V - p plane, whenever the shock shape is slightly modified. However, the additional frequencies only appear for sufficiently strong shocks. The total number of eigenmodes is limited in number by the equation of state of the material. Besides, for strong enough shocks, the piston pressure perturbations also show characteristic oscillations. The predictions of the model are verified for particular cases by studying a van der Waals gas, as in the works of J. W. Bates and D. C. Montgomery [Phys. Fluids **11**, 462 (1999), Phys. Rev. Lett. **84**, 1180 (2000)].

Freeze-out of the Richtmyer-Meshkov instability

J. G. Wouchuk[1] & K. Nishihara[2]

1. E.T.S.I.Industriales, University of Castilla La Mancha,
Campus Universitario s/n
(13071) Ciudad Real, Spain
gwouchuk@ind-cr.uclm.es

2. Institute of Laser Engineering, Osaka University
2-6 Yamada-oka, Suita, Osaka, Japan

It is known that for some values of the initial parameters that define the Richtmyer-Meshkov instability, the normal velocity at the contact surface vanishes asymptotically in time. This phenomenon, called freeze-out, is studied here with an exact analytic model. The instability freeze-out, already considered by previous authors [K. O. Mikaelian, Phys. Fluids **6**, 356 (1994), Y. Yang, Q. Zhang, and D. H. Sharp, Phys. Fluids **6**, 1856 (1994), and A. L. Velikovich, Phys. Fluids **8**, 1666 (1996)], is a subtle consequence of the interaction between the unstable surface and the corrugated shock fronts. In particular, it is seen that the transmitted shock at the contact surface plays a key role in determining the asymptotic behavior of the normal velocity at the contact surface. By properly tuning the fluids compressibilities, the density jump and the incident shock Mach number, the value of the initial circulation deposited by the reflected and trasmitted shocks at the material interface can be adjusted in such a way that the normal growth at the contact surface will vanish for large times. The conditions for this to happen are exactly calculated, by expressing the initial density ratio as a function of the other parameters of the problem: fluids compressibilities and incident shock Mach number. This is done with the aid of a linear theory model developed in a previous work [J. G. Wouchuk, Phys. Rev. E **63**, 056303 (2001)]. The evolution of different cases (freeze-out and non freeze-out) are studied with some detail. The distance traveled by the interface ripple before it stops growing can be also calculated. A comparison with previous works is also presented.

Effect of initial conditions on self-similar turbulent mixing

David L. Youngs

AWE
Aldermaston, UK
david.youngs@awe.co.uk
http://www.awe.co.uk/

Three dimensional simulations of Rayleigh-Taylor (RT) mixing starting with short wavelength random perturbations (growth by mode coupling) give values of the quadratic growth rate coefficient, α , much less than observed, Dimonte et al (2004). However, if a low level of long wavelength perturbations with a $1/k^3$ power spectrum (amplitude $\propto$ wavelength) is added, higher values of α may be obtained which correspond to the experimental values, Youngs (2002).

For the free shear layer (Kelvin-Helmholtz (KH) mixing), Pantano and Sarkar (2002), use broadband initial perturbations to match the observed results. This suggests a similarity with the RT case. Simulations of the time-evolving shear layer are performed with the same perturbations as used in the RT simulations and this confirms that the behaviour is similar. It is suggested here that in both cases low-level long wavelength perturbations are present in typical experiments and have an effect on the growth rate.

For both the RT and KH cases the internal structure of the mixing zone (velocity and concentration fluctuations) for simulations which match the observed growth rates, is compared with the available data measurements and found to be in satisfactory agreement.

For turbulent Richtmyer-Meshkov (RM) mixing, the mix width is usually assumed to have a t^p time variation, where p is a fractional power. Three dimensional simulations are performed with initial perturbation spectra of the form k^{-m} . It is shown that p is not a constant but depends on the exponent m.

Finally the implications of these results for RANS models, in which coefficients are adjusted to match a range of self-similar experiments, are discussed.

References

DiMonte, G. et al. 2004 A comparative study of the turbulent Rayleigh-Taylor (RT) instability using high-resolution 3D numerical simulations: The Alpha-Group collaboration; to be published in Phys. Fluids.

Youngs, D.L. 2002 Review of numerical simulation of mixing due to Rayliegh-Taylor and Richtmyer-Meshkov instability; Proceedings of the 8th IWPCTM, edited by O. Schilling.

Pantano, C. & Sarkar, S. 2002 A study of compressibility effects in the high-speed turbulent shear layer using direct simulation; J. Fluid Mech., 451 325-371.

Numerical investigation of gravitational turbulent mixing with alternating-sign acceleration

V.A. Zhmailo, O.G. Sin'kova, V.N. Sofronov, V.P. Statsenko, Yu.V. Yanilkin, A.P. Guzhova & A.S. Pavlunin

Russian Federal Nuclear Center - VNIIEF,
Sarov, Russia
yan@md08.vniief.ru

The turbulence evolving in gravity field at a plane interface of two incompressible fluids with density ratio n=3 under alternating-sign acceleration is investigated by direct numerical simulation using 3D TREK code.

The results obtained were averaged to determine the moments of the following hydrodynamic quantities: diagonal Reynolds tensor components (turbulent energy), turbulent flows, density profile, and mean-square-root pulsation of velocity.

The resultant values are compared to the predictions by phenomenological models of turbulence [1,2] and the turbulent mixing zone width dependencies are also compared to the available data of experiments [3,4].

The single-point function of probability density is constructed basing on the processed results of direct numerical simulation.

References

1. Yanilkin Yu.V., Nikiforov V.V., Bondarenko Yu.A., Gubkov E.V., Zharova G.V., Statsenko V.P., Tarasov V.I. Two-parameter model and method for computations of turbulent mixing in 2D compressible flows. 5rd International Workshop on the Physics of compressible turbulent mixing, Stony Brook (USA), 1995.
2. Andronov V.A., Bakhrakh S.M., Meshkov E.E., Nikiforov V.V., Pevnitskiy A.V., Tolshmyakov A.I. Experimental investigation and numerical simulation of turbulent mixing in 1D flows. DAN SSSR, 1982, V.264, N 1, pp. 76-82.
3. Yu.A. Kucherenko, V.E. Neuvazhaev, A.P. Pylaev. Behaviour of gravitational turbulent mixing region under conditions leading to separation. 4rd International Workshop on the Physics of compressible turbulent mixing, Cambridge, England, 1993. pp.70-80.
4. Y.A. Kucherenko, A.P. Pylaev., S.I. Balabin et al. Experimental determination of the turbulized mixtures separation rate for different Atwood numbers. 6th International Workshop on the Physics of compressible turbulent mixing, Marseille, France, 1997. pp.274-281.

Self-similarity of flows induced by instabilities

Ye Zhou[1] & Timothy Clark[2]

DNT/AX Division
Lawrence Livermore National Laboratory
Zhou3@llnl.gov

Los Alamos National Laboratory
ttc@lanl.gov

Flows induced by instabilities are found in many engineering and astrophysical circumstances. Specifically, the instabilities induced by acceleration and shear (Rayleigh-Taylor, Richtmyer-Meshkov, and Kelvin-Helmholtz instabilities) have attracted much attention. While the initial linear, nonlinear, and transient processes are complicated, it is widely suspected that at late time the flow will relax toward a self-similar statistical state where the dominant length scale, i.e., the mixing-layer width, is growing as an algebraic function in time. For the Richtmyer-Meshkov mixing layer, analogies with weakly anisotropic turbulence suggest that both the bubble-side and spike-side widths of the mixing layer should evolve as power-law in time, with the same power-law exponent and virtual time origin for both sides. The analogy also bounds the power-law exponent between 2/7 and 1/2. The implication of full self-similarity of the Rayleigh-Taylor mixing layer and the Kelvin-Helmholtz shear layer are examined using a simplified group-theoretic analysis. The constraints on the behavior and evolution of these layers imposed by rigorous self-similarity are identified, and equations are constructed for the growth rate of these layers based on a total energy balance. This analysis does not prove that such flows will become self-similar. Rather, the analysis demonstrates the behaviors that would arise if these flows were to become fully self-similar.

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.

UCRL-ABS-201829

General characteristics of a mixing zone development in a direct simulations of hydrodynamics instabilities with a random phase regular multimode perturbations

Nikolai Zmitrenko[1], Vladimir Tishkin[1], Vladislav Rozanov[2], Roman Stepanov[2], Mikhail Anuchin[3] & Yury Yanilkin[4]

1. Institute of Mathematical Modelling of RAS,
Moscow, Russia
zmitrenko@imamod.ru

2. P.N. Lebedev Physical Institute of RAS,
Moscow, Russia
rozanov@sci.lebedev.ru

3. Russian Federal Nuclear Center – All-Russia Scientific Research Institute of Technical Physics,
Snezhinsk, Russia
m.g.anuchin@vniitf.ru

4. Russian Federal Nuclear Center – All-Russia Scientific Research Institute of Experimental Physics,
Sarov, Russia
yan@md08.vniief.ru

On the base of wide series of numerical simulations, fulfilled in the frame of ISTC project #1481, the detailed studies of mixing zone properties carried out. The general characteristics, such as a zone width, turbulent kinetic energy and mass of a heavy liquid in a zone, corresponding momentum and vorticity and so on, are analyzed. The simple relations between them are established. A particular attention is given to investigation of a dependence of such the characteristics on a random phase set in an initial perturbation. Such the analysis gives a base to develop a wavelet approach to predict zone width growth for the different situations.

The research is supported by ISTC, Project #1481.

Participants

Dr. Snezhana Abarzhi
Center for Turbulence Research
Stanford University
USA
snezha@summer8.stanford.edu

Dr. Florian Abeguile
CPHT
Ecole Polytechnique
Palaiseau
91128
France
abeguile@cpht.polytechnique.fr

Dr. Mark Anderson
Engineering Physics
UW- Madison
1500 Engineering Dr
Madison
WI 53706
USA
manderson@engr.wisc.edu

Prof. Malcolm Andrews
Mechanical Engineering
Texas A&M University
MS 3123
College Station
TX 77843
USA
mandrews@mengr.tamu.edu

Dr. Vadim Anisimov
Department of Experimental Physics
RFNC-VNIITF
Build. 13 Vasilev St.
Snezhinsk
Chelyabinsk region 456770
Russia
kucherenko@five.ch70.chel.su

Dr. Mikhail Anuchin
Scientific Theoretical Department 2 (NTO-2)
RFNC-VNIITF
P.O. Box 245
Snezhinsk
Chelyabinsk Region 456770
Russia
m.g.anuchin@vniitf.ru

Dr. Rufina Ardashova
Department of Experimental Physics
RFNC-VNIITF
Build. 13 Vasilev St.
Snezhinsk
Chelyabinsk region 456770
Russia
kucherenko@five.ch70.chel.su

Dr. Shimon Asida
Racah Ins. of Physics
Hebrew University of Jerusalem
Racah Ins. Of Physics; Givat -Ram; Hebrew University
Jerusalem
91904
Israel
sasida@phys.huji.ac.il

Mr. Andrew Aspden
Department of Applied Mathematics and Theoretical Physics
University of Cambridge
Wilberforce Road
Cambridge
Cambs. CB3 0WA
UK
a.j.aspden@damtp.cam.ac.uk
http://www.damtp.cam.ac.uk/user/lcd/

Mr. Sergey Baban
Scientific Theoretical Department 1 (NTO-1)
RFNC-VNIITF
P.O. Box 246
Snezhinsk
Chelyabinsk Region 456770
Russia
s.a.baban@vniitf.ru

Dr. Oleg Bakunin
Nuclear Fusion Inst., Theoretical Department
Russian Research Center Kurchatov Institute
sq. Kurchatova 1
Moscow
123182
Russia
oleg_bakunin@yahoo.com

Dr. Sergey Balabin
Department of Experimental Physics
RFNC-VNIITF
Build. 13 Vasilev St.
Snezhinsk
Chelyabinsk region 456770
Russia
kucherenko@five.ch70.chel.su

Mr. Chris Barton
Hydrodynamics
AWE
Building H27
Reading
Berkshire RG7 4PR
UK
chris.barton@awe.co.uk
http://www.awe.co.uk

Dr. Alexander Baryshnikov
Ioffe Physical_Technical Institute
194021 Ioffe Physical-Technical Institute; 26 Politechnicheskaya str., S.Petersburg, Russia
S.Petersburg
Russia
al.bar@mail.ioffe.ru

Mr. Kevin Bates
Department of Applied Mathematics and Theoretical Physics
University of Cambridge
Wilberforce Road
Cambridge
Cambs CB3 0WA
UK
k.r.bates@damtp.cam.ac.uk
http://www.damtp.cam.ac.uk/user/lcd/

Dr. Brent Blue
Lawrence Livermore National Laboratory
7000 East Avenue, L-021
Livermore
CA 94550
USA
blue3@llnl.gov

Dr. Stanislav Boldyrev
Department of Astronomy and Astrophysics
University of Chicago
5640 South Ellis Ave
Chicago
Illinois 60637
USA
boldyrev@uchicago.edu

Prof. Riccardo Bonazza
Engineering Physics
University of Wisconsin - Madison
1500 Engineering Drive
Madison
WI 53706
USA
bonazza@engr.wisc.edu
http://www.engr.wisc.edu/ep/faculty/bonazza_riccardo.html

Dr. Carine Boudesocque-Dubois
Direction des Applications Militaires
Commissariat à l Énergie Atomique
CEA/DAM-Ile de France; B.P. 12
Bruyères-le-Chatel
91680
France
carine.boudesocque@cea.fr

Dr. Baolian Cheng
Applied Physics
Los Alamos National Laboratory
T086
Los Alamos
New Mexico 87544
USA
bcheng@lanl.gov

Dr. Andrew Cook
Lawrence Livermore National Laboratory
7000 East Avenue, L-022
Livermore
CA 94550
USA
cook33@llnl.gov

Dr. Stuart Dalziel
DAMTP
University of Cambridge
Wilberforce Road
Cambridge
Cambs CB3 0WA
UK
s.dalziel@damtp.cam.ac.uk
http://www.damtp.cam.ac.uk/lab/

Dr. Ralf Deiterding
Center for Advanced Computing Research
California Institute of Technology
1200 East California Blvd., MC 158-79
Pasadena
CA 91125
USA
ralf@cacr.caltech.edu
http://www.cacr.caltech.edu/~ralf

Prof. Vladimir Demchenko
Computational numerical mathematics
Moscow Institute of Physics and Technology
(State University)
B.9, Institutsky lane, Dolgoprudny
Dolgoprudny
Moscow Region 141700
Russia
vdem@cnm.op.mipt.ru

Dr. Guy Dimonte
x-division
Los Alamos National Laboratory
Mail stop T-086
Los Alamos
New Mexico 87545
USA
dimonte@lanl.gov

Dr. R Paul Drake
Atmospheric Oceanic & Space Science
University of Michigan
2455 Hayward St.
Ann Arbor
MI 48109
USA
rpdrake@umich.edu
http://www.sprl.umich.edu/research_project_site
s/LPE/index.html

Prof. Dimitris Drikakis
Aerospace Sciences
Cranfield University
School of Engineering
Cranfield
Bedfordshire MK43 0AL
UK
d.drikakis@cranfield.ac.uk
http://www.cranfield.ac.uk/~ei2985

Mr. Yonatan Elbaz
Physics
NRCN & BGU
P.O.Box 9001
Beer Sheva
Israel
yelb77@hotmail.com

Dr. James Fincke
Plasma Physics
Los Alamos National Laboratory
PO Box 1663; MS # E526
Los Alamos
New Mexico 87545
USA
jfincke@lanl.gov

Dr. Serge Gauthier
DCSA
CEA/Bruyères-le-Châtel
B.P. 12
Bruyères-le-Châtel
91680
France
serge.gauthier@cea.fr

Mr. Jerome Giordano
Mécanique Energétique
Université de Provence - Polytech Marseille -
IUSTI - CNRS
Technopôle de Chateau-Gombert; 5 rue Enrico
Fermi
Marseille
13013
France
jerome.giordano@polytech.univ-mrs.fr

Dr. James Glimm
Applied Mathematics and Statistics
SUNY at Stony Brook
Math Bldg. Rm. P-138A
Stony Brook
NY 11794-3600
USA
glimm@ams.sunysb.edu
http://cc.sunysb.edu/CEAS/amsweb.nsf

Dr. Bruce Goodwin
Defense and Nuclear Technologies
Lawrence Livermore National Laboratory
PO Box 808; L-160
Livermore
California 94551
USA
btgoodwin@llnl.gov

Dr. Jeff Greenough
AX-Division
Lawrence Livermore National Laboratory
PO Box 808; L-031; 7000 East Avenue
Livermore
California 94550
USA
greenough1@llnl.gov

Dr. Brian Grieves
AWE
Aldermaston
Reading
Berkshire RG1 4PR
UK
brian.grieves@awe.co.uk

Dr. Fernando Grinstein
Institute of Geophysics and Planetary Physics
Los Alamos National Laboratory
MS C305
Los Alamos
NM 87545
USA
fgrinstein@lanl.gov

Mr. Marco Hahn
School of Engineering
Cranfield University
Areospace Sciences Building 83
Cranfield
Bedforshire MK43 0AL
UK
m.hahn@cranfield.ac.uk

Ms. Alison Hart
Department of Applied Mathematics and
Theoretical Physics
University of Cambridge
Wilberforce Road
Cambridge
Cambs. CB3 0WA
UK
a.c.hart@damtp.cam.ac.uk
http://www.damtp.cam.ac.uk/lab/

Dr. David Hill
Aeronautics
California Institute of Technology
1200 E. California Blvd, Mail Code 205-45
Pasadena
California 91125
USA
dh@galcit.caltech.edu

Mr. David Holder
Hydrodynamics
AWE
Building H27
Reading
Berkshire RG7 4PR
UK
david.holder@awe.co.uk
http://www.awe.co.uk

Dr. Joanne Holford
BP Institute
University of Cambridge
Madingley Rise
Cambridge
Cambs. CB3 0EZ
UK
joanne@bpi.cam.ac.uk
http://www.bpi.cam.ac.uk/joanne/

Dr. Richard Holmes
Group X-1
Los Alamos National Laboratory
MS B259
Los Alamos
NM 87545
USA
holmes@lanl.gov

Dr. Colin Horsfield
Plasma Physics Department
AWE
Building E1.1, Aldermaston
Reading
Berkshire RG7 4PR
UK
c.j.horsfield@awe.co.uk
http://www.awe.co.uk

Dr. Lazhar Houas
Mécanique Energétique
Université de Provence - Polytech Marseille - IUSTI - CNRS
Technopôle de Chateau-Gombert; 5 rue Enrico Fermi
Marseille
13013
France
lazhar.houas@polytech.univ-mrs.fr

Dr. Robert Hueckstaedt
Applied Physics
Los Alamos National Laboratory
LANL, X-2; P.O. Box 1663; MS T085
Los Alamos
New Mexico 87545
USA
rmhx@lanl.gov

Dr. Nail Inogamov
Landau Institute for Theoretical Physics
Institutskii Prospekt, 12
Chernogolovka
Moscow Region 142432
Russia
nail@landau.ac.ru

Prof. Jeffrey Jacobs
Aerospace and Mechanical Engineering
University of Arizona
AME Department; 1130 N Mountain Ave
Tucson
Arizona 85721
USA
jwjacobs@u.arizona.edu

Dr. Dan Klem
Lawrence Livermore National Laboratory
7000 East Avenue, L-022
Livermore
CA 94550
USA
klem1@llnl.gov

Mr. Alexander Kozlovskih
Scientific Theoretical Department 1 (NTO-1)
RFNC-VNIITF
P.O. Box 247
Snezhinsk
Chelyabinsk Region 456770
Russia
a.s.kozlovskih@vniitf.ru

Dr. Oleg Kozyrev
Scientific Theoretical Department 2 (NTO-2)
RFNC-VNIITF
P.O. Box 248
Snezhinsk
Chelyabinsk Region 456770
Russia
o.m.kozyrev@vniitf.ru

Dr. Vitaliy Krivets
Aerospace and Mechanical Egineering
University of Arizona
1130 N.Mountain
Tucson
Arizona 85721-00119
USA
vkrivets@email.arizona.edu

Dr. Yury Kucherenko
Department of Experimental Physics
RFNC-VNIITF
Build. 13 Vasilev St.
Snezhinsk
Chelyabinsk region 456770
Russia
kucherenko@five.ch70.chel.su

George Kyrala
Los Alamos National Laboratory,
P.O.Box 1663, MS E-526
Los Alamos
NM 87544
USA
kyrala@lanl.gov

Mr. Marco Latini
Applied and Computational Mathematics
California Institute of Technology
Caltech 217-50
Pasadena
CA 91125
USA
mlatini@caltech.edu

Mr. Guillaume Layes
Mécanique Energétique
Université de Provence - Polytech Marseille - IUSTI - CNRS
Technopôle de Chateau-Gombert; 5 rue Enrico Fermi
Marseille
13013
France
guillaume.layes@polytech.univ-mrs.fr

Mr. Benjamin Le Creurer
Direction des Applications Militaires
Commissariat à l Énergie Atomique
CEA/DAM-Ile de France; B.P. 12
Bruyères-le-Chatel
91680
France
benjamin.le-creurer@cea.fr

Prof. Ivan Lebo
Faculty of Cybernetics
Technical University-MIREA
prospect Vernadskogo, 78
Moscow
Moscow 119684
Russia
lebo@mirea.ru

Dr. Michel Legrand
DAM/DIF
Commissariat à l Énergie Atomique
B.P. 12
Bruyères le Chatel
91680
France
michel.legrand@cea.fr

Dr. David Leppinen
Department of Applied Mathematics and Theoretical Physics
University of Cambridge
Wilberforce Road
Cambridge
Cambs. CB3 0WA
UK
d.m.leppinen@damtp.cam.ac.uk
http://www.damtp.cam.ac.uk/lab/

Kedem Levi
Physics
NRCN & BGU
P.O.Box 9001
Beer Sheva
Israel
kedlevy@hotmail.com

Dr. Mary Jane Lindquist (nee Graham)
DNT/B Division
Lawrence Livermore National Laboratory
P.O. Box 808, 097
Livermore
California 94550
USA
lindquist8@llnl.gov

Dr. Antoine Llor
DPg
Commissariat à l'Energie Atomique
31-31 rue de la Fédération
PARIS CEDEX 15
75752
France
antoine.llor@cea.fr

Dr. Trent Mattner
School of Mathematical Sciences
The University of Adelaide
Adelaide
SA 5005
Australia
tmattner@maths.adelaide.edu.au

Dr. Juan Pedro Mellado
Mechanical and Aerospace Engineering
University of California
9500 Gilman Drive
La Jolla
California 92093
USA
mellado@mae.ucsd.edu

Dr. Evgeny Meshkov
Rosatom
VNIIEF
Shevchenko street 42, 24
Sarov
Nizhny Novgorod 607190
Russia
meshkov@sarfti.sarov.ru

Dr. Karnig Mikaelian
B-Division
Lawrence Livermore National Laboratory
L-97; 7000 East Avenue
Livermore
California 94550-9234
USA
mikaelian1@llnl.gov

Dr. Aaron Miles
Lawrence Livermore National Laboratory
7000 East Avenue, L-021
Livermore
CA 94550
USA
miles15@llnl.gov

Dr. Paul Miller
Lawrence Livermore National Laboratory
7000 East Avenue, L-022
Livermore
CA 94550
USA
miller3@llnl.gov

Dr. Jose Milovich
AX-Division
Lawrence Livermore National Laboratory
PO Box 808; L-031
Livermore
California 94550
USA
milovich1@llnl.gov

Dr. Masakatsu Murakami
Institute of Laser Engineering
Osaka University
Yamada-Oka 2-6, suita
Osaka
565-0871
Japan
mym@ile.osaka-u.ac.jp

Prof. Vladimir Neuvazhaev
Scientific Theoretical Department 2 (NTO-2)
RFNC-VNIITF
P.O. Box 249
Snezhinsk
Chelyabinsk Region 456770
Russia
v.e.neuvazhaev@vniitf.ru

Dr. Nikolay Nevmerzhitsky
Rosatom
VNIIEF
Moozrukov street 17, 165
Sarov
Nizhny Novgorod 607190
Russia
root@gdd.vniief.ru

Dr. Nikos Nikiforakis
Department of Applied Mathematics and
Theoretical Physics
University of Cambridge
Wilberforce Road
Cambridge
Cambs. CB3 0WA
UK
n.nikiforakis@damtp.cam.ac.uk
http://www.damtp.cam.ac.uk/user/lcd/

Prof. Katsunobu Nishihara
Institute of Laser Engineering
Osaka University
2-6, Yamada-oka
Suita
Osaka 565-0871
Japan
nishihara@ile.osaka-u.ac.jp
http://www.ile.osaka-u.ac.jp/

Dr. Anton Nuzhnyy
Laser Plasma Theory
P.N. Lebedev Physical Institute
Leninsky prosp. 53
Moscow
119991
Russia
nuzhny@mail333.com

Mr. Kenneth Parker
Plasma Physics Department
AWE
Building E3.1, Aldermaston
Reading
Berkshire RG7 4PR
UK
kparker@awe.co.uk
http://www.awe.co.uk

Mrs. Olivier Poujade
CEA-Bruyeres
CEA/DAM-Ile de France; BP12
Bruyeres-le-Chatel
91680
France
olivier.poujade@cea.fr

Dr. Dale Pullin
Aeronautics
California Institute of Technology
Mail Stop 105-50; 1200 E. California Blvd.
Pasadena
CA 91125
USA
dale@galcit.caltech.edu

Dr. Anatoly Pylaev
Department of Experimental Physics
RFNC-VNIITF
Build. 13 Vasilev St.
Snezhinsk
Chelyabinsk region 456770
Russia
kucherenko@five.ch70.chel.su

Jose Redondo
Universitat Politecnica de Catalunya
Barcelona
Spain
redondo@fa.upc.es

Dr. François Renaud
Direction des Applications Militaires
Commissariat à l Énergie Atomique
CEA/DAM-Ile de France; B.P. 12
Bruyères-le-Chatel
91680
France
francois.renaud@cea.fr

Dr. William Rider
CCS-2
Los Alamos National Laboratory
MS D413
Los Alamos
New Mexico 87545
USA
rider@lanl.gov

Dr. Paul Rightley
DX-3
Los Alamos National Laboratory
MS P940
Los Alamos
NM 87545
USA
pright@lanl.gov

Dr. Harry Robey
Lawrence Livermore National Laboratory
7000 East Avenue, L-021
Livermore
CA 94550
USA
robey1@llnl.gov

Ms. Paula Rosen
PPD
AWE
Building E3; Aldermaston
Reading
Berkshire RG7 4PR
UK
paula.rosen@awe.co.uk

Mr. Steve Rothman
Plasma Physics Department
AWE
Building E1.1, Aldermaston
Reading
Berkshire RG7 4PR
UK
steve.rothman@awe.co.uk
http://www.awe.co.uk

Prof. Vladislav Rozanov
Laser Plasma Theory
P.N. Lebedev Physical Institute
Leninsky prosp. 53
Moscow
119991
Russia
rozanov@sci.lebedev.ru

Dr. Oleg Schilling
Lawrence Livermore National Laboratory
7000 East Avenue, L-023
Livermore
CA 94550
USA
schilling1@llnl.gov

Dr. Oleg Shestachenko
Department of Experimental Physics
RFNC-VNIITF
Build. 13 Vasilev St.
Snezhinsk
Chelyabinsk region 456770
Russia
kucherenko@five.ch70.chel.su

Prof. Dov Shvarts
Physics
NRCN & BGU
P.O.Box 9001
Beer Sheva
Israel
schwartz@bgumail.bgu.ac.il

Dr. Eduard Son
Physical Mechanics
MIPT
6 Tverskaya app.272 Moscow Russia
Moscow
103009
Russia
son@son.rector.mipt.ru
http://www.mipt.ru

Dr. Anna Stadnik
Rosatom
VNIIEF
Shevchenko street 22, 24
Sarov
Nizhny Novgorod 607190
Russia
a.l.stadnik@md08.vniief.ru

Dr. Roman Stepanov
Laser Plasma Theory
P.N. Lebedev Physical Institute
Leninsky prosp. 53
Moscow
119991
Russia
roman_an@mail.ru

Prof. Kazuyoshi Takayama
Interdisciplinary Shock Wave Research Laboratory
Tohoku University
2-1-1 Katahira Aoba
Sedai
Miyagi 980-8577
Japan
takayama@rainbow.ifs.tohoku.ac.jp
http://ceres.ifs.tohoku.ac.jp/~coe/

Mark Taylor
AWE
Aldermaston
Reading
Berkshire RG7 4PR
UK
mark.j.taylor@awe.co.uk

Prof. Vladimir Tishkin
Numerical Methods of Continuous Media Mechanics
Institute of Mathematical Modeling Russian Academy of Sciences
4A Miusskaya Square
Moscow
Russia 125047
Russia
tishkin@imamod.ru
http://www.imamod.ru

Dr. Nathalie Toque
LATT/DFA
CNRS
14 Avenue Edouard Belin
Toulouse
31400
France
toque@ast.obs-mip.fr
http://webast.ast.obs-mip.fr

Dr. Aleksandr Tyaktev
Department of Experimental Physics
RFNC-VNIITF
Build. 13 Vasilev St.
Snezhinsk
Chelyabinsk region 456770
Russia
kucherenko@five.ch70.chel.su

Dr. Marc Vandenboomgaerde
Commissariat à l'Energie Atomique
Boîte Postale 12
Bruyères-Le-Châtel
91680
France
marc.vandenboomgaerde@cea.fr

Dr. Erik Vold
Applied Physics Division, X-3
Los Alamos National Laboratory
MS F644
Los Alamos
New Mexico 87545
USA
elv@lanl.gov

Dr. Vladimir Volkov
Scientific Theoretical Department 2 (NTO-2)
RFNC-VNIITF
P.O. Box 250
Snezhinsk
Chelyabinsk Region 456770
Russia
v.i.volkov@vniitf.ru

Mr. Anthony Weatherhead
DPD
AWE
Aldermaston
Reading
Berkshire RG7 4PR
UK
anthony.weatherhead@awe.co.uk

Dr. Stephen Weber
Lawrence Livermore National Laboratory
7000 East Avenue, L-016
Livermore
CA 94550
USA
weber8@llnl.gov

Dr. Vincent Weirs
Astronomy & Astrophysics
University of Chicago
5640 S Ellis Avenue, RI-466
Chicago
IL 60637
USA
weirs@flash.uchicago.edu

Dr. Bernhard Wilde
X-2
Los Alamos National Laboratory
MS T087
Los Alamos
NM 87544
USA
bhw@lanl.gov

Dr. Robin Williams
Design Physics
AWE
Building E3.1, Aldermaston
Aldermaston
Berkshire RG7 4PR
UK
robin.williams@awe.co.uk

Dr. Douglas Wilson
X-2, Thermonuclear Applications
Los Alamos National Laboratory
MS T085; P.O.Box 1663
Los Alamos
New Mexico 87545
USA
dcw@lanl.gov

Dr. Juan Gustavo Wouchuk
Industrial Engineering
University of Castilla La Mancha
Campus Universitario s/n
Ciudad Real
Ciudad Real 13071
Spain
gwouchuk@ind-cr.uclm.es
http://www.uclm.es

Prof. Yury Yanilkin
Rosatom
VNIIEF
Kuibyshev street 20, 55
Sarov
Nizhny Novgorod 607190
Russia
yan@md08.vniief.ru

Mr. David Youngs
Design Physics
AWE
Building E3, Aldermaston
Reading
Berkshire RG7 4PR
UK
David.Youngs@awe.co.uk
http://www.awe.co.uk

Dr. Vadim Zhmaylo
Rosatom
VNIIEF
Octyabr. prospect , 5, 6 .
Sarov
Nizhny Novgorod 607190
Russia
vaz@vniief.ru

Dr. Ye Zhou
Lawrence Livermore National Laboratory
7000 East Avenue, L-023
Livermore
CA 94550
USA
zhou3@llnl.gov

Dr. Nikolai Zmitrenko
Mathematical Modeling of Nonlinear
Phenomena
Institute of Mathematical Modeling Russian
Academy of Sciences
4A Miusskaya Square
Moscow
Russia 125047
Russia
zmitrenko@imamod.ru
http://www.imamod.ru

Author Index