

REPORT DOCUMENTATION PAGE

Form Approved
OMB No. 0704-0188

AD-A274 965



is estimated to average 1 hour per response, including the time for reviewing instructions, searching existing data sources, gathering and reviewing the collection of information. Send comments regarding this burden estimate or any other aspect of this reporting burden, to Washington Headquarters Services, Directorate for Information Operations and Reports, 1215 Jefferson Avenue, Washington, DC 20540, and to the Office of Management and Budget, Paperwork Reduction Project (0704-0188), Washington, DC 20503.

REPORT DATE

3. REPORT TYPE AND DATES COVERED
FINAL/01 DEC 89 TO 15 AUG 93

4. TITLE AND SUBTITLE
CONTINUATION AND MULTI-GRID FOR BIFURCATION PROBLEMS

5. FUNDING NUMBERS

2

6. AUTHOR(S)

PROFESSOR MITTELMANN

2304/CS
AFOSR-90-0080

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)
ARIZONA STATE UNIVERSITY
TEMPE, AZ 85287

DTIC
ELECTE
JAN 27 1994

AFOSR-TR-90-0018

8. PERFORMING ORGANIZATION REPORT NUMBER

9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)
AFOSR/NM
110 DUNCAN AVE, SUTE B115
BOLLING AFB DC 20332-0001

10. SPONSORING/MONITORING AGENCY REPORT NUMBER

AFOSR-90-0080

11. SUPPLEMENTARY NOTES

94-02633



12a. DISTRIBUTION / AVAILABILITY STATEMENT

AVAILABILITY STATEMENT

APPROVED FOR PUBLIC RELEASE: DISTRIBUTION IS UNLIMITED

13. ABSTRACT (Maximum 200 words)

In the following we give an overview of the work completed under grant AFOSR-90-0080 since December 1989. The research concerned the numerical solution of bifurcation and nonlinear eigenvalue problems for parameter-dependent partial differential equations and systems. The scope of the research is rather wide, stressing the development, study and implementation of computational methods for several classes of difficult nonlinear problems of difficult nonlinear problems, but, also including the derivation of analytic results in cases where these questions had not been settled before.

This grant was a continuation and extension of grant and extension of grant AFOSR-84-315. The earlier grant has resulted in 26 papers over a 5-year period. The present grant resulted in the publication of 18 papers in refereed journals or refereed high-quality proceedings volumes and of one book. Several of the 26 papers generated under the earlier grant were listed as to appear in the final report for that grant. They all have appeared but are not listed here again. Instead, for simplicity, we refer to the papers and books produced under the

14. SUBJECT TERMS by giving the corresponding number in the list of all our publications which is a part of the attached curriculum vitae. of all our publications which is a part of the attached curriculum vitae.

16. PRICE CODE

17. SECURITY CLASSIFICATION OF REPORT
UNCLASSIFIED

18. SECURITY CLASSIFICATION OF THIS PAGE
UNCLASSIFIED

19. SECURITY CLASSIFICATION OF ABSTRACT
UNCLASSIFIED

20. LIMITATION OF ABSTRACT
SAR (SAME AS REPORT)

Final Technical Report
on Grant AFOSR-90-0080

Continuation and Multi-grid Methods
for
Bifurcation Problems

Duration of Grant: December 1, 1989 – August 15, 1993

Date of Submission: December 31, 1993

Principal Investigator: Hans D. Mittelmann
Department of Mathematics
Arizona State University
Tempe, AZ 85287-1804

Table of Contents

1. Accomplishments under the Grant..... 2

2. Major Areas of Completed Research 3

 2.1 Development of computational methods for and study of free boundary
 problems for partial differential equations..... 3

 2.2 Stability of thermocapillary flows, efficient numerical solution and
 continuation for nonlinear partial differential equations..... 3

3. Curriculum Vita..... 4

Accession For	
NTIS CRA&I	<input checked="" type="checkbox"/>
DTIC TAB	<input type="checkbox"/>
Unannounced	<input type="checkbox"/>
Justification	
By	
Distribution /	
Availability Codes	
Dist	Avail and/or Special
A-1	

DTIC QUALITY INSPECTED 8

1. Accomplishments under the Grant

In the following we give an overview of the work completed under grant AFOSR-90-0080 since December 1, 1989. The research concerned the numerical solution of bifurcation and nonlinear eigenvalue problems for parameter-dependent partial differential equations and systems. The scope of the research is rather wide, stressing the development, study, and implementation of computational methods for several classes of difficult nonlinear problems, but, also including the derivation of analytic results in cases where these questions had not been settled before.

This grant was a continuation and extension of grant AFOSR-84-0315. This earlier grant had resulted in 26 papers over a 5-year period. The present grant resulted in the publication of 18 papers in refereed journals or refereed high-quality proceedings volumes and of one book. Several of the 26 papers generated under the earlier grant were listed as "to appear" in the final report for that grant. They all have appeared but are not listed here again. Instead, for simplicity, we refer to the papers and books produced under the present grant by giving the corresponding number in the list of all our publications which is a part of the attached curriculum vitae.

2. Major Areas of Completed Research

A rough classification of the research completed under the current grant would identify two major areas given below with the resulting publications. To keep the report concise we mainly list the relevant papers and comment shortly on additional work not reflected in those.

2.1 Development of computational methods for and study of free boundary problems for partial differential equations

The following papers were published in the respective sub-areas:

- (a) Variational Inequalities: [54, 57, 58]
- (b) Capillary Surfaces: [56, 60, 65, 68]

2.2 Stability of thermocapillary flows, efficient numerical solution and continuation for nonlinear partial differential equations

The following papers were published in the respective sub-areas:

- (a) Thermocapillary convection: [55, 59, 61–64, 66, 67, 69–71]
- (b) Efficient solution of PDEs: [1] (see below)

The work on 2.1(a),(b) was a continuation of earlier work, partly leading to a certain completion, as was, for example, documented in the survey work [57].

The work in 2.2(a) was also a continuation of research just begun at the end of the previous grant. Here, however, in a series of 11 papers alone major results were obtained settling the question of both energy and linear stability bounds for thermocapillary convection in the float-zone model of crystal growth, in particular under microgravity conditions and for realistic materials. The last paper cited, [71], contains a variety of computational and graphical results not given before. While the float-zone model will not further be investigated, thermocapillary convection, due to its increasing importance, will be subject of our future research. AFOSR, however, turned down a proposal which had this as a major component.

For 2.2(b) we only list one upcoming publication which we did not coauthor, but to which we have continued to contribute in a substantial way as is reflected in the Introduction and the Acknowledgements.

[1] R.E. Bank, PLTMG User's Guide—Edition 7.0, to appear in early 1994 in the series SIAM Frontiers in Applied Mathematics. The corresponding new software will be posted on **netlib**.

In addition, I presented my research at many colloquia and conference talks. Most of this is listed in the CV.

3.

CURRICULUM VITAE

Rev. 12/93

Hans D. Mittelmann

Mailing Addresses:

Department of Mathematics
 Arizona State University
 Tempe, Arizona 85287-1804
 (602) 965-6595 (office)
 (602) 965-3951 (dept.)
 (602) 965-0461 (FAX)

Residence:
 538 E. Geneva Drive
 Tempe, Arizona 85282
 (602) 966-2521 (home)
 mittelmann@math.la.asu.edu
 na.mittelmann@na-net.ornl.gov

Personal Data:

Born January 1, 1945; Permanent U.S. resident; Married 1971, three children

Education:

University of Mainz	1971	M.S. (Mathematics/Physics)
University of Darmstadt	1973	Ph.D. (Mathematics)
University of Darmstadt	1976	Habilitation (Mathematics)

Research and Teaching Interests:

Numerical solution of partial differential equations; finite elements; large-scale scientific computation for linear and nonlinear problems; multi-grid and other fast solution methods; numerical solution of bifurcation problems.

Academic Experience:

University of Mainz	1971-1973	Scientific Staff, Computing Centre
University of Darmstadt	1974-1977	Assistant/Associate Professor
University of Dortmund	1977-1984	Associate Professor/Professor
University of Bochum	1979-1980	Visiting Professor
Stanford University	1981 (Mar-Sept)	Research Visitor
Arizona State University	1982-1983	Visiting Professor
Arizona State University	1983-	Professor
University of Erlangen	1988 (Smr.-Sem.)	Visiting Professor
University of Heidelberg	1988 (Oct.)	Research Visitor
University of Jyväskylä	1991 (Smr.)	Visiting Professor
University of Leipzig	1992 (Oct.)	Research Visitor

Professional Societies:

Society for Industrial and Applied Mathematics, Deutscher Hochschulverband, member of the GAMM activity groups "Discretization Methods in Solid Mechanics" and "Efficient Numerical Methods for Partial Differential Equations".

Reviewer for Mathematical Reviews; Referee for various journals, the National Science Foundation and the Department of Defense; Editor of the International Series in Numerical Mathematics, Birkhäuser-Verlag, Basel

Grant Support

Continuation and Multi-grid Methods for Bifurcation Problems, AFOSR 84-0315 (10/1/84-11/30/89, \$250,000, PI).

Stability and Instability of Thermocapillary Convection in Models of the Float-Zone Process, NAG 3-1054 NASA, Microgravity Science & Applications Division (6/15/89-9/30/92, \$480,000, co-PI)

Spatio-Temporal Complexity and Large Scale Structures in Problems of Continuum Mechanics, AFOSR (URI), (9/1/89-9/30/92, \$300,000, co-PI).

Continuation and Multi-grid Methods for Bifurcation Problems, AFOSR 90-0080, (12/1/89-8/15/93, \$219,282, PI).

Selected invitations to conferences

- 1986 Efficient numerical methods in continuum mechanics, Kiel, Germany.
 Conference on nonlinear pde's, Salt Lake City, Utah.
 First World Congress on Computational Mechanics, Austin, Texas.
 AMS Regional Meeting, Logan, Utah.
 Finite Elements in Continuum Mechanics, Oberwolfach, Germany.
- 1987 Third Copper Mountain Conference on Multigrid Methods, Copper Mountain, Colorado.
 ASU Miniconference on Optimization, Tempe, Arizona.
 AMS-SIAM Summer Seminar on Computational Aspects of VLSI Design, University of Minnesota.
 German-U.S. American Workshop on New Applications and Algorithms for Optimal Control and Parameter Identification, Trier, Germany.
 Annual Dutch Seminar on Numerical Mathematics, Woutschoten, Netherlands.
 Multigrid Methods, Oberwolfach, Germany.
- 1988 AMS-SIAM Summer Seminar on Computational Solution of Nonlinear Systems, Fort Collins, Colorado.
 Recent Trends in Nonlinear Computational Mathematics and Applications, University of Pittsburgh.
 Fundamental Problems in Mechanics, Leipzig, Germany.
 Bifurcation Theory and its Numerical Analysis, Xi'an, PR China.
 Mathematical Modeling and Simulation of Electric Circuits, Oberwolfach, Germany.
 Numerical Treatment of Problems in Solid Mechanics, Bad Honnef, Germany.

- 1989 Fourth Copper Mountain Conference on Multigrid Methods, Copper Mountain, Colorado.
SIAM Annual Meeting, San Diego.
Computational Methods in Solid Mechanics, Oberwolfach, Germany.
Free Boundary Problems, Numerical Treatment & Optimal Control, Oberwolfach, Germany.
Computation of Nonlinear Flow and Instabilities, Austin, Texas.
Workshop on Continuation and Bifurcations: Numerical Techniques and Applications,
Leuven, Belgium.
Miniconference on Newton-like Methods for Large-Scale Nonlinear Methods, Logan, Utah.
- 1990 Fourth International Conference on Computational and Applied Mathematics, Leuven,
Belgium.
Contributions to the Numerics of Partial Differential Equations, Darmstadt, Germany.
Multigrid Methods, Oberwolfach, Germany
Conference on Numerical Methods for Free Boundary Problems, Jyväskylä, Finland.
- 1991 Banach Center, 37th Semester on Numerical Analysis and Mathematical Modeling,
Warsaw, Poland
Bifurcation and Symmetry: Cross Influences between Mathematics and Applications,
Marburg, Germany
- 1992 AMS-SIAM Summer Seminar in Applied Mathematics on Exploiting Symmetries in
Applied and Numerical Analysis, Fort Collins, Colorado
Short Course on Scientific Computing, Darmstadt, Germany
Mathematical Modeling and Simulation of Electric Circuits and Semiconductors,
Oberwolfach, Germany
Surface Tension and Movement by Mean Curvature, Trento, Italy
International Symposium on Numerical Analysis, Prague, Czechoslovakia
First International Colloquium on Numerical Analysis, Plovdiv, Bulgaria
Theory and Numerical Methods for Initial-Boundary Value Problems, Oberwolfach,
Germany
- 1993 Computational Methods for Nonlinear Phenomena, Oberwolfach, Germany
International Conference on Advances in Geometric Analysis and Continuum Mechanics,
Stanford, California
- 1994 Motion by Mean Curvature and Related Topics, Trento, Italy

Conferences/Sessions organized

- 1980 Bifurcation Problems and Their Numerical Solution, Dortmund, Germany.
1983 Numerical Methods for Bifurcation Problems, Dortmund, Germany.
1985 SIAM Fall Meeting, Tempe, Arizona.
1986 Continuation Methods and Algorithms, minisymposium at SIAM National Meeting,
Boston.
1987 Nonlinear Parametrized Equations, minisymposium at ICIAM 87 meeting, Paris, France.
Nonlinear Parameter Dependent PDEs and their Effective Solution, Tempe, Arizona.
1989 Nonlinear Problems in PDE's, minisymposium at SIAM National Meeting, San Diego
1991 Stability Problems in Solid Mechanics, GAMM Workshop, Physics Center, Bad Honnef,
Germany

Selected invitations to Seminars/Colloquia

- 1984 University of Heidelberg, Germany
Federal Institute of Technology,
Lausanne, Switzerland
University of Paderborn, Germany
- 1985 University of Hannover, Germany
University of California, San Diego
University of Darmstadt, Germany
- 1986 University of Bonn, Germany
Free University of Berlin, Germany
Fraunhofer Institute for
Microelectronics, Duisburg,
Germany
Southern Methodist University, Dallas
- 1987 University of Wyoming, Laramie
University of Lyon, France
University of Grenoble, France
Universität der Bundeswehr, Munich,
Germany
University of Erlangen, Germany
University of Darmstadt, Germany
University of Nijmegen, Netherlands
University of Freiburg, Germany
- 1988 University of Mainz, Germany
University of Konstanz, Germany
Technical University of Berlin,
Germany
University of Paderborn, Germany
University of Münster, Germany
University of Cologne, Germany
University of Darmstadt, Germany
University of Augsburg, Germany
University of Würzburg, Germany
University of Heidelberg, Germany
University of Hamburg, Germany
University of Karlsruhe, Germany
University of Kaiserslautern, Germany
- 1989 University of Ulm, Germany
University of Heidelberg, Germany
- 1990 University of Darmstadt, Germany
University of Heidelberg, Germany
North Carolina State University
University of Aachen (RWTH),
Germany
- 1991 University of Kiel, Germany
University of Heidelberg, Germany
University of British Columbia,
Canada
- 1992 University of Stuttgart, Germany
University of Tübingen, Germany
Stanford University
Los Alamos National Laboratory
University of Leipzig, Germany
Technical University of Dresden,
Germany
- 1993 University of Darmstadt, Germany
University of Clausthal, Germany
University of Leipzig, Germany
University of Frankfurt, Germany
- 1994 Emory University
Georgia Institute of Technology

PUBLICATIONS OF HANS D. MITTELMANN

1. Die Approximation der Lösungen gemischter Randwertprobleme quasilinearer elliptischer Differentialgleichungen, *Computing* 13, 253-265 (1974)
2. Finite-Element Verfahren bei quasilinearen elliptischen Randwertproblemen, in "Numerische Behandlung nichtlinearer Integrodifferential- und Differentialgleichungen", R. Ansorge, W. Törnig (eds.), Springer Lecture Notes in Mathematics, vol. 395, 199-214, 1974
3. Stabilität bei der Methode der finiten Elemente für quasilineare elliptische Randwertprobleme, in "Numerische Behandlung von Differentialgleichungen", R. Ansorge, L. Collatz, G. Hämmerlin, W. Törnig (eds.), ISNM 27, 197-226, Birkhäuser-Verlag, Basel and Stuttgart, 1975
4. Existenz und Konvergenz von Lösungen diskreter Variationsprobleme, *Z. Angew. Math. Mech.* 55, T255-T257 (1975).
5. Nichtlineare Dirichletprobleme und einfache finite-element Verfahren, *Bonn. Math. Schr.* 77, 46-61 (1975).
6. Numerische Behandlung des Minimalflächenproblems mit finiten Elementen, in "Finite Elemente und Differenzenverfahren", J. Albrecht, L. Collatz (eds.), ISNM 28, 91-108, Birkhäuser-Verlag, Basel and Stuttgart, 1975.
7. Zur gleichmässigen Konvergenz einer Finite-Elemente Lösung des Minimalflächenproblems, *Z. Angew. Math. Mech.* 56, T304-T306 (1976).
8. Die Methode der finiten Elemente zur numerischen Lösung von Randwertproblemen quasilinearer elliptischer Differentialgleichungen. Habilitationsschrift, 99 pp., Technische Hochschule Darmstadt, 1976.
9. Über die Methode der finiten Elemente zur numerischen Lösung elliptischer Randwertprobleme 2. Ordnung (with W. Törnig), *Jahrbuch Überblicke Mathematik* 1977, 89-105, Bibliographisches Institut, Mannheim.
10. On pointwise estimates for a finite element solution of nonlinear boundary value problems, *SIAM J. Num. Anal.* 14, 773-778 (1977)
11. Numerische Behandlung nichtlinearer Randwertprobleme mit finiten Elementen, *Computing* 18, 67-77 (1977)
12. On the approximation of capillary surfaces in a gravitational field, *Computing* 18, 141-148 (1977)
13. On the approximate solution of nonlinear variational inequalities, *Numer. Math.* 29, 451-462 (1978)

14. Numerical methods for bifurcation problems - A survey and classification (with H. Weber), in "Bifurcation Problems and their Numerical Solution", H. D. Mittelmann, H. Weber (eds.), ISNM 54, 1-45, Birkhäuser-Verlag, Basel and Stuttgart, 1980
15. On the efficient solution of nonlinear finite element equations I, Numer. Math. 35, 277-291 (1980)
16. On the efficient solution of nonlinear finite element equations II. Bound-constrained problems, Numer. Math. 36, 375-387 (1981)
17. Some remarks on the discrete maximum-principle for finite elements of higher order (with W. Höhn), Computing 27, 145-154 (1981)
18. On the efficient solution of nonlinear finite element systems, in "Nonlinear Finite Element Analysis in Structural Mechanics", W. Wunderlich, E. Stein and K. J. Bathe (eds.), 621-636, Springer-Verlag, Berlin, 1981
19. On the numerical solution of contact problems, in "Numerical Solution of Nonlinear Equations", E. L. Allgower, K. Glashoff and H. O. Peitgen (eds.), Springer Lecture Notes in Mathematics, vol. 878, 259-274, 1981
20. Multi-grid methods for simple bifurcation problems, in "Multi-grid methods", W. Hackbusch, U. Trottenberg (eds.), Springer Lecture Notes in Mathematics, vol. 960, 558-575, 1982
21. Bifurcation problems for discrete variational inequalities, Math. Meth. in the Appl. Sci. 4, 243-258 (1982)
22. A Bibliography on Numerical Methods for Bifurcation Problems, Preprint 56, (Angewandte Mathematik), 32 pp., Universität Dortmund, 1982.
23. A fast solver for nonlinear eigenvalue problems, in "Iterative Solution of Nonlinear Systems", A. R. Ansorge, T. Meis and W. Törnig (eds.), Springer Lecture Notes in Mathematics, vol. 953, 46-67, 1982
24. On multi-grid methods for variational inequalities (with W. Hackbusch), Numer. Math. 42, 65-76 (1983)
25. An efficient algorithm for bifurcation problems of variational inequalities, Math. of Comp. 41, 473-485 (1983)
26. Multi-grid solution of bifurcation problems (with H. Weber), SIAM J. Sci. Stat. Comp. 6, 49-60 (1985)
27. Continuation near symmetry-breaking bifurcation points, in "Numerical Methods for Bifurcation Problems", T. Küpper, H. D. Mittelmann and H. Weber (eds.), ISNM 70, Birkhäuser-Verlag, 319-334, 1984.
28. A free boundary problem and stability for the nonlinear beam (with E. Miersemann), Math. Meth. in the Appl. Sci. 8, 516-532 (1986).

29. Multi-level continuation techniques for nonlinear boundary value problems with parameter-dependence, *Appl. Math. Comp.* 19, 265-282 (1986).
30. An algorithm that exploits symmetries in bifurcation problems (with B. Thomson), *Notes on Numer. Fluid Mech.* 16, 52-68 (1987).
31. A pseudo-arclength continuation method for nonlinear eigenvalue problems, *SIAM J. Numer. Anal.* 23, 1007-1016 (1986).
32. Continuation and multi-grid for nonlinear elliptic systems (with R. Bank), in "Multigrid Methods II", W. Hackbusch, U. Trottenberg (eds.), *Springer Lecture Notes in Mathematics*, vol. 1228, 24-37, 1986.
33. Multi-grid continuation and spurious solutions for nonlinear boundary value problems, *Rocky Mountain Math. J.* 18, 387-401 (1988).
34. A free boundary problem and stability for the circular plate (with E. Miersemann), *Math. Meth. in the Appl. Sci.* 9, 240-250 (1987).
35. On continuation for variational inequalities, *SIAM J. Numer. Anal.* 24, 1374-1381 (1987)
36. Approximation of obstacle problems by continuation methods (with F. Conrad and R. Herbin), *SIAM J. Numer. Anal.* 25, 1409-1431 (1988).
37. Continuity of closest rank-p approximations to matrices (with J. A. Cadzow), *IEEE Trans. Acoust., Speech, Signal Processing*, Vol. ASSP-35, 1211-1212 (1987).
38. On the continuation for variational inequalities depending on an eigenvalue parameter (with E. Miersemann), *Math. Meth. in the Appl. Sci.* 11, 95-104 (1989).
39. Continuation methods for parameter-dependent boundary value problems, *AMS Lectures in Appl. Math.* 25, 159-175 (1990).
40. A multi-grid continuation strategy for parameter-dependent variational inequalities (with R. H. W. Hoppe), *J. Comput. Appl. Math.* 26, 35-46 (1989).
41. Extension of Beckert's continuation method to variational inequalities (with E. Miersemann), *Math. Nachr.* 148, 183-195 (1990).
42. Step size selection in continuation procedures and damped Newton's method (with R. E. Bank), *J. Comput. Appl. Math.* 26, 67-77 (1989).
43. A finite element method for capillary surfaces with volume constraints (with U. Hornung), *J. Comput. Phys.* 87, 126-136 (1990).
44. Continuation for parametrized nonlinear variational inequalities (with E. Miersemann), *J. Comput. Appl. Math.* 26, 23-34 (1989).
45. The augmented skeleton method for parametrized surfaces of liquid drops (with U. Hornung), *J. Colloid Interface Sci.* 133, 409-417 (1989)
46. Nonlinear parametrized equations: new results for variational problems and inequalities, *AMS Lectures in Appl. Math.* 26, 451-466 (1990).

47. A free boundary problem and stability for the rectangular plate (with E. Miersemann), *Math. Meth. in the Appl. Sci.* 12, 129-138 (1990).
48. The obstacle Bratu problem, *AMS Lectures in Appl. Math.* 26, 747-748 (1990).
49. The augmented Skeleton method for parametrized capillary surfaces, in *Proceedings of the Fifth International Symposium on Numerical Methods in Engineering*. Vol. 2, 227-234, R. Gruber, J. Periaux, and R. P. Shaw (eds.) Springer-Verlag, Berlin, 1989.
50. On the stability in obstacle problems with applications to the beam and plate (with E. Miersemann), *Z. Angew. Math. Mech.* 71, 311-321 (1991).
51. Energy stability of thermocapillary convection in a model of the float-zone, crystal-growth process (with Y. Shen, G.P. Neitzel and D. F. Jankowski), *J. Fluid Mech.* 217, 639-660 (1990).
52. Computing stability bounds for thermocapillary convection in a crystal-growth free boundary problem, in "Free Boundary Problems," K.-H. Hoffmann, J. Sprekels (eds.), *ISNM 95*, 165-180, Birkhäuser-Verlag, Basel, 1990.
53. Stability of Marangoni convection in a microgravity environment, in "Continuation and Bifurcations: Numerical Techniques and Applications," D. Roose, B. De Dier, and A. Spence (eds.), *NATO ASI Series C*, Vol. 313, 363-377, Kluwer, Dordrecht, 1990.
54. The nonlinear beam via optimal control with bounded state variables (with H. Maurer), *Optimal Control Applications and Methods* 12, 19-31 (1991).
55. A large sparse and indefinite generalized eigenvalue problem from fluid mechanics (with C. Law, D. F. Jankowski, G. P. Neitzel), *SIAM J. Sci. Stat. Comp.* 13, 411-424 (1992).
56. Computation of parametrized capillary surfaces, in "Contributions to the Numerics of Partial Differential Equations," *THD Schriftenreihe Wissenschaft und Technik*, vol. 52, 187-202, Technical University of Darmstadt Press, Darmstadt, 1991.
57. Stability and continuation of solutions to obstacle problems (with E. Miersemann), *J. Comp. Appl. Math.* 35, 5-31 (1991).
58. Stability in obstacle problems for the von Karman plate (with E. Miersemann), *SIAM J. Math. Anal.* 23, 1099-1116 (1992).
59. Stability of thermocapillary convection in float-zone crystal growth (with C. Law, D.F. Jankowski, G.P. Neitzel), in "Numerical Methods for Free Boundary Problems," P. Neittaanmäki (ed.), *ISNM99*, 58-69, Birkhäuser-Verlag, Basel, 1991.
60. Bifurcation of axially symmetric capillary surfaces (with U. Hornung), *J. Colloid Interface Sci.* 146, 219-225 (1991).
61. Stability and instability of thermocapillary convection in models of float-zone crystal growth (with G. P. Neitzel, C. C. Law, D. F. Jankowski), in *Proceedings of the AIAA/IKI Microgravity Sciences Symposium*, Moscow, USSR, pp. 57-65, 13-17 May 1991.
62. Energy stability of thermocapillary convection in a model of the float-zone crystal-growth process. Part 2. Non-axisymmetric disturbances (with G. P. Neitzel, C. C. Law, D. F. Jankowski), *Phys. Fluids A*. 3, 2841-2846 (1991).

63. Linear stability of axisymmetric thermocapillary convection in crystal growth (with K.-T. Chang, D. F. Jankowski, and G. P. Neitzel). In "Bifurcation and Symmetry," E. Allgower, K. Böhmer, and M. Golubitsky (eds.), ISNM 104, 275-284, Birkhäuser-Verlag, Basel., 1992.
64. Linear-stability theory of thermocapillary convection in a model of float-zone crystal growth (with G. P. Neitzel, K.-T. Chang, and D. F. Jankowski), Paper AIAA-92-0604, Proceedings of the AIAA 30th Aerospace Sciences Meeting, Reno, NV, January 6-9, 1992.
65. Symmetric capillary surfaces in a cube, *Math. Comp. Simulation* 35, 139-152 (1993).
66. Iterative solution of the eigenvalue problem in Hopf bifurcation for the Boussinesq equations (with G. P. Neitzel, K.-T. Chang, and D. F. Jankowski), to appear in *SIAM J. Sci. Stat. Comp.*
67. Linear-stability theory of thermocapillary convection in a model of the float-zone crystal growth process (with G. P. Neitzel, K.-T. Chang, and D. F. Jankowski), *Phys. Fluids A*, 5, 108-114 (1993).
68. Symmetric capillary surfaces in a cube, part II: Near the limit angle, *AMS Lectures in Appl. Math.* 29, 339-361 (1993)
69. Stability analysis of thermocapillary convection in semiconductor crystal growth, to appear in "Mathematical Modeling and Simulation of Electrical Circuits and Semiconductor Devices," R.E. Bank, R. Bulirsch, H. Gajewski, and K. Merten (eds.), ISNM series, Birkhäuser-Verlag, Basel.
70. Thermocapillary convection instability in microgravity crystal growth (with G. P. Neitzel, D. F. Jankowski, and K.-T. Chang), in *Proceedings of the VIIIth European Symposium on Materials and Fluid Sciences in Microgravity*, European Space Agency, ESA SP-333, 463-467, Paris, France, 1992.
71. Hydrodynamic stability of thermocapillary convection in cylindrical liquid bridges, submitted to *Math. Comp. Modelling*.

BOOKS/EDITORSHIPS

1. *Bifurcation Problems and their Numerical Solution* (editor; H. Weber coeditor), ISNM 54, Birkhäuser - Verlag, Basel and Boston, 1980.
2. *Numerical Methods for Bifurcation Problems*, (editor; T. Küpper and H. Weber coeditors), ISNM 70, Birkhäuser - Verlag, Basel and Boston, 1984.
3. *Continuation Techniques and Bifurcation Problems* (editor; D. Roose coeditor), special volume 26 (1989) of *Journal of Computational and Applied Mathematics*, reprinted as ISNM 92, Birkhäuser-Verlag, Basel and Boston, 1990.