Recipient:
Dr. Gary M. Johnson
Sc-31
U. S. Department of Energy (SC-64)
19901 Germantown, MD 20874-1290

DOE ID: #DE-FG02-90ER25084

FINAL REPORT

Multiscale Stochastic Simulation and Modeling

Co-Principal Investigators:
James Glimm and Xiaolin Li
University at Stony Brook

Reporting Period:
January 1, 1990 – December 14, 2005

Recipient:
Research Foundation
University at Stony Brook
Stony Brook, NY 11794-3366

Unexpended Funds: $0

1 Findings and Significance

We emphasize results from recent years.

Acceleration driven instabilities of fluid mixing layers include the classical cases of Rayleigh-Taylor (RT) instability, driven by a steady acceleration and Richtmyer-Meshkov (RM) instability, driven by an impulsive acceleration. References to this subject, which has attracted a high level of interest over many decades, include [12, 128]; more recent references can be traced from the series [32] and earlier volumes in this series.

Our program starts with high resolution methods of numerical simulation of two (or more) distinct fluids, continues with analytic analysis of these solutions, and the derivation of averaged equations. A striking achievement has been the systematic agreement we obtained between simulation and experiment by using a high resolution numerical method and improved physical modeling, with surface tension. Our study is accompanied by analysis using stochastic modeling and averaged equations for the multiphase problem. We have quantified the error and uncertainty using statistical modeling methods.

1.1 Advanced Numerical Methods

The front tracking method provides the high resolution we require. It has been our major tool for large scale computation. This method has was proved in comparison [43] to be superior to other interface methods such as the level set method and the volume of fluid method.

1.1.1 Local Grid Based Tracking

In grid free tracking, the tracked front is a triangulated surface, propagating freely through a rectangular volume filling mesh. In grid based tracking, the front is regularized, or reconstructed, at each time step. After propagation, the points of intersection of the front with all grid cell edges are determined. Assuming at most one such intersection for each grid cell edge, the complete interface is reconstructed in a simple manner from these intersections.

Grid based tracking is very robust. (It is similar to the level set in this sense, the presentation of the interface in both methods being derived from computer science graphics routines). However, grid based tracking is inaccurate, as is the level set method. Grid based tracking, the level set, and untracked simulations, which also determine an interface from grid based information, all have a form of interface smoothing which resembles surface tension.

Local grid based tracking [43] combines the two tracking algorithms, preserving the advantages of each. This algorithm relies on the more accurate grid free tracking unless there is a bifurcation. The algorithm is robust as the problems with the grid free propagation occur only with bifurcations of the interface. When a bifurcation occurs, a small box is constructed around it. Grid based propagation is used inside the box. The grid free surface triangulation near the box has to be rejoined to the reconstructed grid inside the box in a construction which also has a grid based flavor. The result is favorable: the accuracy of grid free tracking and the robustness of grid based tracking are both preserved.

We carried out a systematic study [43] of this new algorithm in comparison to other interface methods (level sets, volume of fluids), and found that locally grid based front tracking is the best of all methods tested.

1.1.2 Improved Physical Models

Front Tracking offers a very convenient framework to support surface based physics. Normal vectors and curvature tensors are supported by the code. Surface tension forces a pressure jump at the interface proportional to the surface curvature. In the front tracking algorithm, it introduces a modification to the Riemann solver, used in the normal propagation of the front.

To compute with physical mass diffusion, we first eliminate numerical mass diffusion, with the use of Front Tracking. The second step is to add limited amounts of mass diffusion back into the calculation, on the basis of prescribed values for the physical mass diffusion constant. Our algorithm computes the required diffusion per time step with the use of the analytic solution of the diffusion equation.

1.1.3 FronTier-Lite

We have extracted the purely geometrical (physics independent) parts of the front tracking code. This code is modular and can be called as an external library in other codes. It is released for public distribution. We have built a user-friendly interface for the interaction of the front tracking library with other scientific code with the dynamic interface as part of its scientific description. This library package can be accessed through the internet at the site:

`http://www.ams.sunysb.edu/FTdownload`

1.1.4 Simulation of Rayleigh-Taylor Instability

A signal success of our program has been the simulation of 3D Rayleigh-Taylor instability with results in agreement with experiment. Our improved front tracking method was combined with improved accuracy of physical

Experiment Simulation	Comment	α
Five experiments	Immiscible [124, 129]	0.060–0.073
FronTier	Immiscible [55]	0.062
TVD	Ideal Untracked [53]	0.035
FronTier	Ideal	0.09

Table 1: Mixing rates compared: FronTier simulation compared to experiment and contrasted to untracked (TVD) and ideal fluid FronTier simulations.

modeling for this purpose [55]. We compare simulation and experiment in terms of the growth rate of the bubble side of the mixing layer, defined by the dimensionless constant α in the equation

$$h = \alpha A g t^2 \tag{1}$$

for the bubble (light fluid) penetration h in terms of the Atwood number A, gravity g and time t. The values of $\alpha = \alpha_b$ are given in Table 1. Other statistical measures of the mixing rate (such as the bubble width) were also recorded and also agree with experiment.

1.2 Applied Mathematical Modeling

We derived the two-phase flow equations by averaging the microscopic dynamics. Let the function X_k be the phase indicator for material k ($k = 1, 2$); *i.e.*, $X_k(t, \mathbf{x})$ equals 1 if position $\mathbf{x}$ is in fluid k at time t, zero otherwise. We average the advection law [42] for X_k,

$$\frac{\partial X_k}{\partial t} + v_{\rm int} \cdot \nabla X_k = 0 \ . \tag{2}$$

Here $v_{\rm int}$ is the microphysical velocity evaluated at the interface (the velocity component normal to the boundary ∂X_k is continuous so that $v_{\rm int}\dot{\nabla} X_k$ is well defined). We also average the microscopic conservation equations

$$\frac{\partial \rho}{\partial t} + \nabla \cdot \rho \mathbf{v} = 0 \ , \tag{3}$$

$$\frac{\partial \rho \mathbf{v}}{\partial t} + \nabla \cdot \rho \mathbf{v} \mathbf{v} = -\nabla p + \rho g \ , \tag{4}$$

$$\frac{\partial \rho E}{\partial t} + \nabla \cdot \rho \mathbf{v} E = -\nabla \cdot p \mathbf{v} + \rho \mathbf{v} g \ . \tag{5}$$

Here the dependent variables $\mathbf{v}$, ρ, p, g, and E denote, respectively, the velocity, density, pressure, gravity and total energy with $E = e + \mathbf{v}^2/2$ and e the internal energy.

We denoted the ensemble average $\langle \cdot \rangle$. The average $\langle X_k \rangle$ of the indicator function X_k is denoted β_k. The quantities ρ_k and p_k are, respectively, phase averages of the density ρ and pressure p while the quantities v_k and E_k are phase mass-weighted averages of the fluid z-velocity v_z and total energy E:

$$\rho_k = \frac{\langle X_k \rho \rangle}{\langle X_k \rangle} \ , \quad p_k = \frac{\langle X_k p \rangle}{\langle X_k \rangle} \ , \quad v_k = \frac{\langle X_k \rho v_z \rangle}{\langle X_k \rho \rangle} \ , \quad E_k = \frac{\langle X_k \rho E \rangle}{\langle X_k \rho \rangle} \ . \tag{6}$$

Applying the ensemble average to Eqs. (2)-(5), we obtain the one-dimensional two-pressure two-phase flow averaged equations. We follow [42, 15, 19, 125] to obtain

$$\frac{\partial \beta_k}{\partial t} + \langle \mathbf{v} \cdot \nabla X_k \rangle = 0 \ , \tag{7}$$

$$\frac{\partial \beta_k \rho_k}{\partial t} + \frac{\partial \beta_k \rho_k v_k}{\partial z} = 0 \ , \tag{8}$$

$$\frac{\partial \beta_k \rho_k v_k}{\partial t} + \frac{\partial \beta_k \rho_k v_k^2}{\partial z} + \frac{\partial (\beta_k p_k)}{\partial z} = \left\langle p \frac{\partial X_k}{\partial z} \right\rangle + \beta_k \rho_k g \ , \tag{9}$$

$$\frac{\partial \beta_k \rho_k E_k}{\partial t} + \frac{\partial [\beta_k v_k (\rho_k E_k + p_k)]}{\partial z} = \langle p \mathbf{v} \cdot \nabla X_k \rangle + \beta_k \rho_k v_k g \ . \tag{10}$$

In [79] the interface velocity v^*, where $v^* \partial \beta_k / \partial z =< v \cdot X_k >$, has been derived exactly from (7) and (8) independently of any closure assumption.

Theorem The interface quantity v^* has the exact formula

$$v^* = \frac{\beta_1 \left[\frac{\partial v_1}{\partial z} + \frac{D_1 \rho_1}{\rho_1 Dt} \right] v_2 + \beta_2 \left[\frac{\partial v_2}{\partial z} + \frac{D_2 \rho_2}{\rho_2 Dt} \right] v_1}{\beta_1 \left[\frac{\partial v_1}{\partial z} + \frac{D_1 \rho_1}{\rho_1 Dt} \right] + \beta_2 \left[\frac{\partial v_2}{\partial z} + \frac{D_2 \rho_2}{\rho_2 Dt} \right]} \equiv \mu_1^v v_2 + \mu_2^v v_1 \ , \tag{11}$$

$$\mu_k^v = \frac{\beta_k}{\beta_k + d_k^v \beta_{k'}} \ , \quad d_k^v(z,t) = \left[\frac{\partial v_{k'}}{\partial z} + \frac{D_{k'} \rho_k{}'}{\rho_{k'} Dt} \right] / \left[\frac{\partial v_k}{\partial z} + \frac{D_k \rho_k}{\rho_k Dt} \right] \ . \tag{12}$$

The factor $d_k^v(z,t)$ in (12) is a ratio of logarithmic rates of volume creation for the two phases. A closure condition of spatial homogeneity assumes

$$d_k^v(t) = \left[\int_{Z_k}^{Z_{k'}} \frac{\partial v_{k'}}{\partial z} + \frac{D_{k'\rho_k{}'}}{\rho_{k'} Dt} \, dz \right] / \left[\int_{Z_k}^{Z_{k'}} \frac{\partial v_k}{\partial z} + \frac{D_k \rho_k}{\rho_k Dt} \, dz \right] \ . \tag{13}$$

The identity (13) states that the relative extent of volume creation for the two fluid species is independent of the spatial location in the mixing zone. In the incompressible case, this is seen clearly from the closed form solution

$$d_k^v(t) = \left| \frac{V_{k'}}{V_k} \right| \ . \tag{14}$$

The p^* closure is presented in [79] following related ideas. Closed form incompressible solutions are given in [104], with extensions to an arbitrary number n of fluid layers in [26].

1.3 Stochastic Methods to Quantify Uncertainty

The need for computer assisted decision making is driven by two related factors. The first is the importance of complex scientific/technical decisions, such as those related to global warming, for which controlled experiments are not feasible. The second is the need for rapid or timely decisions, using incomplete information, such as in shortening the time to market of a product design cycle, mandating a reduction of the role of the human in the loop.

The central issue considered here is an accurate assessment of errors in numerical simulations [77]. Uncertainty quantification (UQ) can be viewed as the process of adding error bars to a simulation prediction. The error bars refer to all sources of uncertainty in the prediction, including data, physics and numerical modeling error. The requirement for UQ comes from the increasing use of simulation model based predictions to guide decision making. In this sense, the need for UQ is a natural consequence of simulation's attainment of a status parallel to that of experiment and theory. Our approach to uncertainty quantification uses a Bayesian framework. Specifically the Bayesian likelihood is (up to normalization) a probability, which specifies the probability of occurrence of an error of any given size. Our approach is to use solution error models as defining one contribution to this likelihood. We provide a scientific basis for the probabilities associated with numerical solution errors.

We have studied UQ for petroleum reservoir modeling [78, 113] and for shock physics simulations [119, 63, 64], with a focus on statistical analysis of errors in numerical solutions.

For chaotic interfacial mixing, the central UQ problem is to define the solution errors for chaotic flow regimes, since the chaotic simulations do not converge in a pointwise sense, but rather add new complexity with each new level of mesh refinement. See, for example Fig. 1. The solution is to look for convergence in averaged quantities, *i.e.,* the statistical moments, and the averages which define them.

The fine scale raw data is averaged, producing coarser data, which is subject to the normal tests of convergence and order of convergence studies, and which may satisfy its own averaged equations. Thus the problem is very much akin to turbulence modeling, which achieves repeatability only by

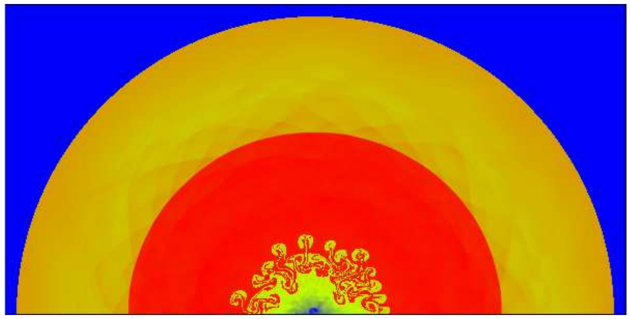

Figure 1: Density plot for a spherical implosion simulation with a perturbed interface. The outer orange-blue boundary is the edge of the computational domain. The red-orange circular boundary is an outgoing reflected shock and the chaotic inner interface is the object of study. The grid size is 800×1600.

use of averaged quantities or statistical descriptions of fluctuating quantities. Intrinsic variation, of importance in this study, is analyzed as statistical fluctuations, and these converge not pointwise, but in their statistical character, *i.e.* their means, variance and possible higher moments. See [138, 47]. The main conclusion of [138] is that convergence is very spotty, and depends on how it is defined. Different behavior is observed in the singly and doubly shocked material, in the single and the mixed phase material, and in the region near the origin, where circular waves give rise to transient singular pressures at the origin. In some cases, ensemble averages, spatial averages, and extremely fine meshes are needed to observe convergence, which may be as low as half order or marginal in Δx.

1.4 Publications Resulting from DOE Support

The publications (listed in the references section), supported from the completed grant were:

- 1991: [6, 33, 51, 58, 57, 62, 90, 97, 105, 109, 111]

- 1992: [16, 34, 36, 50, 52, 91, 94, 95, 139]
- 1993: [11, 17, 37, 39, 59, 96, 98, 115, 134]
- 1994: [5]
- 1995: [3, 28, 29, 60, 135]
- 1996: [10, 14, 13, 18, 61, 69, 99, 100, 121, 122, 130];
- 1997: [8, 30, 31, 84, 101, 106, 117]
- 1998: [4, 67, 82, 103, 102, 107, 142]
- 1999: [22, 38, 70, 104, 108, 110, 133]
- 2000: [68, 71, 75, 114]
- 2001: [21, 23, 66, 74, 76, 79, 89, 118, 83, 132];
- 2002: [24, 25, 72, 40, 41, 56, 65, 87, 86, 113, 73, 85, 9];
- 2003: [1, 2, 20, 45, 46, 54, 77, 80, 88, 92, 113, 35, 120, 126, 131, 143];
- 2004: [47, 48, 63, 119, 81, 78, 93, 116];
- 2005: [26, 53, 64, 27, 112];
- In press and submitted: [7, 43, 44, 49, 55, 137, 138, 123, 127, 136, 138, 137, 140, 141].

2 References

[1] S. I. Abarzhi, J. Glimm, and An-Der Lin. Rayleigh-Taylor instability for fluids with a finite density contrast. *Phys. Fluids*, 15:2190–2197, 2003.

[2] S. I. Abarzhi, J. Glimm, and K. Nishihara. Rayleigh-Taylor instability and Richtmyer-Meshkov instabilities for fluids with a finite density contrast. *Phys. Lett. A*, 11:1–7, 2003.

[3] L. An, J. Glimm, D. H. Sharp, and Q. Zhang. Scale up of flow in porous media. In A. Burgeat, C. Carasso, S. Luckhaus, and A. Mikelic, editors, *Mathematical Modeling of Flow Through Porous Media*, pages 26–44. World Scientific, 1995.

[4] J. Asvestas, B. Bielefeld, Y. Deng, J. Glimm, S. R. Simanca, and F. Tangerman. Electromagnetic scattering from large cavities: Iterative methods. *Communications in Applied Analysis*, 2:37–48, 1998.

[5] J. Asvestas, B. Bielefeld, Y. Deng, J. Glimm, and F. Tangerman. Boundary integral methods applied to electromagnetic scattering problems on parallel processors. *Proc. Amer. Math. Soc.*, 122:719–726, 1994.

[6] D. Besnard, J. Glimm, J. F. Haas, R. M. Rauenzahn, V. Rupert, and D. Youngs. Numerical simulation of 2D shock-tube multimaterial flow. In *Proceedings of Third International Workshop on The Physics of Compressible Turbulent Mixing at Royaumont France*. 1991.

[7] W. Bo, B. Cheng, J. Du, B. Fix, E. George, J. Glimm, J. Grove, X. Jia, H. Jin, H. Lee, Y. Li, X. Li, X. Liu, D. H. Sharp, L. Wu, and Yan Yu. Recent progress in the stochastic analysis of turbulent mixing. *Contemporary Mathematics*, 2005. Submitted. Stony University Preprint Number SUNYSB-AMS-05-18, Los Alamos National Laboratory LAUR Number LAUR-05-7102.

[8] B. Boston, J. Glimm, J. W. Grove, R. Holmes, and Q. Zhang. Multiscale structure for hyperbolic waves. *Studies in Advanced Mathematics*, 3:1–9, 1997.

[9] D. Brown, L. Freitag, and J. Glimm. Creating interoperable meshing and discretization software: The terascale simulation tools and technology center. In Bharat Soni, editor, *Proceedings of the 8th International Conference on Numerical Grid Generation in Computational Field Simulations, June 2-6, 2002, Honolulu Hawaii*. 2002.

[10] G. Campbell, Y. Deng, J. Glimm, Y. Wang, Q. Yu, M. Eisenberg, and A. Grollman. Analysis and prediction of protein binding on DNA pattern recognition of hydrogen bonds. *J. Comp. Chemistry*, 17:1712–1725, 1996.

[11] G. Campbell, Y. Deng, J. Glimm, and Q. Yu. Analysis and prediction of protein binding on dna: pattern recognition of hydrogen bonds. Mardi gras conference on computational science, Louisiana State University, 1993.

[12] S. Chandrasekhar. *Hydrodynamic and Hydromagnetic Stability*. Oxford University Press, Oxford, 1961.

[13] G.-Q. Chen and J. Glimm. Global solutions to the compressible Euler equations with geometrical structure. *Commun. Math. Phys.*, 180:153–193, 1996.

[14] G.-Q. Chen and J. Glimm. Global solutions to the cylindrically symmetric rotating motion of isentropic gases. *ZAMP*, 47:353–372, 1996.

[15] Y. Chen. *Two Phase Flow Analysis of Turbulent Mixing in the Rayleigh-Taylor Instability*. PhD thesis, University at Stony Brook, 1995.

[16] Y. Chen, Y. Deng, J. Glimm, and G. Li. Parallel interface methods for multi-phase flow problems on i PSC/860. In *Intel Supercomputer Systems Conference Proceedings: Technology Focus Conference*, pages 377–391. 1992.

[17] Y. Chen, Y. Deng, J. Glimm, G. Li, D. H. Sharp, and Q. Zhang. A renormalization group scaling analysis for compressible two-phase flow. *Phys. Fluids A*, 5(11):2929–2937, 1993.

[18] Y. Chen, J. Glimm, D. Saltz, D. H. Sharp, and Q. Zhang. A two-phase flow formulation for the Rayleigh-Taylor mixing zone and its renormalization group solution. In R. Young, J. Glimm, and B. Boston, editors, *Proceedings of the Fifth International Workshop on Compressible Turbulent Mixing*, pages 23–32. World Scientific, Singapore, 1996. ISBN 981-02-2910-0.

[19] Y. Chen, J. Glimm, D. H. Sharp, and Q. Zhang. A two-phase flow model of the Rayleigh-Taylor mixing zone. *Phys. Fluids*, 8(3):816–825, 1996.

[20] B. Cheng, J. Glimm, H. Jin, and D. H. Sharp. Theoretical methods for the determination of mixing. *Laser and Particle Beams*, 21:429–436, 2003.

[21] B. Cheng, J. Glimm, X. L. Li, and D. H. Sharp. Subgrid models and DNS studies of fluid mixing. In E. Meshkov, Y. Yanilkin, and V. Zhmailo, editors, *Proceedings of the 7th International Conference on the Physics of Compressible Turbulent Mixing, (1999)*, pages 385–390, Sarov, Nizhny Novgorod region, Russia, 2001. RFNC-VNIIEF.

[22] B. Cheng, J. Glimm, D. Saltz, and D. H. Sharp. Boundary conditions for a two pressure two phase flow model. *Physica D*, 133:84–105, 1999.

[23] B. Cheng, J. Glimm, and D. H. Sharp. A 3-D RNG bubble merger model for Rayleigh-Taylor mixing. *Chaos*, 12:267–274, 2002.

[24] B. Cheng, J. Glimm, and D. H. Sharp. Dynamical evolution of the Rayleigh-Taylor and Richtmyer-Meshkov mixing fronts. *Phys. Rev. E*, 66:1–7, 2002. Paper No. 036312.

[25] B. Cheng, J. Glimm, and D. H. Sharp. A three-dimensional renormalization group bubble merger model for Rayleigh-Taylor mixing. *Chaos*, 12:267–274, 2002.

[26] B. Cheng, J. Glimm, D. H. Sharp, and Y. Yu. A multiphase flow model for the unstable mixing of layered incompressible materials. *Phys. of Fluids*, 17, 2005. Paper No. 087102. LANL Preprint Number LA-UR-05-0078. Stony Brook University Preprint Number SUNYSB-AMS-05-01.

[27] M. A. Christie, J. Glimm, J. W. Grove, D. M. Higdon, D. H. Sharp, and M. M. Wood-Schultz. Error analysis and simulations of complex phenomena. *Los Alamos Science*, 29:2–25, 2005.

[28] W. K. Chui, J. Glimm, F. M. Tangerman, A. P. Jardine, and J. S. Madsen. Modeling of resin transfer molding. In *Proceedings of the First Regional Symposium on Manufacturing Science and Technology*, Stony Brook, New York, 1995.

[29] W. K. Chui, J. Glimm, F. M. Tangerman, A. P. Jardine, J. S. Madsen, T. M. Donnellan, and R. Leek. Porosity migration in RTM. In R. W. Lewis and P. Durbetaki, editors, *Numerical Methods in Thermal Problems, Volume IX, Part 2*, pages 1323–1333, Swansea U.K., 1995. Pineridge Press.

[30] W. K. Chui, J. Glimm, F. M. Tangerman, A. P. Jardine, J. S. Madsen, T. M. Donnellan, and R. Leek. Process modeling in resin transfer molding as a method to enhance product quality. *SIAM Review*, 39(4):714–727, 1997.

[31] W. K. Chui, J. Glimm, F. M. Tangerman, H. Zhang, and V. Prasad. A parallel algorithm for multizone, multiphase systems with application to crystal growth. *J. Crystal Growth*, 180(3-4):534–542, 1997.

[32] S. B. Dalziel, editor. *Proceedings of the 9th International Workshop on the Physics of compressible turbulent mixing.* Cambridge, England, 2004.

[33] Y. Deng and J. Glimm. The performance of parallel interface algorithms on distributed-memory MIMD systems. In A. K. Noor and

B. H. V. Topping, editors, *Computing Systems in Engineering*. Pergamon Press, Oxford, 1991.

[34] Y. Deng and J. Glimm. Fluid dynamics using interface methods on parallel processors. In Horst D. Simon, editor, *Parallel CFD. Implementations and Results Using Parallel Computers*, pages 257–270. MIT Press, Cambridge, 1992.

[35] Y. Deng, J. Glimm, J. Davenport, X. Cai, and E. Santos. Performance models on QCDOC for molecular dynamics with coulomb potentials. *International Journal of High Performance Computing Applications*, 18:183–198, 2004. SUNYSB-AMS-00-04.

[36] Y. Deng, J. Glimm, and D. H. Sharp. Perspectives on parallel computing. *Daedalus*, 12:31–52, 1992.

[37] Y. Deng, J. Glimm, and D. H. Sharp. Mixing and chaotic microstructure. *Los Alamos Science*, 21:124–132, 1993.

[38] Y. Deng, J. Glimm, Y. Wang, M. Eisenberg, A. Grollman, and A. Korobka. Prediction of protein binding to DNA in the presence of water-mediated hydrogen bonds. *Journal of Molecular Modeling*, 5:125–133, 1999.

[39] Y. Deng, J. Glimm, Q. Yu, and M. Eisenberg. Global minimization for problems with multiple local minima. *Appl. Math. Lett.*, 6(2):89–90, 1993.

[40] B. DeVolder, J. Glimm, J. W. Grove, Y. Kang, Y. Lee, K. Pao, D. H. Sharp, and K. Ye. Uncertainty quantification for multiscale simula-

tions. *Journal of Fluids Engineering*, 124:29–41, 2002. LANL report No. LA-UR-01-4022.

[41] R. P. Drake, H. F. Robey, O. A. Hurricane, Y. Zhang, B. A. Remington, J. Knauer, J. Glimm, D. Arnett, J. O. Kane, K. S. Budil, and J. W. Grove. Experiments to produce a hydrodynamically unstable spherically diverging system of relevance to instabilities in supernovae. *Astrophysical Journal*, 564:896–906, 2002.

[42] D. A. Drew. Mathematical modeling of two-phase flow. *Ann. Rev. Fluid Mech.*, 15:261–291, 1983.

[43] Jian Du, Brian Fix, James Glimm, Xicheng Jia, Xiaolin Li, Yunhua Li, and Lingling Wu. A simple package for front tracking. *J. Comp. Phys.*, 2005. In press. Stony Brook University preprint SUNYSB-AMS-05-02.

[44] S. Dutta, E. George, J. Glimm, J. Grove, H. Jin, T. Lee, X. Li, D. H. Sharp, K. Ye, Y. Yu, Y. Zhang, and M. Zhao. Shock wave interactions in spherical and perturbed spherical geometries. 2004. In Press; University at Stony Brook preprint number SB-AMS-04-09 and LANL report No. LA-UR-04-2989.

[45] S. Dutta, E. George, J. Glimm, X. L. Li, A. Marchese, Z. L. Xu, Y. M. Zhang, J. W. Grove, and D. H. Sharp. Numerical methods for the determination of mixing. *Laser and Particle Beams*, 21:437–442, 2003. LANL report No. LA-UR-02-1996.

[46] S. Dutta, J. Glimm, J. W. Grove, D. H. Sharp, and Y. Zhang. A fast algorithm for moving interface problems. In V. Kumar et al., editor, *Computational Science and Its Applications - ICCSA 2003, LNCS*

2668, pages 782–790. Springer-Verlag, Berlin Heidelberg, 2003. LANL report No. LA-UR-02-7895.

[47] S. Dutta, J. Glimm, J. W. Grove, D. H. Sharp, and Y. Zhang. Error comparison in tracked and untracked spherical simulations. *Computers and Mathematics with Applications*, 48:1733–1747, 2004. University at Stony Brook preprint number AMS-03-10 and LANL report No. LA-UR-03-2920.

[48] S. Dutta, J. Glimm, J. W. Grove, D. H. Sharp, and Y. Zhang. Spherical Richtmyer-Meshkov instability for axisymmetric flow. *Mathematics and Computers in Simulations*, 65:417–430, 2004. University at Stony Brook preprint number AMS-03-13.

[49] S. Dutta, J. Glimm, and Y. Zhang. LES simulations of turbulent combustion in a type Ia supernovae. *Astrophysical Journal*, 2005. submitted,University at Stony Brook preprint number AMS-05-05.

[50] A. Friedman, J. Glimm, and J. Lavery. *The Mathematical and Computational Sciences in Emerging Manufacturing Technologies and Management Practices*. SIAM, Philadelphia, 1992.

[51] F. Furtado, J. Glimm, W. B. Lindquist, and F. Pereira. Characterization of mixing length growth for flow in heterogeneous porous media. In *Proceedings of the 11th SPE Symposium on Reservoir Simulation*, pages 317–322. Society of Petroleum Engineers, Richardson, TX, 1991. SPE 21233.

[52] F. Furtado, J. Glimm, W. B. Lindquist, F. Pereira, and Q. Zhang. Time dependent anomalous diffusion for flow in multi-fractal porous

media. In T. M. M. Verheggan, editor, *Proceedings of the Workshop on Numerical Methods for the Simulation of Multiphase and Complex Flow*, volume 398 of *Lecture Notes in Physics*, pages 79–89. Springer-Verlag, New York, 1992.

[53] E. George and J. Glimm. Self similarity of Rayleigh-Taylor mixing rates. *Phys. Fluids*, 17:054101–1–054101–13, 2005. Stony Brook University Preprint number SUNYSB-AMS-04-05.

[54] E. George, J. Glimm, J. W. Grove, X. L. Li, Y. J. Liu, Z. L. Xu, and N. Zhao. Simplification, conservation and adaptivity in the front tracking method. In T. Hou and E. Tadmor, editors, *Hyperbolic Problems: Theory, Numerics, Applications*, pages 175–184. Springer Verlag, Berlin and New York, 2003.

[55] E. George, J. Glimm, X. L. Li, Y. H. Li, and X. F. Liu. The influence of surface tension on turbulent mixing rates of immiscible fluids. *Phys. Rev. Lett.*, 2005. Submitted. Stony Brook University Preprint number SUNYSB-AMS-05-11.

[56] E. George, J. Glimm, X. L. Li, A. Marchese, and Z. L. Xu. A comparison of experimental, theoretical, and numerical simulation Rayleigh-Taylor mixing rates. *Proc. National Academy of Sci.*, 99:2587–2592, 2002.

[57] J. Glimm. Nonlinear and stochastic phenomena: The grand challenge for partial differential equations. *SIAM Rev.*, 33:626–643, 1991.

[58] J. Glimm. Nonlinear waves: Overview and problems. In J. Glimm and A. Majda, editors, *Multidimensional Hyperbolic Problems and Com-*

putations, volume 29 of *IMA Volumes in Mathematics and its Applications*, pages 89–106. Springer-Verlag, New York–Heidelberg–Berlin, 1991.

[59] J. Glimm. Stochastic partial differential equations and the chaotic mixing of fluids. In M. J. Pacífico, editor, *Anais do* 19^o *Colóquio Brasileiro Matemática*. Instituto de Matemática Pura e Aplicada, Rio de Janeiro, 1993.

[60] J. Glimm, M. J. Graham, J. W. Grove, X.-L. Li, T. M. Smith, D. Tan, F. Tangerman, and Q. Zhang. Front tracking in two and three dimensions. *Comput. Math. Appl.*, 35(7):1–11, 1998.

[61] J. Glimm, M. J. Graham, T. M. Smith, and F. Tangerman. Stochastic simulations of fluid mixing and other applications of the front tracking method. In A. Tentner, editor, *High Performance Computing 1996*. Society for Computer Simulation, San Diego, 1996.

[62] J. Glimm, J. W. Grove, Y. Chen, and X.-L. Li. Chaotic mixing at unstable interfaces. In *3rd International Workshop on the Physics of Compressible Turbulent Mixing*, pages 19–28. CEA DAM, 1991.

[63] J. Glimm, J. W. Grove, Y. Kang, T. Lee, X. Li, D. H. Sharp, Y. Yu, K. Ye, and M. Zhao. Statistical riemann problems and a composition law for errors in numerical solutions of shock physics problems. *SISC*, 26:666–697, 2004. University at Stony Brook Preprint Number SB-AMS-03-11, Los Alamos National Laboratory number LA-UR-03-2921.

[64] J. Glimm, J. W. Grove, Y. Kang, T. Lee, X. Li, D. H. Sharp, Y. Yu, K. Ye, and M. Zhao. Errors in numerical solutions of spherically sym-

metric shock physics problems. *Contemporary Mathematics*, 371:163–179, 2005. University at Stony Brook Preprint Number SB-AMS-04-03, Los Alamos National Laboratory number LA-UR-04-0713.

[65] J. Glimm, J. W. Grove, X. L. Li, Yingjie Liu, and Zhiliang Xu. Unstructured grids in 3D and 4D for time-dependent interface in front tracking with improved accuracy. In B. K. Soni et al., editor, *Proc. 8th Int. Conf. Num. Grid Generation in Comp. Field Simulations*, pages 179–188. 2002. LANL report No. LA-UR-02-0893.

[66] J. Glimm, J. W. Grove, X. L. Li, W. Oh, and D. H. Sharp. A critical analysis of Rayleigh-Taylor growth rates. *J. Comp. Phys.*, 169:652–677, 2001.

[67] J. Glimm, J. W. Grove, X.-L. Li, K.-M. Shyue, Q. Zhang, and Y. Zeng. Three dimensional front tracking. *SIAM J. Sci. Comp.*, 19:703–727, 1998.

[68] J. Glimm, J. W. Grove, X.-L. Li, and D. C. Tan. Robust computational algorithms for dynamic interface tracking in three dimensions. *SIAM J. Sci. Comp.*, 21:2240–2256, 2000.

[69] J. Glimm, J. W. Grove, X.-L. Li, R. Young, Q. Zhang, and Y. Zeng. Front tracking: A parallelized approach for internal boundaries and interfaces. In J. Dongarra, K. Masden, and J. Wasniewski, editors, *Applied Parallel Computing. Lecture Notes in Computer Science 1041*, pages 257–266. Springer Verlag, Berlin, Heidelberg, New York, 1996.

[70] J. Glimm, J. W. Grove, X.-L. Li, and N. Zhao. Simple front tracking. In G.-Q. Chen and E. DiBenedetto, editors, *Contemporary Mathematics*, volume 238, pages 133–149. Amer. Math. Soc., Providence, RI, 1999.

[71] J. Glimm, J. W. Grove, and Y. Zhang. Three dimensional axisymmetric simulations of fluid instabilities in curved geometry. In M. Rahman and C. A. Brebbia, editors, *Advances in Fluid Mechanics III*, pages 643–652. WIT Press, Southampton, UK, 2000.

[72] J. Glimm, J. W. Grove, Y. Zhang, and S. Dutta. Numerical study of axisymmetric Richtmyer-Meshkov instability and azimuthal effect on spherical mixing. *J. Stat. Physics*, 107:241–260, 2002.

[73] J. Glimm, Yoon ha Lee, and Kenny Ye. A simple model for scale up error. *Contemporary Mathematics*, 295:241–251, 2002.

[74] J. Glimm, S. Hou, H. Kim, Y. Lee, D. Sharp, K. Ye, and Q. Zou. Risk management for petroleum reservoir production: A simulation-based study of prediction. *J. Comp. Geosciences*, 5:173–197, 2001.

[75] J. Glimm, S. Hou, H. Kim, D. Sharp, and K. Ye. A probability model for errors in the numerical solutions of a partial differential equation. *CFD Journal*, 9, 2000.

[76] J. Glimm, S. Hou, Y. Lee, D. Sharp, and K. Ye. Prediction of oil production with confidence intervals. SPE 66350, Society of Petroelum Engineers, 2001. SPE Reservoir Simulation Symposium held in Houston, Texas, 11-14 Feb.

[77] J. Glimm, S. Hou, Y. Lee, D. Sharp, and K. Ye. Solution error models for uncertainty quantification. *Contemporary Mathematics*, 327:115–140, 2003. SUNYSB preprint 02-16. LANL preprint LA-UR: 02-5987.

[78] J. Glimm, S. Hou, Y. Lee, D. Sharp, and K. Ye. Sources of uncertainty and error in the simulation of flow in porous media. *Comp. and Ap-*

plied Mathematics, 23:109–120, 2004. SUNYSB preprint 03-08. LANL preprint LA-UR-03-2328.

[79] J. Glimm and H. Jin. An asymptotic analysis of two-phase fluid mixing. *Bol. Soc. Bras. Mat.*, 32:213–236, 2001.

[80] J. Glimm, H. Jin, M. Laforest, F. Tangerman, and Y. Zhang. A two pressure numerical model of two fluid mixing. *SIAM J. Multiscale Model. Simul.*, 1:458–484, 2003.

[81] J. Glimm, H. Jin, and Y. Zhang. Front tracking for multiphase fluid mixing. In A. A. Mammoli and C. A. Brebbia, editors, *Computational Methods in Multiphase Flow II*, pages 13–22. WIT Press, Southampton, UK, 2004.

[82] J. Glimm, H. Kim, D. Sharp, and T. Wallstrom. A stochastic analysis of the scale up problem for flow in porous media. *Computational and Applied Mathematics*, 17:67–79, 1998.

[83] J. Glimm, H. Kirk, X. L. Li, J. Pinezich, R. Samulyak, and N. Simos. Simulation of 3D fluid jets with application to the muon collider target design. In *Advances in Fluid Mechanics III*, volume 26, pages 191–200. WIT Press, Southampton, Boston, 2000.

[84] J. Glimm, H. Kranzer, D. Tan, and F. Tangerman. Wave fronts for Hamilton-Jacobi equations: The general theory for Riemann solutions in R^n. *Commun. Math. Phys.*, 187(3):647–677, 1997.

[85] J. Glimm, X.-L. Li, and A.-D. Lin. Nonuniform approach to terminal velocity for single mode Rayleigh-Taylor instability. *ACTA MATHEMATICAE APPLICATAE SINICA*, 18:1–8, 2002.

[86] J. Glimm, X.-L. Li, and Y.-J. Liu. Conservative front tracking in higher space dimensions. *Transactions of Nanjing University of Aeronautics and Astronautics*, 18, Suppl.:1–15, 2001. Proceedings of International Workshop on Computational Methods for Continuum Physics and Their Applications (IWCCPA), Nanjing, China.

[87] J. Glimm, X.-L. Li, and Y.-J. Liu. Conservative front tracking in one space dimension. *Contemporary Mathematics*, 295:253–264, 2002. Proceedings of the Joint Summer Research Conference on Fluid Flow and Transport in Porous Media: Mathematical and Numerical Treatment. Report SUNYSB-AMS-01-16.

[88] J. Glimm, X.-L. Li, Y.-J. Liu, Z. L. Xu, and N. Zhao. Conservative front tracking with improved accuracy. *SIAM J. Numerical Analysis*, 41:1926–1947, 2003.

[89] J. Glimm, X.-L. Li, Y.-J. Liu, and N. Zhao. Conservative front tracking and level set algorithms. *Proc. National Academy of Sci.*, 98:14198–14201, 2001.

[90] J. Glimm, X.-L. Li, R. Menikoff, D. H. Sharp, and Q. Zhang. volume 29 of *IMA Volumes in Mathematics and its Applications*, pages 107–122. Springer-Verlag, New York–Heidelberg–Berlin, 1991.

[91] J. Glimm, X.-L. Li, R. Menikoff, D. H. Sharp, and Q. Zhang. Statistical theories of Rayleigh-Taylor instability for compressible fluids. In W. Dannevik, A. Buckingham, and C. Lieth, editors, *Advances in Compressible Turbulent Mixing*, pages 85–94. National Technical Information Service, U.S. Department of Commerce, 5285 Port Royal Rd. Springfield VA 22161, 1992.

[92] J. Glimm, X. L. Li, W. Oh, A. Marchese, M.-N. Kim, R. Samulyak, and C. Tzanos. Jet breakup and spray formation in a diesel engine. In *Proceedings of the Second MIT Conference on Computational Fluid and Solid Mechanics*. Cambridge, MA, 2003. SUNY Stony Brook preprint No. susb-ams-02-20.

[93] J. Glimm, X.-L. Li, and Z.-L. Xu. Front tracking algorithm using adaptively refined meshes. In *Proceedings of the 2003 Chicago Workshop on adaptive Mesh Refinement Methods*. 2004. the Lecture Notes in Computational Science and Engineering, ISSN: 1439-7358.

[94] J. Glimm and W. B. Lindquist. Scaling laws for macrodispersion. In T. F. Russell, R. E. Ewing, C. A. Brebbia, W. G. Gray, and G. F. Pinder, editors, *Computational Methods in Water Resources IX, vol. 2: Mathematical Modeling in Water Resources*, pages 35–49. Computational Mechanics Publications, Southampton, 1992.

[95] J. Glimm, W. B. Lindquist, F. Pereira, and R. Peierls. The multi-fractal hypothesis and anomalous diffusion. *Mat. Aplic. Comput.*, 11:189–207, 1992.

[96] J. Glimm, W. B. Lindquist, F. Pereira, and Q. Zhang. A theory of macrodispersion for the scale up problem. *Transport in Porous Media*, 13:97–122, 1993.

[97] J. Glimm, W. B. Lindquist, and Q. Zhang. Front tracking, oil reservoirs, engineering problems and mass conservation. In J. Glimm and A. Majda, editors, *Multidimensional Hyperbolic Problems and Computations*, volume 29 of *IMA Volumes in Mathematics and its Appli-*

cations, pages 123–139. Springer-Verlag, New York–Heidelberg–Berlin, 1991.

[98] J. Glimm, B. Plohr, and D. Sharp. A conservative formulation for large-deformation plasticity. *Appl. Mech. Rev.*, 46:519–526, 1993.

[99] J. Glimm, B. Plohr, and D. Sharp. Tracking of shear bands I. The one-dimensional case. *Mech. Materials*, 24:31–41, 1996.

[100] J. Glimm, D. Saltz, and D. H. Sharp. Renormalization group solution of two-phase flow equations for Rayleigh-Taylor mixing. *Phys. Lett. A*, 222:171–176, 1996.

[101] J. Glimm, D. Saltz, and D. H. Sharp. A general closure relation for incompressible mixing layers induced by interface instabilites. In G. Jourdan and L. Houas, editors, *Proceedings of the Sixth International Workshop on the Physics of Compressible Turbulent Mixing*, pages 179–184. Imprimerie Caractère, Marseille, France, 1997.

[102] J. Glimm, D. Saltz, and D. H. Sharp. Statistical evolution of chaotic fluid mixing. *Phys. Rev. Lett.*, 80(4):712–715, 1998.

[103] J. Glimm, D. Saltz, and D. H. Sharp. Two-pressure two-phase flow. In G.-Q. Chen, Y. Li, and X. Zhu, editors, *Nonlinear Partial Differential Equations*, pages 124–148. World Scientific, Singapore, 1998.

[104] J. Glimm, D. Saltz, and D. H. Sharp. Two-phase modeling of a fluid mixing layer. *J. Fluid Mech.*, 378:119–143, 1999.

[105] J. Glimm and D. H. Sharp. A random field model for anomalous diffusion in heterogeneous porous media. *J. Stat. Phys.*, 62:415–424, 1991.

[106] J. Glimm and D. H. Sharp. Stochastic partial differential equations: Selected applications in continuum physics. In R. A. Carmona and B. L. Rozovskii, editors, *Stochastic Partial Differential Equations: Six Perspectives*, Mathematical Surveys and Monographs. American Mathematical Society, Providence, 1997.

[107] J. Glimm and D. H. Sharp. Stochastic methods for the prediction of complex multiscale phenomena. *Quarterly J. Appl. Math.*, 56:741–765, 1998.

[108] J. Glimm and D. H. Sharp. Prediction and the quantification of uncertainty. *Physica D*, 133:152–170, 1999.

[109] J. Glimm, D. H. Sharp, and Q. Zhang. The renormalization group dynamics of chaotic mixing of unstable interfaces. *Phys. Fluids A*, 3:1333–1335, 1991.

[110] J. Glimm, S. R. Simanca, D. C. Tan, F. M. Tangerman, and G. VanDer-Woude. Front tracking simulations of ion deposition and resputtering. *SIAM J. Sci. Comp.*, 20:1905–1920, 1999.

[111] J. Glimm and Q. Zhang. A quantitative theory of fluid chaos. In M. Shearer, editor, *Viscous Profiles and Numerical Methods for Shock Waves*, pages 49–65. SIAM, Philadelphia, 1991.

[112] James Glimm, M.-N. Kim, X.-L. Li, R. Samulyak, and Z.-L. Xu. Jet simulation in a diesel engine. In *Computational Fluid and Solid Mechanics 2005*. Elsevier Science, 2005.

[113] James Glimm, Yunha Lee, David H Sharp, and Kenny Q Ye. Prediction using numerical simulations, A Bayesian framework for uncer-

tainty quantification and its statistical challenge. In Bilal M. Ayyub and Nii O. Attoh-Okine, editors, *Proceedings of the Fourth International Symposium on Uncertainty Modeling and Analysis (ISUMA 2003)*. IEEE, Computer Society, 2003.

[114] J. W. Grove, J. Glimm, and X. L. Li. High resolution numerical methods for multiphase flows. In *Modelisation Numerique des Couplages Thermiques, Mecaniques et Chimiques dan les Ecoulements Industriels*. Institut Universitaire des Systems Thermiques Industriels, Universite Marseille, Marseille, 2000. LANL Report LA-UR-00-2639.

[115] J. W. Grove, Y. Yang, Q. Zhang, D. H. Sharp, J. Glimm, B. Boston, and R. Holmes. The application of front tracking to the simulation of shock refractions and shock accelerated interface mixing. In *Proceedings of the 4th International Workshop on the Physics of Compressible Turbulent Mixing*. Cambridge Univ., Cambridge, 1993.

[116] H. Jin, X. F. Liu, T. Lu, B. Cheng, J. Glimm, and D. H. Sharp. Rayleigh-Taylor mixing rates for compressible flow. *Phys. Fluids*, 17:024104–1–024104–10, 2005. Stony Brook University Preprint number SUNYSB-AMS-04-06 and Los Alamos National Laboratory LAUR Number LA-04-1384.

[117] J. M. Guevara Jordan and J. Glimm. A mixed finite element for Hele Shaw cell equations. *Comp. Geosciences*, 1:35–58, 1997.

[118] M. Laforest. *A posteriori error estimate for front-tracking*. Ph. d. thesis, State University of New York at Stony Brook, 2001.

[119] T. Lee, Y. Yu, M. Zhao, J. Glimm, X. Li, and K. Ye. Error analysis of composite shock interaction problems. *Conference Proceedings of*

PMC04, 2004. University at Stony Brook Preprint Number SB-AMS-04-08.

[120] L. Li, J. Glimm, and X.-L. Li. All isomorphic distinct cases for multi-component interfaces in a block. *J. Comp. Appl. Mathematics*, 152:263–276, 2003.

[121] X.-L. Li and J. Glimm. A numerical study of Richtmyer-Meshkov instability in three dimensions. In H. Kubota and S. Aso, editors, *Proceedings of the Second Asia CFD Conference, Tokyo*, volume 1, pages 87–92. Japan Society of Computational Fluid Dynamics, 1996.

[122] X.-L. Li, B. X. Jin, and J. Glimm. Numerical study for the three dimensional Rayleigh-Taylor instability using the TVD/AC scheme and parallel computation. *J. Comp. Phys.*, 126:343–355, 1996.

[123] J.-J. Liu, J. Glimm, and X.-L. Li. A conservative front tracking method. In *Proceedings of the Tenth International Conference on Hyperbolic Problems: Theory, Numerics, and Applications*. Yokohama Publishers, Osaka, Japan, 2005. In Press.

[124] K. I. Read. Experimental investigation of turbulent mixing by Rayleigh-Taylor instability. *Physica D*, 12:45–58, 1984.

[125] D. Saltz and D. Sendersky. Computation of two-phase mixing properties in Rayleigh-Taylor instability. Technical report, University at Stony Brook, 1999.

[126] R. Samulyak, J. Glimm, W. Oh, H. Kirk, and K. McDonald. Simulation of free surface MHD flows: Richtmyer - meshkov instability and applications. *Lecture Notes in Com. Sci.*, 2667:558–567, 2003.

[127] R. Samulyak, T. Lu, Y. Prykarpatskyy, J. Glimm, Z. Xu, and M. N. Kim. Comparison of direct and homogeneous numerical approaches to cavitation modeling. *Int. J. For Multiscale Comp. Eng.*, 2004. Submitted.

[128] D. H. Sharp. An overview of Rayleigh-Taylor instability. *Physica D*, 12:3–18, 1984.

[129] V. S. Smeeton and D. L. Youngs. Experimental investigation of turbulent mixing by Rayleigh-Taylor instability (part 3). AWE Report Number 0 35/87, 1987.

[130] Y. Song, W. Chui, J. Glimm, B. Lindquist, and F. Tangerman. Applications of front tracking to the simulation of resin transfer modeling. *Computers & Mathematics with Applications*, 33(9):47–60, 1997.

[131] N. Stojić, J. W. Davenport, M. Komelj, and J. Glimm. Surface magnetic moment in α-uranium by density-functional theory. *Phys. Rev. B*, 68, 094407:(5 pages), 2003.

[132] N. Stojic, J. Glimm, Y. Deng, and J. Haus. Transverse magnetic modes in two-dimensional triangular photonic crystals. *Phys. Rev. E*, 64:1–7, 2001. Paper number 056614.

[133] John Walter, James Glimm, John W. Grove, Hyun-Cheol Hwang, Xiao Lin, Bradley J. Plohr, David H. Sharp, and Dahai Yu. Eulerian front tracking for solid dynamics. In Kailasam Iyer and Shun chin Chou, editors, *Proceedings of the 15th US Army Symposium on Solid Mechanics*, pages 343–366, Myrtle Beach, SC, 1999. Battelle Memorial Institute, Battelle Press (www.battelle.org/bookstore). published on CD-ROM (ISBN 1-57477-083-7).

[134] F. Wang, J. Glimm, J. W. Grove, B. Plohr, and D. Sharp. A conservative Eulerian numerical scheme for elasto-plasticity and application to plate impact problems. *Impact Comput. Sci. Engrg.*, 5:285–308, 1993.

[135] F. Wang, J. Glimm, and B. Plohr. A model for rate-dependent plasticity. *J. Mech. Phys. Solids*, 43:1497–1503, 1995.

[136] Xuena Wang, Wei Zhu, Kith Pradham, Chen Ji, Yeming Ma, Oliver Semmes, James Glimm, and Joseph Mitchell. Feature extration in the analysis of proteomic mass spectra. *Proteomics*, 2005. Accepted for publication.

[137] Z. L. Xu, M. Kim, W. Oh, J. Glimm, R. Samulyak, X. L. Li, and C. Tzanos. Atomization of a high speed jet. *Physics of Fluids*, 2005. in press. SB Preprint Number: SUNYSB-AMS-05-08.

[138] Y. Yu, M. Zhao, T. Lee, N. Pestieau, W. Bo, J. Glimm, and J. W. Grove. Uncertainty quantification for chaotic computational fluid dynamics. *J. Comp. Phys.*, 2005. Stony Brook Preprint number SB-AMS-05-16 and LANL preprint number LA-UR-05-6212; submitted.

[139] Q. Zhang and J. Glimm. Inertial range scaling of laminar shear flow as a model of turbulent transport. *Comm. Math. Phys.*, 146:217–229, 1992.

[140] Y. Zhang, P. Drake, J. Glimm, J. Grove, and D. H. Sharp. Radiation coupled front tracking simulations for laser driven shock experiments. *J. Nonlinear Analysis*, 2005. In press. LANL report No. LA-UR-04-2381.

[141] Y. Zhang, J. Glimm, and S. Dutta. Tracked flame simulation for Type Ia supernova. In *Proceeding of Third MIT Conference*. Elsevier, 2005. accepted.

[142] W. Zhu, Stephen Finch, Hongshik Ahn, James Glimm, Ray Mugno, and Lu Zheng. On the application of statistical methodology to pattern recognition in a half terabyte data set. In *American Statistical Association 1998 Proceedings of the Sections on Government Statistics and Social Statistics*, pages 223–226. American Statistical Association, Alexandria, VA, 1998.

[143] Wei Zhu, Xuena Wang, Yeming Ma, Manlong Rao, James Glimm, and John Kovach. Detection of cancer specific markers amidst massive mass spectral data. *Proc. Nat. Aca. Sci.*, 100:14666–14671, 2003.