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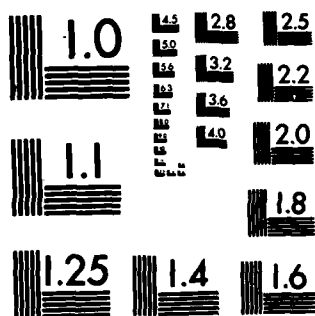
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Final Technical Report

U. S. Army Research Office

Grant DAAG29 76 G 0294

September 1, 1976 - August 31, 1979

Principal Investigator: Professor J. P. LaSalle

Grant DAAG29-79 C 0161

September 1, 1979 - September 24, 1982

Principal Investigators: H. T. Banks
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H. T. Banks
January 10, 1983

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ABSTRACT

This Final Technical Report summarizes research findings supported by Grants DAAG29 76 G 0294 (during period 9/1/76-8/31/79) and DAAG29 79 C 0161 (during period 9/1/79-9/24/82). The principal areas of research ^{reported} are:

- 1) Functional and partial differential equations and their control and estimation;
- 2) Hyperbolic systems of conservation laws;
- 3) Continuum physics;
- 4) Stability of nonlinear evolution equations;
- 5) Linear and nonlinear dynamical systems and their stability; and
- 6) Bifurcation theory.

This report briefly summarizes results and refers to specific publications and reports previously reported to the U. S. Army Research Office.



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I. Foreword

This is the Final Technical Report on the research project entitled Research on Nonlinear Dynamical Systems supported through Grants DAAG29 76 G 0294 during the period September 1, 1976 - August 31, 1979 and DAAG29-79 C 0161 During the period September 1, 1979 - September 24, 1982.

The focus of research in this project was in several inter-related areas: 1) Control and parameter estimation for delay and partial differential equations, 2) Qualitative theory including stability and bifurcation for delay and partial differential equations, and 3) Conservation laws and stability in continuum physics.

A brief summary of major research accomplishments and applications is reported in Section II. Each subsection, reporting on a research area, refers to reports or publications previously reported to the U. S. Army Research Office. These publications and reports are listed in Section III.

The final section reports the personnel supported from these grants.

II. Summary of Research Accomplishments and Applications

Banks and coworkers in [1-6,8-10,14-16]^{*} deal with approximation methods for delay equations with applications to computational algorithms for optimal control and parameter estimation, including estimation of multiple delays in nonlinear systems. In [7,11-13,15,17-19,21,22] are found results for spline and modal approximation schemes for parabolic and hyperbolic systems of partial differential equations, including higher order equations of elasticity based on the Euler-Bernoulli and Timoshenko theories. The approximation ideas are applied to develop algorithms for estimation of parameters including unknown functional coefficients and boundary parameters.

Dafermos and coworkers have obtained [28],[34],[38] results pertaining to existence, smoothness, and asymptotic behavior of solutions to hyperbolic conservation laws. Results in continuum physics related to the role of the second law of thermodynamics in inducing admissibility, uniqueness, and stability of solutions can be found in [30-33], while the role of dissipation as a stabilizing mechanism that counterbalances the destabilizing effects of nonlinearity in evolution equations is investigated in [33,36,37,39,40].

Hale and his coworkers have investigated fundamental aspects of functional differential equations, including qualitative questions (stability, nonlinear oscillations), in [42,45,47,52-57,62,66,68,74]. Specific problems in nonlinear oscillations (subharmonics, homoclinic orbits, etc.) in ordinary differential equations are dealt with in [43,44,50,60,61,70,71] using bifurcation theory and averaging. General bifurcation theory and the change in

^{*} References refer to publications listed in Section III.

stability at bifurcation for finite and infinite dimensional dynamical systems is investigated in [46,48-51,58,59,63,64,69]. Finally, stability and bifurcation in parabolic partial differential equations is the focus of [64,65,67,72,73].

In addition to these broad ranges of activities by the principal investigators, a number of postdocs and visitors have investigated a diverse number of related topics which have been detailed in the previous progress reports and in the references found in the next section.

III. Publications supported by ARO Grant DAAG29 76 G 0294 during period September 1, 1976 - August 31, 1979, and by Grant DAAG29-79 C 0161 during period September 1, 1979 - September 24, 1982. Copies of all publications have been previously sent to the Army Research Office and are numbered below as references to Section II.

BANKS, H.T.

- [1] Approximation of delay systems with applications to control and identification, Proc. International Conference on FDE and Approximation of Fixed Points, Bonn, July 1978, Springer Verlag Lecture Notes in Math., Vol. 730, (1979), pp. 65-76.
- [2] (with F. Kappel), Spline approximations for functional differential equations, J. Differential Equations, 34(1979), pp.496-522.
- [3] (with J. Burns and E. Cliff), Spline based approximation methods for control and identification of hereditary systems, International Symposium on Systems Optimization and Analysis (A. Bensoussan and J.L. Lions, eds.), Lecture Notes in Control & Info. Sciences, Vol.14, Springer, Heidelberg, 1979, pp.314-320.
- [4] (with J.A. Burns and E.M. Cliff), Parameter estimation and identification for systems with delays, SIAM J. on Control & Optimization, 19 (1981), pp.791-828.
- [5] (with J.A. Burns and E.M. Cliff), A comparison of numerical methods for identification and optimization problems involving control systems with delays, LCDS Tech. Report 79-7, 11/1979.
- [6] Identification of nonlinear delay systems using spline methods, Proc. Conf. on Nonlinear Phenomena in Math. Sciences (V. Lakshmikantham, ed.), Academic Press, 1982, pp.47-55.
- [7] (with K. Kunisch), Parameter estimation techniques for nonlinear distributed parameter systems, Proc. Conf. Nonlinear Phenomena in Math. Sciences (V. Lakshmikantham, ed.), Academic Press, 1982, pp.57-67.
- [8] Computational difficulties in the identification and optimization of control systems, (T. Vincent, ed.), Lecture Notes in Biomath. Vol.40, Springer-Verlag, 1981, pp.79-94.
- [9] Parameter identification techniques for physiological control systems, Lectures in Applied Math., Amer. Math. Soc., Prov., R.I., Vol.19 (1981), pp.361-383.

page 2 of publications

BANKS, H.T. - continued

- [10] (with I.G. Rosen), Approximation techniques for parameter estimation in hereditary control systems, Proc. 19th IEEE Conference on Decision and Control, (1980), pp.741-743.
- [11] (with K. Kunisch), An approximation theory for nonlinear partial differential equations with applications to identification and control, SIAM J. Control & Optimization, 20, 11(1982), pp.815-849.
- [12] (with J.M. Crowley and K. Kunisch), Cubic spline approximation techniques for parameter estimation in distributed systems, IEEE Trans. Auto. Control, to appear.
- [13] (with J.M. Crowley), Parameter estimation for distributed systems arising in elasticity, Proc. Symposium on Engineering Sciences and Mechanics (National Cheng Kung University), Tainan, Taiwan, Dec. 1981, pp.158-177.
- [14] (with P.L. Daniel), Estimation of delays and other parameters in nonlinear functional differential equations, SIAM J. Control & Optimization, to appear.
- [15] (with P.L. Daniel), Parameter estimation of nonlinear non-autonomous distributed systems, Proc. 20th IEEE Conf. on Decision and Control, San Diego, Dec. 1981, pp.228-232.
- [16] (with I.G. Rosen), Spline approximations for linear nonautonomous delay systems, ICASE Rep. No. 81-33, NASA Langley Res. Center, 10/1981, J. Math. Anal. & Appl., to appear.
- [17] (with J.M. Crowley), Parameter estimation in Timoshenko beam models, J. Astronautical Sci., to appear.
- [18] Distributed system optimal control and parameter estimation: computational techniques using spline approximations, Proc. 3rd IFAC Symposium on Control of Distributed Parameter Systems, Toulouse, France, June 29-July 2, 1982.
- [19] Algorithms for estimation in distributed models with applications to large space structures, Proc. Workshop on Applications of Distributed System Theory to the Control of Large Space Structures, JPL, Calif. Inst. Tech, (July 1982), Pasadena, Calif.
- [20] (same as [14]) (with P.L. Daniel), Estimation of delays and other parameters in nonlinear functional differential equations, SIAM J. Control & Optimization, to appear.
- [21] (with P. Kareiva), Parameter estimation techniques for transport equations with application to population dispersal and tissue bulk flow models, J. Math. Biol., submitted.

page 3 of publications

BANKS, H.T. - continued

- [22] (with P.L. Daniel), Estimation of variable coefficients in parabolic distributed systems, IEEE Trans. Auto.Control, submitted.

CARR, J.

- [23] (with N. Al-Amood), Rate of decay estimates in critical cases: I, Finite dimensional problems, II, Infinite dimensional problems, JMAA 75, 5(1980), pp.242-250 and JMAA 75, 6(1980), pp.293-299.
- [24] Applications of Centre Manifold Theory, Applied Math. Science Series, Springer-Verlag 1980.

CHIPOT, M.

- [25] (with Jose-Francisco Rodrigues), On the steady-state continuous casting Stefan problem with nonlinear cooling, Quarterly of Applied Math., to appear.
- [26] Variational inequalities and flow in porous media, LCDS Lecture Notes, Brown University #LN 82-1, July 1982.
- [27] On the equations of age-dependent population dynamics, LCDS Report #82-1, Brown University, March 1982.

DAFERMOS, C.M.

- [28] Generalized characteristics and the structure of solutions of hyperbolic conservation laws, Indiana Univ. Math. J. 26(1977), 1097-1119.
- [29] Almost periodic processes and almost periodic solutions of evolution equations. Dynamical Systems (A Bednarek and L. Cesari, Eds.), Academic Press, New York 1977, pp.43-57.
- [30] Stability of motions of thermoelastic fluids, J. Thermal Stresses, 2(1979), pp.127-134.
- [31] The second law of thermodynamics and stability, Arch. Rat. Mech. Anal., 70(1979), pp.167-179.
- [32] Hyperbolic balance laws in continuum physics, Springer Lecture Notes in Physics, No. 98(1979), pp.107-121.
- [33] The equations of elasticity are special, Trends in Applications of Pure Mathematics to Mechanics, Vol. III (R.J. Knops, Ed.), Pitman, London (1981), pp.96-103.

page 4 of publications

DAFERMOS, C.M. - continued

- [34] Asymptotic behavior of solutions of hyperbolic balance laws, Bifurcation Phenomena in Mathematical Physics (C. Bardos, Ed.), D. Reidel, Dordrecht, 1980, pp.521-533.
- [35] Conservation laws with dissipation, Proc. International Conf. on Nonlinear Phenomena in Mathematical Sciences (V. Lakshmikantham, Ed.), Academic Press, 1982.
- [36] Can dissipation prevent the breaking of waves? Proc. of 26th Conf. of Army Mathematicians, June 9-12, 1980, Hanover, N.H., (1981) pp.187-198.
- [37] (with J.A. Nohel) A nonlinear hyperbolic Volterra equation in visco-elasticity, American J. Math. Supplement dedicated to P. Hartman (1981), pp.87-116.
- [38] (with L. Hsiao) Hyperbolic systems of balance laws with inhomogeneity and dissipation, Indiana U. Math. Journal, to appear.
- [39] (with L. Hsiao) Adiabatic shearing of incompressible fluids with temperature dependent viscosity, LCDS Report #82-12, Brown University, 3(1982).
- [40] Stabilizing effects of dissipation, Proceedings of Equadiff 1982, to appear.

DACOROGNA, B.

- [41] A generic result for non-convex problems in the calculus of variations, LCDS Report #81-3, Brown University, 3(1981).

HALE, J.K.

- [42] Theory of Functional Differential Equations, Applied Math. Science Series, Vol. 3, 1977, Springer-Verlag.
- [43] (with H. Rodrigues) Bifurcation in the Duffing equation with several parameters, II. Proc. of the Royal Society of Edinburgh, Series A, 79A (1977), pp.317-326.
- [44] (with Táboas) Interaction of damping and forcing in a second order equation, J. Nonlinear Analysis: Theory, Methods & Applications, Vol. 2, No.1(1978), pp.77-84.
- [45] (with J. Kato) Phase space for retarded equations with infinite delays, Funk. Ekvacioj, Vol.21, No.1, 12(1978), pp.11-41.

page 5 of publications

HALE, J.K. - continued

- [46] Bifurcation near families of solutions. Proc. International Conf. on Differential Equations, Uppsala (1977) Lecture Notes in Math., Springer-Verlag.
- [47] (with P. Martinez-Amores) Stability in neutral equations, J. Nonlinear Analysis: Theory Methods and Applications, Vol. 1, No. 2, (1977), pp.161-173.
- [48] Restricted generic bifurcation. Proc. Math. Conference, Gainesville, Florida, March 23-26, 1976.
- [49] Bifurcation from simple eigenvalues for several parameter families, J. Nonlinear Analysis: Theory, Methods & Applications, Vol.2, No.4, pp.491-497.
- [50] Bifurcation near degenerate families, J. Applicable Analysis Vol. 11 (1980), pp.21-37. (with Táboas)
- [51] Topics in local bifurcation theory (Bifurcation Theory & Applications in Scientific Disciplines - Okan Gurel & Otto E. Rossler, Eds.), Annals, N.Y.Academy of Sciences, Vol. 316 (1979), pp.605-607.
- [52] Some recent results on dissipative processes, Functional Differential Equations and Bifurcation, Springer Lecture Notes in Mathematics, Vol.799 (1979).
- [53] Retarded equations with infinite delays. Proc. Functional Differential Equations & Approximation of Fixed Points (Ed. Peitgen & Walther), Lecture Notes in Mathematics, Vol. 730 (1979).
- [54] Nonlinear oscillations in equations with delays. Proc. at A.M.S. 10th Summer Seminar on Nonlinear Oscillations in Biology, Univ. of Utah, Salt Lake City, June 12-23, 1978.
- [55] Variations in delays in difference and differential equations. Proc. IV Escuela Latina America, Lima, Peru, 1978.
- [56] (with C.E. Avellar), On the zeros of exponential polynomials, JMAA, Vol. 73(1980), pp.434-452.
- [57] (with J.C.F. de Oliveira), Hopf bifurcation for functional equations, JMAA, Vol. 74(1980) pp.41-59.
- [58] (with J.C.F. de Oliveira), Dynamic behavior from bifurcation equations, Tohoku Math. Journal, Vol. 32, No.4.
- [59] Stability from the bifurcation function, Differential Equations, Academic Press, Inc. 1980, pp.23-30.

HALE, J.K. - continued

- [60] Remarks on bifurcation theory in differential equations, Proc. New Approaches to Nonlinear Problems in Dynamics (P.J. Holmes, ed.) SIAM Publications (1980).
- [61] (with S-N Chow and J. Mallet-Paret)
An example of bifurcation to homoclinic orbits, J. Differential Equations, Vol.37(1980), pp.351-373.
- [62] Generic properties of an integro-differential equation, Conf. on Differential Equations in Analysis and Geometry, April 24,25,1980, Baltimore, Maryland.
- [63] Topics in Dynamic Bifurcation Theory, Proc. NSF-CBMS Conf., Arlington, Texas, June 16-20, 1980.
- [64] Stability and bifurcation in a parabolic equation, Proc. of Dynamical Systems, Stability and Turbulence, Univ. of Warwick, England, July 1980, Lecture Notes in Math, Springer-Verlag, 1981.
- [65] (with J. Vegas), A nonlinear parabolic equation with varying domain, Archives of Rational Mechanics, submitted.
- [66] (with Luis Magalhães), An example of boundary layer in delay equations, Proc. Volterra & Functional Differential Equations, Lecture Notes in Pure & Applied Math. 81 (Eds. Hannsgen, Herdman, Stech, Wheeler), Marcel-Dekker 1982.
- [67] (with P. Massatt), Asymptotic behavior of gradient-like systems, Proc. International Symposium on Dynamical Systems, Gainesville, Florida, Feb. 1981.
- [68] (with K. Rybakowski), On a gradient-like integro-differential equation, Proc. Royal Society of Edinburgh, to appear.
- [69] Infinite dimensional dynamical systems, Proc. Conf. on Dynamical Systems, Rio de Janeiro, Brazil, July 27- Aug.1981, to appear.
- [70] (with A. Spezamiglio), Perturbation of homoclinics and subharmonics in Duffing's equation, J. Nonlinear Analysis: Theory, Methods & Applications, to appear.
- [71] (with L.C. Pavlu), Dynamic behavior from asymptotic expansions, Quarterly of Applied Math., submitted.
- [72] (with M. Chipot), Stable equilibria with variable diffusion, Proc. Non-linear PDE Conf., Contemporary Math. Series, American Mathematical Society, to appear.

page 7 of publications

HALE, J.K. - continued

- [73] Dynamics in parabolic equations - An example, Proc. of LMS Advanced Study Institute, D. Reidel Pub. Co. (NATO Series).
- [74] (with E.F. Infante and F.P. Tsen), Stability in linear delay equations, to be submitted to JMAA.

HARAUX, A.

- [75] Behaviour at infinity for dissipative systems with forcing term in Hilbert Space. Proc. of Royal Soc. of Edinburgh 84A(1979), nn.214-234.
- [76] (with Marco Biroli) Asymptotic behavior for an almost periodic, strongly dissipative wave equation. J. Differential Equations, 38 (1980), pp.422-440.

INFANTE, E.F.

- [77] (with J.A. Walker) A perturbation approach to the stability of undamped linear elastic systems subjected to follower forces, JMAA 63, 5(1978), pp.654-677.
- [78] (with W.B. Castelan) A Liapunov functional for a matrix difference-differential equation, J. of Differential Equations, 29, 9(1978), pp.439-451.
- [79] (with W.B. Castelan) On a functional equation arising in the stability theory of difference-differential equations, Quarterly of Applied Math., XXXV, 10(1977), pp.311-319.
- [80] (with J.A. Walker) A Liapunov functional for a scalar differential difference equation, Proc. of Royal Soc. of Edinburgh, 79A, (1977), pp.307-316.
- [81] (with J.A. Walker) On the behavior of linear undamped elastic systems perturbed by the following forces. Proc. of Int'l Symposium on Dynamical Systems, Gainesville, Florida (A. Bednarek, ed.) Dynamical Systems, (1977) pp.101-112.
- [82] (with J.A. Walker) On the stability of an operator equation modeling nuclear reactors with delayed neutrons. Quarterly of Applied Math., 1(1977), pp.421-427.
- [83] (with W.B. Castelan) A Liapunov functional for a matrix neutral difference-differential equation with one delay, JMAA, 71, 9(1979), pp.105-130.
- [84] (with W.B. Castelan) On the structure of a Liapunov functional for a difference-differential equation with one delay. Proc. of Equadiff '78.

page 8 of publications

INFANTE, E.F. - continued

- [85] (with J.A. Walker) A stability investigation for an incompressible simple fluid with fading memory, Archives for Rational Mechanics 72, (1980).
- [86] (with L.A.V. Carvalho and J.A. Walker) On the existence of simple Liapunov functions for linear retarded difference differential equations, Tohoku Math. J. 32, 6(1980) pp.283-297.

JAKUBCZYK, B.

- [87] Invertible realizations of nonlinear discrete-time systems. Proc. Conference on Information Sciences and Systems, March 1980.

KAPPEL, F.

- [88] An approximation scheme for delay equations, Proc. of International Conf. on Nonlinear Phenomena in Mathematical Sciences, June 1980.

KUNISCH, K.

- [89] The Riccati integral equation arising in optimal control of delay differential equations. Proc. of International Conf. on Nonlinear Phenomena in Mathematical Sciences, June 1980.
- [90] Approximation schemes for nonlinear neutral optimal control systems, JMAA 82 (1981), pp.112-143.
- [91] Approximation schemes for the linear-quadratic optimal control problem associated with delay equations, SIAM J. Control and Optimization, 20 7(1982), pp.506-540.
- [92] A semigroup approach to partial differential equations with delay, Pitman Research Notes in Mathematics.

LANGENIOP, C.E.

- [93] Controllability and stabilizability of regular singular linear systems with constant coefficients, SIAM J. on Control & Optimization (1981).

page 9 of publications

LaSALLE, J.P.

- [94] Stability of nonautonomous systems, Journal of Nonlinear Analysis: Theory, Methods, and Applications, Vol.1, No.1, (1976), pp.83-91.
- [95] New stability results for nonautonomous systems. Proc. of Int'l Symposium on Dynamical Systems, Gainesville, Florida, (Ed. A. Bednarek) Dynamical Systems (1977), pp.101-112.
- [96] Stability Theory for Difference Equations, MAA Studies in Math. Jack K. Hale, editor), Vol. 14, (1977), pp.1-31.

MALLET-PARET, J.

- [97] Buckling of cylindrical shells with small curvature, Quarterly of Applied Math. 10(1977), pp.383-400.
- [98] (with S.N. Chow) The parameterized obstacle problem, Journal of Nonlinear Analysis: Theory, Methods & Applications 4, (1980), pp.73-91.
- [99] (with S.N. Chow) The Fuller index and global Hopf bifurcation, Journal of Differential Equations 28(1978), pp.66-85.
- [100] (with S.N. Chow and J.A. Yorke) Finding zeros of maps: homotopy methods that are constructive with probability one. Journal of Math. Computation 32, 7(1978), pp.887-899.
- [101] (with S.N. Chow and J.A. Yorke) Global Hopf bifurcation from a multiple eigenvalue, Journal of Nonlinear Analysis: Theory, Methods & Applications 2, (1978), pp.753-763.
- [102] Generic periodic solutions of functional differential equations, Journal of Differential Equations 25, 8(1977), pp.163-183.
- [103] (with S.N. Chow) Integral averaging and bifurcation, Journal of Differential Equations 26, 10(1977), pp.112-159.
- [104] Generic bifurcation in the obstacle problem, Quarterly of Applied Math., (1978).
- [105] Generic unfoldings and normal forms of some singularities arising in the obstacle problem, Duke Math. Journal 46 9(1979), pp.645-683.
- [106] (with S.N. Chow and J.A. Yorke) A homotopy method for locating all zeros of a system of polynomials, Lecture Notes in Mathematics, Springer-Verlag vol. 730, (1979), pp.77-88.

page 10 of publications

MALLET-PARET, J. - continued

- [107] (with J.A. Yorke) Snakes: Oriented families of periodic orbits, their sources, sinks, and continuation 43 3(1982), pp.419-450.
- [108] (with K.T. Alligood and J.A. Yorke) Families of periodic orbits: local continuability does not imply global continuability. J. of Topology (1982).
- [109] (with S.N. Chow and J.A. Yorke) A periodic orbit index which is a bifurcation invariant, LCDS Report #81-15, Brown University, 6(1981).

OLIVA, W.M.

- [110] Retarded equations on the sphere induced by linear equations, Journal of Differential Equations, submitted.

ROSEN, I.G.

- [111] A discrete approximation framework for hereditary systems. Journal of Differential Equations 40, 6(1981), pp.377-448.

RYBAKOWSKI, K.

- [112] Wazewski's principle for retarded functional differential equations, Journal of Differential Equations 39, 2(1981), pp.131-150.

Personnel

1. Faculty Personnel

The following faculty personnel were partially supported by
Grant #DAAG29 76 G 0294 during the period 9/1/76 - 8/31/79:

Professor D. M. Dafermos

Professor Jack K. Hale

Professor E. F. Infante

Professor J. P. LaSalle

Professor J. Mallet-Paret

2. Graduate Student Personnel

The following graduate students were partially supported by
the above grant during this period:

* R. M. Bates, Research Assistant

G. Fusco, Research Assistant

* J. M. Mahaffy, Research Assistant

* J. W. Palmer, Research Assistant

* D. C. Reber, Research Assistant

* F. S. Tsen, Research Assistant

L. Turyn, Research Assistant

* Awarded Ph.D. degree
in Applied Mathematics

Personnel

1. Faculty Personnel

The following faculty personnel were partially supported by

Grant #DAAG29 79 C 0161 during the period 9/1/79 - 9/24/82:

Professor H. T. Banks
Professor C. M. Dafermos

Professor Jack K. Hale

* Professor E. F. Infante

Professor J. P. LaSalle

Professor J. Mallet-Paret

* On leave of absence from Brown University for the period 9/1/79 - 8/31/80
and also for the period 9/10/81 - 8/31/82.

2. Graduate Student Personnel

The following graduate students were partially supported by the
above grant during this period:

Sungki Chun, Research Assistant

* P. L. Daniel, Research Assistant

* W. J. Hrusa, Research Assistant

R. H. Laprade, Research Assistant

D. C. Levine, Research Assistant

* L. T. Magalhaes, Research Assistant

K. A. Murphy, Research Assistant

J. Quandt, Research Assistant

* I. G. Rosen, Research Assistant

A. Shwartz, Research Assistant

N. C. Sternberg, Research Assistant

* E. A. Takigawa, Research Assistant

* L. Turyn, Research Assistant

J. Vegas, Research Assistant

* Awarded Ph.D. degree
in Applied Mathematics

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