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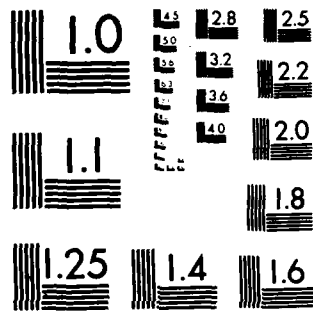
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Applied Mathematics Group
Department of Mathematics, Stanford University

PROGRESS REPORT for
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Principal Investigator: Professor Joseph B. Keller

The research activities of the Applied Mathematics Group during the first nine months of 1983 are described in this report. In the next section a brief outline of the research is presented. This is followed by a list of publication status of the work, and the abstracts of papers submitted for publication during this period.

Joseph B Keller

Joseph B. Keller Principal Investigator

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Brief Outline of Research Findings

Section II of this report indicates the publication status of the research work of members of the Applied Mathematics Group. A number of papers previously accepted have been published, others previously submitted have been accepted, and a number of new ones have been submitted.

Among the latter are two papers by Professor Keller and his former student Dr. Kevin C. Nunan. They calculated the effective elastic behaviour of a composite of rigid spheres located at lattice points in an elastic matrix. They also calculated the effective viscosity of a similar arrangement of rigid spheres in a viscous fluid. The novelty of this work is that it covers all concentrations from zero to close packing.

Professors Geer and Keller completed their work on the eigenvalues of slender cavities, which provides a simple method for calculating such eigenvalues accurately. Their results agreed very well with previous numerical calculations for prolate spheroids.

Dr. Margaret Cheney has completed two new works on inverse scattering in two dimensions. This provides a further step towards making inverse scattering theory applicable to real physical problems.

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II. PUBLICATIONS OF APPLIED MATHEMATICS GROUP

50. J. B. Keller Optimum inspection policies
Pub: Management Sci., 28, 447-450, 1982.
51. P. S. Hagan Travelling and stacked travelling wave solutions of parabolic equations
Pub: SIAM J. Math. Anal., 13, 717-738, 1982.
52. J.-M. Vanden-Broeck Contact problems involving the flow past an inflated aerofoil
Pub: J. Appl. Mech., 49, 263-265, 1982.
53. J.-M. Vanden-Broeck Nonlinear two-dimensional sail theory
Pub: Phys. Fluids, 25, 420-423, 1982.
55. P. S. Hagan Spiral waves in reaction diffusion equations
Pub: SIAM J. Appl. Math., 42, 762-786, 1982.
56. J.-M. Vanden-Broeck Parabolic approximations for ship waves and wave resistance
J. B. Keller
Pub: Proceedings of the Third International Conference on Numerical Ship Hydrodynamics, Paris, France, June 16-19, 1981.
57. A. Jeffrey Asymptotic Methods in Nonlinear Wave Problems
T. Kawahara
Pub: Pitman Publishing, Ltd., London, 1982.
58. M. J. Miksis Rising Bubbles
J.-M. Vanden-Broeck
J. B. Keller
Pub: J. Fluid Mech., 123, 31-42, 1982.
59. J. C. Neu Resonantly interacting waves
Pub: SIAM J. Appl. Math., 43, I, 141-156, 1983.
60. J. B. Keller Surface tension driven flows
M. J. Miksis
Pub: SIAM J. Appl. Math., 43, II, 268-277, 1983.
61. A. Jepson Folds in solutions of two parameter systems
A. Spence and their calculation: Part I
Pub: Stanford Univ. Numer. Anal. Report, 82-02.

62. J. B. Keller Time-dependent queues
Pub: SIAM Rev., 24, 401-412, 1982.
63. R. E. Caflisch Shock profile solutions of the Boltzmann equation
B. Nicolaenko
Pub: Comm. Math. Phys., 86, 161-194, 1982.
64. P. S. Hagan Arrow's model of optimal pricing, use and
R. E. Caflisch exploration of undertain natural resources
J. B. Keller
Sub: Econometrica
65. R. E. Caflisch Radiation transport in a hot plasma
Acc: SIAM J. Appl. Math., in press.
66. J. B. Keller Jets rising and falling under gravity
J.-M. Vanden-Broeck
Pub: J. Fluid Mech., 124, 335-345, 1982.
67. R. E. Caflisch Fluid dynamics and the Boltzmann equation
Pub: Stud. Stat. Mech., 5, 194-223, 1983.
- 68.* M. S. Falkovitz Theory of periodic structures in lipid
M Seul bilayer membranes
H. L. Frisch
H. M. McConnell
Pub: Proc. Nat. Acad. Sci., 79, 3918, 1982.
69. R. E. Caflisch The fluid-dynamic limit of a model Boltzmann
equation in the presence of a shock
Pub: Institute National de Recherche en
Informatique et en Automatique, INRIA
No. 81, June 1981, 1-34.
70. P. F. Rhodes-Robinson On the short surface waves due to half-immersed
circular cylinder oscillating on water of
infinite depth
Pub: Proc. Royal Soc. London A, 384, 333-357, 1982.
71. P. F. Rhodes-Robinson Note on the reflexion of water waves at a
wall in the presence of surface tension
Pub: Math. Proc. Cambridge Philosophical Soc.,
92, 369-373, 1982.

*Not supported by AFOSR or ONR.

72. P. F. Rhodes-Robinson On the generation of water waves at an inertial surface
Acc: J. Australian Math. Soc. B, in press.
73. R. E. Caflisch Dynamic theory of suspensions with Brownian effects
G. C. Papanicolaou
Acc: SIAM J. Appl. Math., in press.
74. R. E. Caflisch Instability in settling of suspensions due to Brownian effects
G. C. Papanicolaou
Pub: Proceedings of conference Two-Phase Flow.
75. R. E. Caflisch Shock waves and the Boltzmann equation
B. Nicolaenko
Pub: Proceedings NSF-AMS conference non-linear PDE.
76. J. H. Maddocks Restricted quadratic forms and their application to bifurcation and stability in constrained variational principles
Sub: SIAM J. Appl. Math.
77. M. S. Falkovitz Spatially inhomogeneous polymerization in unstirred bulk
L. A. Segel
Pub: SIAM J. Appl. Math., 43, 386-416, 1983.
78. M. S. Falkovitz The scale of non-homogeneity as defined by diffusion measurements
J. L. Frisch
Pub: Journal of Membrane Science, 10, 61, 1982.
79. M. S. Falkovitz Optimal catalyst distribution in a membrane
H. L. Frisch
J. B. Keller
Acc: Chem. Eng. Sci., in press.
- 80.* M. S. Falkovitz Crawling of Worms
J. B. Keller
Acc: J. Theor. Biol., in press.
81. A. Jeffrey The random choice method and the free-surface water profile after the collapse of a dam wall
J. Mvungi
Pub: Wave Motion, 4, 381-389, 1982.

*Not supported by AFOSR or ONR.

82. J. G. Watson
E. L. Reiss
A statistical theory for imperfect bifurcation
Pub: SIAM J. Appl. Math., 42, 135-148, 1982.
83. J. G. Watson
J. B. Keller
Reflection, scattering and absorption of acoustic waves by rough surfaces
Acc: J. Acoust. Soc. Am.
84. M. I. Weinstein
Global existence for a generalized Korteweg - de Vries equation
Sub: SIAM J. Math. Anal.
85. M. I. Weinstein
Nonlinear Schrödinger equations and sharp interpolation estimates
Pub: Commun. Math. Phys., 87, 567-576, 1983.
86. M. Cheney
Two-dimensional scattering: the number of bound states from scattering data
Sub: J. Math. Phys.
87. L. L. Bonilla
A. Liñán
Relaxation oscillations, pulses, and travelling waves in the diffusive Volterra delay-differential equation
Acc: SIAM J. Appl. Math., in press.
88. P. F. Rhodes-Robinson
Note on the effect of surface tension on water waves at an inertial surface
Pub: J. Fluid Mech., 125, 375-377, 1982.
89. J. B. Keller
J. Hunter
Weak shock diffraction
Acc: Wave Motion, in press.
90. J. B. Keller
J. Hunter
Weakly nonlinear high frequency waves
Pub: Comm. Pure Appl. Math., 36, 547-569, 1983.
91. J. B. Keller
J. C. Neu
Asymptotic analysis of a viscous Cochlear model
Sub: J. Acoust. Soc. Am.
92. J. B. Keller
J.-M. Vanden-Broeck
Parabolic approximations for ship waves and wave resistance
Pub: Proc. 3rd Intl. Conf. on Numerical Ship Hydrodynamics, Paris, France, June 16-19, 1981.

93. A. Spence
A. Jepson
The numerical computation of turning points of
nonlinear equations
Pub: Treatment of Integral Equations by Numerical
Methods, 169-183, London, 1982.
94. J. B. Keller
R. Burridge
Biot's poroelasticity equations by homogenization
Pub: Springer Lecture Notes, in Macroscopic
Properties of Disordered Media, NY, 51-57, 1982.
95. J. B. Keller
Capillary waves on a vertical jet
Acc: J. Fluid Mech., in press.
96. J. B. Keller
A. S. Whittemore
Survival estimation using censored data
Sub: J. Royal Statist. Soc., Series B
97. J. B. Keller
J. F. Geer
Eigenvalues of slender cavities and waves in
slender tubes
Acc: J. Acoust. Soc. Am., in press.
98. J. B. Keller
R. Voronka
Valuation of stocks and options
To be submitted.
99. M. Cheney
Inverse scattering in dimension two
Acc: J. Math. Phys., in press.
100. K. C. Nunan
J. B. Keller
Effective viscosity of a periodic suspension
Sub: J. Fluid Mech.
101. K. C. Nunan
J. B. Keller
Effective elasticity Tensor of a Periodic Composite
Acc: J. Mech. Phys. Solids, in press.
102. J. B. Keller
Breaking of liquid films and threads
Acc: Phys. Fluids, in press.
103. J. B. Keller
G. R. Verma
Hanging rope of minimum elongation
Acc: SIAM Rev.

104. M. Cheney
S. Coen
A. Weglein
Velocity & density of a two-dimensional acoustic
medium from point source surface data
Sub: Phys. Rev. Lett.
105. J. B. Keller
Probability of a shutout in racquetball
Acc: SIAM Rev.
106. S. Venakides
The Zero Dispersion Limit of the Korteweg-de Vries
Equation for Initial Potentials with Non-trivial
Reflection Coefficient
Sub: Comm. Pure Appl. Math.
107. J. H. Maddocks
Stability of Nonlinearly Elastic Rods
Acc: Arch. Rat. Mech. Anal., in press.
- 108.* J. B. Keller
Genetic Variability Due to Geographical Inhomogeneity
Sub: J. Math. Biol.
109. J. B. Keller
M. S. Falkovitz
Precipitation pattern formation
In preparation.

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III. ABSTRACTS OF MANUSCRIPTS SUBMITTED OVER REPORT PERIOD

1. WEAK SHOCK DIFFRACTION, by J. Hunter and J.B. Keller.

The diffraction of a weak shock by a rigid wedge is analyzed theoretically via the theory of weakly nonlinear geometrical acoustics, which is the same as Whitham's nonlinearization technique. First linear and weakly nonlinear geometrical acoustics are explained. Then the linear acoustics results for weak shock diffraction by a wedge are presented. Next these results are modified according to the principles of weakly nonlinear geometrical acoustics. The results show that the compressive diffracted wavefronts of linear acoustics are actually shocks, and their positions and strengths are found. The infinite gradients of the linear acoustics rarefaction waves are found to be finite but discontinuous gradients. Finally the results are specialized to a shock hitting a right-angled wedge, a shock coming off a right-angled wedge, and a shock hitting a thin semi-infinite screen.

2. WEAKLY NONLINEAR HIGH FREQUENCY WAVES, by J. Hunter and J.B. Keller.

We shall present a method for finding small-amplitude, high-frequency wave solutions of hyperbolic systems of quasilinear partial differential equations. The method applies in any number of space dimensions, and reduces to "geometrical optics" when the equations are linear. Therefore we call it *weakly nonlinear geometrical optics*.

The method yields the first terms in an asymptotic expansion of a solution with respect to a small parameter ϵ . This parameter is a measure of both the amplitude and the period of a wave. The solution consists of a slowly varying mean and a superposition of small-amplitude, high-frequency waves. Each of these waves undergoes distortion due to nonlinear selfinteraction. When the distortion leads to multi-valuedness, shocks are introduced to maintain single-valuedness. For conservative systems, the shock locations are found to obey an equal area rule. The interaction among the various waves is a higher-order effect which is negligible unless a certain resonance condition holds. The present method does not apply in the resonant case.

3. CAPILLARY WAVES ON A VERTICAL JET, by J.B.Keller.

Geer and Strikwerda devised a slender jet theory for a jet falling vertically, with surface tension present. They solved the resulting problem numerically by extending a method they had developed previously. Their results showed that the cross-section of the jet decreased in area and oscillated in shape with distance along the jet. They compared the oscillations with Rayleigh's results for oscillations of a jet of constant circular cross-section. There was agreement qualitatively but not quantitatively.

We shall analyze the oscillations of a vertically falling jet on the basis of their theory in order to obtain a quantitative description of them which agrees with the numerical

results. First we find the solution for a vertical jet with a circular cross-section. Then we determine its small amplitude oscillations. Our analysis differs from Rayleigh's because our unperturbed jet is falling, so its velocity and radius are not constant.

4. SURVIVAL ESTIMATION WITH CENSORED DATA, by A. Whittemore and J.B. Keller.

New nonparametric methods are given for estimating survival probability using randomly right-censored data. A class of estimators is obtained by the maximum likelihood method, in which the hazard rate is approximated by a suitably chosen spline function. The class includes the estimator proposed by Nelson (1969) and Altshuler (1970). The estimators are shown to be uniformly consistent and to have the same asymptotic weak convergence properties as the Kaplan-Meier estimator. In small and in heavily censored samples, new estimators in the class have uniformly smaller mean squared error than do the Kaplan-Meier (1958) and Nelson-Altshuler estimators, according to computer simulations. The methods are extended to provide new estimates for both the baseline hazard rate and the regression coefficients in the proportional hazards model proposed by Oakes (1972). Several existing estimates for these quantities, including that obtained using the partial likelihood, occur as special cases of the general procedure. The methods are illustrated using experimental carcinogenesis data.

5. EFFECTIVE VISCOSITY OF A PERIODIC SUSPENSION, by K. Nunan and J.B. Keller

Most The effective viscosity of a suspension is defined to be the four-tensor which relates the average deviatoric stress to the average rate of strain. We determine the effective viscosity of an array of spheres centered on the points of a periodic lattice in an incompressible Newtonian fluid. The formulation involves the traction exerted on a single sphere by the fluid, and an integral equation for this traction is derived. For lattices with cubic symmetry the effective viscosity tensor involves just two parameters. They are computed numerically for simple, body-centered and face-centered cubic lattices of spheres with solute concentrations up to 90% of the close-packing concentration. Asymptotic results for high concentrations are obtained for arbitrary lattice geometries, and found to be in good agreement with the numerical results for cubic lattices. The low concentration asymptotic expansions of Zuzovsky also agree well with the numerical results.

6. THE ZERO DISPERSION LIMIT OF THE KORTEWEG-DE VRIES EQUATION FOR INITIAL POTENTIALS WITH NON-TRIVIAL REFLECTION COEFFICIENT, by S. Venakides.

The inverse scattering method is used to determine the distribution limit as $\varepsilon \rightarrow 0$ of the solution $u(x, t, \varepsilon)$ of the initial value problem:

$$u_t - 6uu_x + \varepsilon^2 u_{xxx} = 0$$

$$u(x, 0) = v(x)$$

where $v(x)$ is a positive bump which decays sufficiently fast as $x \rightarrow \pm\infty$. The case $v(x) \leq 0$ has been solved by Peter D. Lax and C.D. Levermore.

The computation of the distribution limit of $u(x, t, \varepsilon)$ as $\varepsilon \rightarrow 0$ is reduced to a quadratic maximization problem.

7. VELOCITY AND DENSITY OF A TWO-DIMENSIONAL ACOUSTIC MEDIUM FROM POINT SOURCE SURFACE DATA, by S. Coen, Margaret Cheney and A. Weglein.

An inverse acoustic scattering theory and algorithm is presented for the reconstruction of a two dimensional inhomogeneous acoustic medium from surface measurements. The measurements of the surface pressure due to a harmonically oscillating surface point source at two arbitrary frequencies allows the separate reconstruction of the density and velocity of the subsurface. This is a first step towards solving the inverse problem of exploration geophysics.

8. GENETIC VARIABILITY DUE TO GEOGRAPHICAL INHOMOGENEITY, by J.B. Keller.

The frequency ratio of two alleles is studied as a function of position and time, in a two-dimensional region, by means of a nonlinear diffusion equation. Each allele is assumed to have a selective advantage in some part of the region. An asymptotic solution is constructed when the selection coefficient is large compared to the diffusion coefficient, i.e., when selection acts more rapidly than diffusion. As time increases, the solution tends to an equilibrium distribution in which both alleles are present everywhere, each predominating where it has the advantage.