MODELING AMPHIBIOUS LANDINGS INVOLVING MINE WARFARE

C. F. Borges, Associate Professor
Department of Mathematics
Sponsor: Office of Naval Research

OBJECTIVE: To continue to build upon a model representation of special operations units and mine warfare components in a traditionally land-based combat model. The research will evaluate the ability of the model to capture the salient aspects of these warfare types. These additions, if practical, will make the current JANUS Joint Warfare scenario more robust in its ability to represent operations in a littoral environment. This work will extend our current scenarios of an amphibious landing to include the continuation of operations ashore.

SUMMARY: This research was integrated into the student theses of CPT Bob Lazzell (USA), Capt Ron Middlebrook (USMC), and CPT Kent Wineingar (USA). A fairly complex scenario for an amphibious assault on a mined beach in JANUS was built. This scenario was based on the KERNEL BLITZ 1995 exercise. An attempt was made to duplicate it in some detail. Actual information was used for staging this exercise to determine troop and equipment placement and routes, etc. Some aspects of this work were presented at the 65th MORS conference. Various aspects of this work have been briefed to visiting flag officers and others.

CONFERENCE PRESENTATION:

Middlebrook, E.E., Mansager, B, and Borges, C.F. "A Combat Simulation Analysis of Autonomous Legged Underwater Vehicles," 65th Military Operations Research Society Symposium, Quantico, VA, June 1997. (This presentation was voted best in working group and was nominated for the Barchi prize.)

DoD KEY TECHNOLOGY AREA: Modeling and Simulation

KEYWORDS: Mine Countermeasures, High-Resolution Combat Simulation

COMPRESSION OF IMAGES IN SUPPORT OF TACTICAL OPERATIONS

C. F. Borges, Associate Professor
Hal Fredricksen, Professor
Department of Mathematics
Sponsor: Navy Engineering Logistics Office

OBJECTIVE: To investigate image compression algorithms, especially the Radiant TIN algorithm and its use on tactical imagery.

SUMMARY: Several aspects of this problem were examined. The main initial thrust focused on trying to understand the workings of the Radiant TIN algorithm and to look for areas which might be improved. It was noted that the algorithm might benefit from the use of simple representations of texture that were not deterministic. The focused was primarily on investigating that possibility and developing a number of methods that might allow the use of Markov Random Fields in this capacity. One thesis student worked on this project, and one paper is in review containing results from this project.

PUBLICATION:

Borges, C.F., "On Estimating the Parameters of a Markov Random Field," submitted to *IEEE Transactions on Pattern Analysis and Machine Intelligence.*

THESIS DIRECTED:

Korn, Chris, "Using Markov Random Fields for Texture Compression," Master's Thesis, Naval Postgraduate School, March 1997.

DoD KEY TECHNOLOGY AREA: Other (Image Processing)

KEYWORDS: Image Compression, Markov Random Fields

NUMERICAL SIMULATION OF THERMOCAPILLARY CONVECTION IN WELDING

D. R. Canright, Associate Professor
Department of Mathematics
Sponsor: Naval Postgraduate School

OBJECTIVE: The goal of this project is to determine the scaling and structure of the "cold-corner singularity" in thermocapillary flow in weld pools. This is a continuing project.

SUMMARY: Recent work in modeling thermocapillary convection in materials processing, for example in the pool of liquid metal formed during welding, shows a region of rapid flow and intense heat transfer, concentrated in the "cold corner" region. A theoretical understanding of this region, currently lacking, is essential for accurate numerical models. The objective of this study is to analyze the coupled thermal and flow fields in this important region. The results should be useful in developing more complete numerical models of the welding process, to understand how to make welds more reliable.

Work in 1997 extended the working simulation code through the development, implementation, and testing of two additional components: the moving phase-change boundary and the Eulerian-Lagrangian Method (ELM) for the nonlinear convective terms. The phase interface moves through the local fixed triangular grid (adapted to the smallest local length scales) as material melts or solidifies, as governed by the heat balance. Because of the variety of ways the interface can cross the grid elements, many different cases had to be considered. The nonlinear convective terms were initially implemented using Finite-Volume Elements (FVE) for the flow velocity as well as the convected quantity (heat or vorticity, depending), but this was found to be inaccurate for convectively-dominated regimes. Hence these terms were reformulated using ELM, which is known to be both accurate and stable (with appropriate restrictions on the local time step) for the full range of parameters. The details of discretization and implementation for these two components were fully worked out, and most of the programming was completed and partly debugged.

DoD KEY TECHNOLOGY AREA: Materials, Processes, and Structures

KEYWORDS: Thermocapillary, Solidification, Welding, Crystal Growth, Marangoni, Convection

LINEAR ELASTIC BEHAVIOR OF ORTHOGONALLY STIFFENED PLATE PANELS

D. A. Danielson, Professor
Department of Mathematics
Sponsor: Naval Surface Warfare Center-Carderock Division

OBJECTIVE: To improve structural design of ships.

SUMMARY: The subject of this work is the mechanical behavior of stiffened plates, basic structural components of ships and submarines. The buckling loads of grillages subjected to axial compression with and without lateral pressure are calculated using a finite element based eigenvalue analysis.

PUBLICATION:

Danielson, D., "Buckling of Ship Grillages," Naval Postgraduate School Technical Report, NPS-MA-97-005, September 1997.

DoD KEY TECHNOLOGY AREAS: Computing and Software, Modeling and Simulation, Other (Structures, Ships)

KEYWORDS: Plates, Ships, Structures, Buckling

COMANCHE PROGRAM REVIEW

D. A. Danielson, Professor
Department of Mathematics
E.R. Wood, Professor
Department of Aeronautics and Astronautics
J. H. Gordis, Assistant Professor
Department of Mechanical Engineering
Sponsor: U.S. Army Comanche Program Office

OBJECTIVE: To study vibration/structural dynamics of the RAH66 Comanche helicopter.

SUMMARY: Nine structural modifications to the Comanche tailcone were developed conceptually, then analyzed using the NASTRAN/PATRAN finite element code. The addition of radar absorbing material (RAM) on the outer skin of the modified model costs only a 6 per cent reduction in torsional stiffness from baseline values, as compared to a 24 per cent reduction in tailcone stiffness for adding the same amount of RAM were these structural modifications not incorporated into the design. Additional suggested improvements include reversing the tail landing gear assembly, so that it would be anchored to the forward landing gear bay bulkhead and not to the aft landing gear bay bulkhead.

PUBLICATIONS:

Danielson, D. A., "Buckling of Ship Grillages," Naval Postgraduate School Technical Report, NPS-MA-97-005, September 1997.

Danielson, D. A, et al., "Research in the Structural Dynamic Response of the RAH-66 Comanche Helicopter," Naval Postgraduate School Report, December 1997.

THESES DIRECTED:

Shoop, B., "Structural Design Analysis of the Tail Landing Gear Bay and the Vertical/Horizontal Stabilizer of the RAH-66 Comanche Helicopter," Master's Thesis, Naval Postgraduate School, September 1997.

Tobin, V., "Analysis of Potential Structural Design Modification for the Tail Section of the RAH-66 Comanche Helicopter," Master's Thesis, Naval Postgraduate School, June 1997.

DoD KEY TECHNOLOGY AREAS: Computing and Software, Air Vehicles, Modeling and Simulation, Other (Structures)

KEYWORDS: Helicopters, Dynamics, Vibrations

APPLICATION OF PERIODIC OPTIMAL CONTROL TO SPACE MANEUVERS

F. Fahroo, Assistant Professor
Department of Mathematics
Sponsor: Naval Postgraduate School

OBJECTIVE: To apply the theory of Optimal Periodic Control theory to the problem of orbit control of Low-Earth-orbiting or LEO spacecraft.

SUMMARY: In this research the theory of Optimal Periodic Control was applied to determine the optimal reboosting strategy for a Low-Earth-orbiting or LEO spacecraft to achieve minimum consumption of fuel. Analytical as well as numerical solutions were sought for this optimization problem. This project is a joint project with Professor I. Michael Ross, Department of Aeronautics and Astronautics.

PUBLICATIONS:

Jensen, K., Fahroo, F., and Ross, I.M., "Application of Optimal Periodic Control Theory to the Orbit Reboost Problem," *Proceedings of the AAS/AIAA Space Flight Mechanics Meeting*, February 1998, in the Advances in the Astronomical Sciences Series.

CONFERENCE PRESENTATION:

Fahroo, F. and Ross, I.M., "A Spectral Collocation Method for Solving Optimal Periodic Control Problems," to be presented in 1998 AAIA GNC Conference, Boston, MA, August 1998.

DoD KEY TECHNOLOGY AREA: Space Vehicles

KEYWORDS: Necessary Optimality Conditions, Periodic Optimal Control Theory, Low-Earth Orbiting Spacecraft, Minimum Fuel Consumption

OPTIMAL DESIGN OF DAMPING AND CONTROL MECHANISMS FOR DISTRIBUTED PARAMETER SYSTEMS

F. Fahroo, Assistant Professor
Department of Mathematics
Sponsor: Naval Postgraduate School

OBJECTIVE: To examine different damping designs for achieving exponential stability of flexible structures.

SUMMARY: This study addressed the question of "optimal" damping design for flexible structures in an abstract setting and precisely defined and analyzed various design criteria which are of importance in applications. In particular, damping designs as well as optimal parameter design of feedback controllers were considered to achieve not only exponential stability but moreover obtain better and faster rate of decay for the energy of the system. The results were illustrated in application to a damped wave equation and a flexible beam, and performed numerous numerical experiments for different damping designs for these examples.

PUBLICATIONS:

Fahroo, F. and Ito, K., "Variational Formulation of Optimum Damping Designs," *Optimization Methods in PDEs*, in the Contemporary Mathematics Series by the American Mathematical Society, Vol 209, pp. 95-115.

Fahroo, F. and Wang, Y., "Optimal Location of Piezoceramic Actuators for Vibration Suppression of a Flexible Structure," in the *Proceedings of IEEE Conference on Decision and Control*, San Diego, CA, December 1997.

CONFERENCE PRESENTATION:

Fahroo, F. and Wang, Y., "Optimal Location of Piezoceramic Actuators for Vibration Suppression of a Flexible Structure," Conference on Decision and Control, San Diego, December 1997.

DoD KEY TECHNOLOGY AREA: Materials, Processes, and Structures

KEYWORDS: Distributed Parameter Systems, Damping Mechanism, Optimization

NUMERICAL STUDY OF EXPONENTIAL STABILITY OF COUPLED FLUID/STRUCTURE SYSTEMS

F. Fahroo, Assistant Professor
Department of Mathematics
Sponsor: Naval Postgraduate School

OBJECTIVE: To study the exponential stability of several acoustic-structure models by numerical approximation of these models. Convergence and stability of these numerical approximations are also studied.

SUMMARY: In this project a fluid-structure model was considered which consisted of a two dimensional air cavity and a vibrating flexible beam that formed a portion of the boundary of the cavity. A "porous" boundary condition was proposed for the beam equation which allowed the flow of air through the beam. The focus of the work was on establishing uniform exponential stability for the model, and to achieve this goal the multiplier technique was used which has already been used successfully in establishing exponential decay rates for wave equations with boundary feedback damping. After proving the desired stability result for the infinite-dimensional model, the effect of choosing different boundary conditions on the stability of the model was explored by performing numerous numerical simulations and different numerical schemes were also investigated that would preserve the exponential stability of the original model under approximation.

PUBLICATION:

Fahroo, F. and Wang, C., "Numerical Experiments on Approximated Acoustic-Structure Systems," *Journal of Mathematical Systems, Estimation, and Control*, Vol 8, No 2, to appear February 1998.

CONFERENCE PRESENTATION:

Fahroo, F. and Wang, C., "In the Infinite-Horizon LQR Problem for Acoustic-Structure System," the SIAM Annual Conference, Stanford, CA, July 1997.

DoD KEY TECHNOLOGY AREA: Other (Active Noise Control)

KEYWORDS: Exponential Stability, Acoustic-Structure Models, Numerical Approximations

LINE AND CIRCLE TRACKING FOR NONHOLONOMIC AUTONOMOUS VEHICLES

F. Fahroo, Assistant Professor
Department of Mathematics
Sponsor: Naval Postgraduate School

OBJECTIVE: To develop a new algorithm for nonholonomic vehicles for tracking a given line or a circle.

SUMMARY: In this joint research project with the Department of Computer Science, the problem of finding an algorithm for the movement of a vehicle under the nonholonomic constraint to track a given directed line without allowing any

spinning motion was investigated. A new principle was proposed for computing the derivative of path curvature as a linear combination of the current vehicle path curvature, vehicle orientation, and positional difference. This function is called a steering function. By linearization an optimal selection of parameters for critically damped motions was found and a single parameter, smoothness, for tracking was obtained. Numerous simulation results as well as experimental results were obtained on the autonomous robot, Yamabico, at the Naval Postgraduate School which showed the effectiveness of this method.

This research project has resulted in submission of one journal paper and appearance of two conference papers.

PUBLICATIONS:

Kanayama, Y. and Fahroo, F., "A New Line Tracking Method for Nonholonomic Vehicles," *ICRA Conference Proceedings*, Albuquerque, NM, 1997, pp. 2908-2913.

Kanayama, Y. and Fahroo, F., "A Circle Tracking Method for Nonholonomic Vehicles," *Proceedings of the SYROCO '97 Conference on Robot Control*, Nantes, France, September 1997.

CONFERENCE PRESENTATIONS:

Kanayama, Y. and Fahroo, F., "A New Line Tracking Method for Nonholonomic Vehicles," the ICRA Conference, Albuquerque, NM, 1997.

Kanayama, Y. and Fahroo, F., "A Circle Tracking Method for Nonholonomic Vehicles, SYROCO 97 Conference on Robot Control, Nantes, France, September 1997.

DoD KEY TECHNOLOGY AREAS: Ground Vehicles, Other (Robotics)

KEYWORDS: Nonholonomic Vehicles, Path Tracking, Steering Function

LEAST SQUARES MULTIQUADRIC APPROXIMATION

Richard Franke, Professor
Department of Mathematics
Sponsor: Unfunded

OBJECTIVE: The objective of this project was to continue research in the approximation of scattered data using radial basis function methods, in particular multiquadric functions in a least squares setting.

SUMMARY: This work builds on previous work of the investigator. Here, the nonlinear optimization was over the location of the basis functions (centers or knots) and simultaneously for a transformation of the domain to another, over which the actual approximation is performed. An eleven parameter biquadratic Bezier function was used for the transformation. It was designed in such a way that the one-to-one transformed region is a convex quadrilateral. Examples were constructed showing that the additional eleven degrees of freedom were more valuable in the transformation than simply adding an equivalent number of additional terms to the multiquadric approximation. In addition, the qualitative behavior of the approximations tended to be improved by the method.

PUBLICATION:

Franke, R. and Hagen, H., "Least Squares Surface Approximation Using Multiquadrics and Parametric Domain Distortion," manuscript submitted to CAGD.

DoD KEY TECHNOLOGY AREAS: Computing and Software, Modeling and Simulation

KEYWORDS: Scattered Data, Radial Basis Functions, Surface Approximation, Least Squares, Domain Distortion

COVARIANCE FUNCTIONS FOR 3-DIMENSIONAL DATA ASSIMILATION I, II

Richard Franke, Professor
Department of Mathematics
Sponsor: Naval Research Laboratory-Monterey

OBJECTIVE: The objective of the first part of the project was to investigate methods for more rigorous modeling of the three-dimensional spatial covariance function for the error in numerical weather forecasts, with the goal of improving data assimilation methods. One aim was to determine properties that will guarantee that the model has the requisite positive definiteness. The objective of the second phase of the research was to continue the investigation by applying methods derived in the first part to real data. Innovation data for a two-month period from the NOGAPS model was used in an investigation of the properties of the data and the generation of a consistent model of the forecast and observation errors.

SUMMARY: A survey of methods for modeling covariance 3-dimensional functions was conducted. A method incorporating a simultaneous transformation of the domain and a fit to the data was experimented with using data from the literature. A 3-dimensional model of the innovation data was constructed using a second order autoregressive (SOAR) function in the horizontal with parameters varying with pressure level. Fitting the innovation data with the model resulted in estimates of the prediction and observation error covariances as a function of pressure level, and also a parameter known as the correlation distance. The prediction and observation error covariances were then fit as functions of pressure level by simultaneous transformations to a domain and fit using a SOAR plus constant model in each case. The variations in the correlation distance at various pressure levels was fit using a cubic curve. The overall 3-d covariance model was then a partially separated model, the product of a horizontal covariance function (varying with pressure level) and a vertical correlation function. Extensive simulations found no evidence that the resulting model was not positive definite. As a by-product of the investigation it was determined that the predictive errors for NOGAPS tend to be smaller than radiosonde observation errors over the United States.

PUBLICATIONS:

Franke, R., "Three Dimensional Covariance Functions: Theory," NRL/MR/7531/97/7231, October 1997 (submitted to *Monthly Weather Review*).

Franke, R., "Three Dimensional Covariance Functions: Real Data," NRL/MR/7532/97/7232, October 1997 (submitted to *Monthly Weather Review*).

DoD KEY TECHNOLOGY AREAS: Computing and Software, Modeling and Simulation

KEYWORDS: Objective Analysis, Data Assimilation, Covariance Functions, Numerical Weather Prediction

ALGORITHMS FOR SEGMENTED DATA

Richard Franke, Professor
Department of Mathematics
Sponsor: Unfunded

OBJECTIVE: Segmented data is data in 3-space that has a classification associated with each point. The objective was to construct computationally simple algorithms for constructing a surface that separates the various classes of data and the volumes that contain only data of one of the various classes.

SUMMARY: The approach taken was to first construct a Delaunay terahedrization of the (possibly scattered) data points. Then a marching cubes approach was taken in that each tetrahedron was processed nearly independently of the others. Since there are only four vertices in a tetrahedron, there are only four (nontrivial) cases to consider: three vertices of one class, one of another; two vertices of one class, two of another; two vertices of one class, one each of two other (different) classes; and all vertices of a different classes. Using these four cases it is then possible to write out a list of triangles composing the separating surface and a list of tetrehedra composing the volume for each class. In certain cases care must be taken to avoid the crack problem of marching cubes, but this is easily handled assuming an order on the input points.

PUBLICATIONS:

Nielson, G. and Franke, R., "Computing the Separating Surface for Segmented Data," *Proceedings of Visualization '97*, IEEE Press, October 1997, pp. 229-233.

Nielson, G. and Franke, R., "Computing Segmented Volumes," to appear in the *Proceedings of Dagstuhl Seminar on Scientific Visualization.*

Freeden, W., Schreiner, M. and Franke, R., "A Survey on Spherical Spline Approximation," *Surveys on Mathematics for Industry,* 7(1997)28-85.

CONFERENCE PRESENTATIONS:

Franke, R., "Computing the Separating Surface for Segmented Data," IEEE Visualization '97, Phoenix, AZ October 1997.

Franke, R., "Computing Segmented Volumes," Dagstuhl Seminar on Scientific Visualization, Dagstuhl Castle, Germany, June 1997.

DoD KEY TECHNOLOGY AREAS: Computing and Software, Modeling and Simulation

KEYWORDS: Scattered Data, Segmented Data, Marching Cubes, Separating Surface

DE BRUIJN SEQUENCES FOR CRYPTOGRAPHIC APPLICATIONS

H. Fredericksen, Professor
Department of Mathematics
Sponsor: Teledyne Industries

OBJECTIVE: The work under this agreement will be pursued in three phases as follows: the mathematical foundations of the generalized combs and nonlinear sequences associated with them will be developed. Classes of nonlinear sequence possessing good auto-correlation and cross-correlation properties will be identified. Permutations for the generation of the sequences will be determined. Cryptographic systems employing the new sequences and their permutations will be developed.

DoD KEY TECHNOLOGY AREA: Other (Cryptographic Applications)

KEYWORDS: Nonlinear Sequences, De Bruijn Sequences, Cryptographic

FAST, STABLE, COMPUTATIONAL ALGORITHMS FOR SPECTRAL DECOMPOSITION OF STATIONARY TIME SERIES

W. B. Gragg, Professor
Department of Mathematics
Sponsor: Naval Postgraduate School

OBJECTIVE: To implement, rigorously test, and prove numerical stability of, new stable algorithms for executing the second phase of Pisarenko's signal processing algorithm, now reformulated so as to solve a well-conditioned problem. The new algorithms, stabilized forms of the unitary Hessenberg QR (uhqr) algorithm, permit fast, O(n^2), solution of problems of (essentially) arbitrarily high order. To do the same for the related inverse algorithms (iuhqr). Together, these algorithms provide algorithms for fast adaptive recursive least squares modeling of stationary time series by trigonometric polynomials (spectral estimation).

SUMMARY: The "stabilization" of the uhqr algorithm developed gives rather massive numerical evidence that it is effective. A generalization of the uhqr algorithm permits, in principle, the O(n^2) computation of all zeros of nth degree polynomials. Thus, it solves a long-standing open problem of computational complex analysis. The details of implementation of a stable form of this algorithm will be decidedly nontrivial.

PUBLICATIONS:

Gates, K. and Gragg, W.B., "Notes on tqr Algorithms," *Journal of Computational. Applied Mathematics*, 86 (1997) 195-203.

Gragg, W.B., "Stabilization of the uhqr Algorithm?" *Proceedings of Guangzhou International Conference on Computational Mathematics,* Guangzhou, China, August 1997.

PRESENTATIONS:

Gragg, W.B., "Stabilization of the uhqr Algorithm," University of Kentucky, Lexington, KY, 3 March 1997.

Gragg, W.B., "Stabilization of the uhqr Algorithm," Royal Institute of Technology, Stockholm, Sweden, 18 March 1997.

Gragg, W.B., "Stabilization of the uhqr Algorithm," University of California-Berkeley, Berkeley, CA, 25 March 1997.

Gragg, W.B., "Stabilization of the uhqr Algorithm," Arizona State University, Tempe, AZ, 14 April 1997.

Gragg, W.B., "Stabilization of the uhqr Algorithm," Air Force Institute of Technology, Dayton, OH, 23 June 1997.

Gragg, W.B., "Stabilization of the uhqr Algorithm," Northern Illinois University, DeKalb, IL, 1 August 1997.

Gragg, W.B., "Stabilization of the uhqr Algorithm?" Guangzhou International Conference on Computational Mathematics, Guangzhou, China, 12 August 1997.

Gragg, W.B., "An O(n^2) QR Algorithm (shqz) for Polynomial Zeros," International Conference on Computational Methods and Function Theory, Nicosia, Cyprus, 12 October 1997.

DoD KEY TECHNOLOGY AREA: Computing and Software

KEYWORDS: Pisarenko's Method, Signal Processing, Fast Algorithms, QR Algorithms, Unitary Hessenberg Matrices, Spectral Estimation, Stationary Time Series

ALGEBRAIC MULTIGRID FOR LARGE-SCALE SIMULATIONS ON UNSTRUCTURED GRIDS: PHASE II

Emden van Henson, Assistant Professor
Department of Mathematics
Department of Energy-Lawrence Livermore National Laboratory

OBJECTIVE: Several applications important to the nation's science-based stockpile stewardship mission require the numerical solution of elliptic PDEs on extremely large grids whose gridpoints are irregularly space-unstructured grids. Algebraic multigrid (AMG) is a method developed for use with unstructured grids. In phase I of this project, it was determined that AMG can be applied to such problems in general, but that extensive algorithmic development will be required to solve the specific problems of interest. This proposal, for Phase II, is intended to design AMG-based algorithms that solve the specific problems of interest; and to develop a prototype serial AMG code with a design allowing later conversion to a parallel version.

DoD KEY TECHNOLOGY AREA: Computing and Software

KEYWORDS: Multigrid, Algebraic Multigrid, Parallel Processing, Stockpile Stewardship

RELIABILITY MODELING OF CONCURRENT SOFTWARE MODULES

T. Jayachandran, Professor
Department of Mathematics
Sponsor: Unfunded

OBJECTIVE: To develop probability models for the reliability of concurrent software modules used to build redundancy to increase reliability.

SUMMARY: This is an ongoing unfunded project. Unlike for hardware, failures of redundant software are correlated and, therefore, the determination of the improvement in reliability is difficult. An algorithm to compute the probability of failure of one of the models proposed in the literature has been developed. Work to develop alternative models is in progress.

PUBLICATION:

Jayachandran, T., "An Intensity Distribution for Concurrent Software Failures," submitted to the *IEEE Transactions on Software Engineering*.

DoD KEY TECHNOLOGY AREA: Computing and Software

KEYWORDS: Software Reliability, Redundancy, Intensity Distribution

APPLICATIONS OF BIFURCATION CONTROL BY STATE FEEDBACK

Wei Kang, Assistant Professor
Department of Mathematics
Sponsor: Naval Postgraduate School

OBJECTIVE: The objective of this project was to: **(**1) To develop a stabilization feedback design methodology for nonlinear control systems near bifurcation points; (2) To control the rotating stall and surge in gas engine compressors; (3) To design feedbacks for depth control in the dive plane of submarines near the critical Froude number where pitchfork bifurcation occurs; and (4). To enhance the research partnership of the Mathematics Department with engineering departments of NPS in the fields involving analysis, design, and scientific computation.

SUMMARY: A control system, in general, has infinitely many equilibrium points. The stability properties at different equilibrium points are not always the same, especially when bifurcation occurs. The equilibrium sets of control systems and their bifurcations are classified based on normal forms and invariants of the system. The bifurcation analysis for control systems is applied to engineering problems such as engine compressor control and submersible vehicles.

PUBLICATIONS:

Barbot, J.P. and Kang, W., "Higher Order Approximations for Chained Form," *Proceedings of European Control Conference,* Brussels, Belgium, 4 July 1997.

Byrnes, C.I., Priscoli, F.S., Isidori, A., and Kang, W., "Structurally Stable Output Regulation of Nonlinear Systems," *Automatica*, 33 (1997), 369-385.

Kang, W. and Huang, J., "Calculation of the Minimal Dimension-order Robust Servo-regulator," *IEEE Transaction Automatic Control,* 42 (1997), 382-386.

Kang, W., "Bifurcation and Normal Form of Nonlinear Control Systems - Part I," *SIAM Journal of Control and Optimization,* to appear.

Kang, W., "Bifurcation and Normal Form of Nonlinear Control Systems - Part II," *SIAM Journal of Control and Optimization,* to appear.

Kang, W., Gu, G., Sparks, A., and Banda, S., "Surge Control and Test Functions for Axial Flow Compressors," *Proceedings of American Control Conference*, Albuquerque, NM, 6 June 1997, 3721-3725.

Kang, W. and Papoulias, F., "Bifurcation and Normal Forms of Dive Plane Reversal of Submersible Vehicles," *Proceedings of 7th International Offshore and Polar Engineering Conference, Vol. II*, pp. 62-69, Honolulu, HI, 25-30 May 1997.

Kang, W., "The Stability and Invariants of Control Systems with Pitchfork or Cusp Bifurcations," *Proceedings of IEEE Conference on Decision and Control*, San Diego, CA, 10-12 December 1997.

Kang, W., "Invariants and Stability of Control Systems with Transcritical and Saddle-node Bifurcations," *Proceedings of IEEE Conference on Decision and Control*, San Diego, CA, 10-12 December 1997.

CONFERENCE PRESENTATIONS:

Kang, W., "Bifurcation Control for Systems with a Single Uncontrollable Mode," PRET Workshop, AFOSR-PRET Center, UCSB, Santa Barbara, CA, 1 February 1997.

Kang, W., "Bifurcation Control via State Feedback," 45th SIAM Annual Meeting, Stanford, CA, 15 July 1997.

Ph.D. DISSERTATION DIRECTED:

Fitch, O., "The Control of Bifurcations with Engineering Applications," Ph.D. Dissertation, Naval Postgraduate School, September 1997.

DoD KEY TECHNOLOGY AREAS: Air Vehicles, Space Vehicles, Surface/Under Surface Vehicles – Ships and atercraft

KEYWORDS: Nonlinear Control Systems, Bifurcations, Invariants, Normal Forms

CLOSE COMBAT ANTI-ARMOR WEAPON SYSTEM (CCAWS) TECHNOLOGY ANALYSIS

B. K. Mansager, Senior Lecturer
Department of Mathematics
Sponsor: CCAWS Project Office

OBJECTIVE: To provide PM CCAWS Information regarding the sensitivity of weapon parameters (system preparation time ability to fire on the move, and the use of "shoot and scoot" tactics) for three candidate systems (XJAV, XTOW, and CLOS) using the measures of effectiveness of survivability and engagement range.

DoD KEY TECHNOLOGY AREA: Other (Environmental Effects)

KEYWORDS: Antitank Missiles, Close Combat Antitank Systems, Tow Missile Improvements

PARALLEL VERSION OF SPECIAL PERTURBATION

B. Neta, Professor
Department of Mathematics
Sponsor: U.S. Air Force-Phillips Laboratory

OBJECTIVE: The objective of this work is to develop a parallel version of a special perturbation code using task rather than data decomposition. Code for the solution of systems of differential equations has been implemented

SUMMARY: Parallelization can be achieved by either control or domain decomposition. The latter was tried for analytic (by Neta et al.), semianalytic (by Wallace) and numerical propagators (by Neal and Coffey). The control decomposition idea is inefficient for analytic propagators (Neta et al.), because the computation time is too short. A control decomposition approach to parallelize a numerical orbit propagator which is more computationally intensive is discussed.

PUBLICATIONS:

Neta, B., "Parallelization of Satellite Motion Models," *SIAM News*, 30, November 1997.

Neta, B. and Vallado, D., "On Satellite Umbra/Penumbra Entry and Exit Positions*," Proceedings of Seventh AAS/AIAA Space Flight Mechanics Meeting*, Huntsville, AL, in 10-12 February 1997, Paper Number AAS 97-155.

Neta, B., "Parallel Version of Special Perturbations Orbit Propagator*," Proceedings of AAS/AIAA Astrodynamics Conference,* Sun Valley, ID, 4-7 August 1997, Paper Number 97-688.

CONFERENCE PRESENTATION:

Neta, B., "On Satellite Umbra/Penumbra Entry and Exit Positions," Seventh AAS/AIAA Space Flight Mechanics Meeting, Huntsville, AL, 10-12 February 1997.

Neta, B., "Parallel Version of Special Perturbations Orbit Propagator," AAS/AIAA Astrodynamics Conference, Sun Valley, ID, 4-7 August 1997.

DoD KEY TECHNOLOGY AREAS: Computing and Software, Space Vehicles, Modeling and Simulation

KEYWORDS: Satellites, Orbit prediction, Umbra/penumbra

FINITE DIFFERENCES VERSUS FINITE ELEMENTS

B. Neta, Professor
Department of Mathematics
Sponsor: Unfunded

OBJECTIVE: The objective of this research is: (1) to investigate a linear analysis of the shallow water equations in spherical coordinates for the Turkel-Zwas explicit large time-step scheme, and (2) to analyze the stability of finite element approximation to the linearized two dimensional advection-diffusion equation.

SUMMARY: A linear analysis of the shallow water equations in spherical coordinates for the Turkel-Zwas explicit large time-step scheme is presented. This coordinate system is more realistic in meteorology and more complicated to analyze, since the coefficients are no longer constant. The analysis suggests that the Turkel-Zwas scheme must be staggered in a certain way in order to get eigenvalues and eigenfunctions approaching those of the continuous case. The importance of such an analysis is the fact that it is also valid for non-constant coefficients and thereby applicable to any numerical scheme.

Another paper analyzed the stability of the finite element approximation to the linearized two-dimensional advection-diffusion equation. Bilinear basis functions on rectangular elements are considered. Giraldo and Neta have numerically compared the Eulerian and semi-Lagrangian finite element approximation to the advection-diffusion equation. This paper analyzes the finite element schemes used there.

PUBLICATIONS:

Neta, B., Giraldo, F.X., and Navon, I.M., "Analysis of the Turkel-Zwas Scheme for the Two-Dimensional Shallow Water Equations in Spherical Coordinates," *Journal of Computational Physics,* 133, pp. 102-112, 1997.

Giraldo, F.X. and Neta, B., "A Comparison of a Family of Eulerian and Semi-Lagrangian Finite Element Methods for the Advection-Diffusion Equation," in *Computer Modeling of Seas and Coastal Regions III*, J. R. Acinas and C. A. Brebbia (eds), Computational Mechanics Publications, Southampton, U. K., pp. 217-229, 1997.

CONFERENCE PRESENTATION:

Giraldo, F.X. and Neta, B., "A Comparison of a Family of Eulerian and Semi-Lagrangian Finite Element Methods for the Advection-Diffusion Equation," Computer Modeling of Seas and Coastal Regions, La Coruna, Spain, 23-25 June 1997.

THESIS DIRECTED:

Hamrick, T.A., "Analysis of the Numerical Solution of the Shallow Water Equations," Master's Thesis, Naval Postgraduate School, September 1997.

DoD KEY TECHNOLOGY AREAS: Computing and Software, Modeling and Simulation

KEYWORDS: Finite Elements, Finite Differences, Shallow Water, Stability Analysis

TARGETING SUB-STATE POLITICAL GROUPS

Guillermo Owen, Professor
Department of Mathematics
Gordon H. McCormick, Associate Professor
Special Operations Curriculum Committee
Sponsor: Assistant Secretary of Defense, Special Operations-Low Intensity Conflict (SOLIC)

OBJECTIVES: The objective of this research was to: (1) To develop a formal framework for evaluating the dynamics of sub-state conflict, and (2) To employ this framework to improve our ability to target terrorist and other sub-state politico-military organizations.

SUMMARY: The growing incidence of direct and indirect U.S. involvement in locally driven sub-state conflicts—coupled with the poor track record in this area—requires that the analytical aids used to evaluate, measure and respond to such engagement effectively be improved. This project employed formal modeling to isolate and examine the variables and relationships that define the dynamics of internal wars in an effort to improve the ability to control and diffuse such conflicts.

PUBLICATIONS:

Owen, G. and McCormick, G., "Violence, Factionalism and State-Terrorist Bargaining."

Owen, G. and McCormick, G., "Security and Coordination in a Clandestine Organization."

DoD KEY TECHNOLOGY AREA: Other (Sub-State Political Group)

KEYWORDS: Terrorist, Sub-State Politico-Military Organizations

EVALUATION OF COMPLETION-BASED HEURISTICS FOR GRAPH COLORING

Craig W. Rasmussen, Associate Professor
Department of Mathematics
Sponsor: Naval Postgraduate School

OBJECTIVE: To develop and evaluate heuristics for finding approximate solutions to hard combinatorial optimization problems, such as graph coloring, that arise in diverse problems such as scheduling and frequency assignment. These problems are generally NP-complete, but typically are easily solved on certain families of highly structured problem instances. These families themselves possess more internal structure than was previously known, and the idea is to exploit this structure to obtain useful approximate solutions to the hard instances.

SUMMARY: This summary covers the continuation of a project that was initiated in FY94 and which was partially funded by the Naval Postgraduate School in FY95 - FY97. The focus during the period covered by this summary was implementation of an algorithm for approximating the chromatic number of a graph. MATLAB codes were developed for the following: (1) Recognition of chordal graphs, which have good algorithmic properties; (2) Construction of completion sequences of chordal graphs; (3) Location of a maximal chordal subgraph of an arbitrary input graph; and (4) Constructively determining the chromatic number of a chordal graph.

Equipped with these codes, the idea is to accept as input a randomly generated graph G, locate a maximal chordal subgraph H of G, use H to initialize a completion algorithm that terminates when a chordal supergraph K of G is found. K is then assigned a coloring that is subsequently inherited by G.

THESIS DIRECTED:

Eggen, L., "Approximating the Chromatic Number of an Arbitrary Graph Using a Supergraph Heuristic," Master's Thesis, Naval Postgraduate School, June 1997.

DoD KEY TECHNOLOGY AREA: Other (Applied Mathematics)

KEYWORDS: Chordal Graphs, Graph Coloring

p-COMPETITION GRAPHS: CHROMATIC PROPERTIES AND CHARACTERIZATIONS

Craig W. Rasmussen, Associate Professor
Department of Mathematics
Sponsor: Naval Postgraduate School

OBJECTIVE: Characterize competition graphs and p-competition graphs of various highly structured families of graphs and digraphs.

SUMMARY: This is ongoing work that is conducted jointly with colleagues at Colorado University-Denver, Kenyon College, and the University of the Pacific. The project is an outgrowth of a project that was supported during FY93 and FY94 by the Research Initiation Program (RIP) at NPS. A related area is that of upper-bound graphs of posets. Joint work in that area is with the Denver group and with a colleague at the University of Louisville.

PUBLICATIONS:

Langley, L., Lundgren, J.R., McKenna, P.A., Merz, S.K., and Rasmussen, C.W., "p-Competition Graphs of Strongly Connected and Hamiltonian Digraphs," *Ars Combinatoria* v47, December 1997.

Langley, L., Lundgren, J.R., Merz, S.K., and Rasmussen, C.W., "Posets with Interval or Chordal Strict Upper and Lower Bound Graphs," *Congressus Numerantium,* December 1997.

McMorris, F.R. and Rasmussen, C.W., "Phi-Tolerance Upper-Bound Graphs of Partially Ordered Sets," *Congress Numerantium,* December 1997.

CONFERENCE PRESENTATIONS:

Lundgren, J.R., Langley, L., Merz, S.K., and Rasmussen, C.W., "Digraphs with Interval or Chordal Competition and Resource Graphs," 28th Southeastern International Conference on Combinatorics, Graph Theory, and Computing, Boca Raton, FL, March 1997.

Lundgren, J.R., Langley, L., Merz, S.K., and Rasmussen, C.W., "Posets with Interval Upper and Lower Bound Graphs," 28th Southeastern International Conference on Combinatorics, Graph Theory, and Computing, Boca Raton, FL, March 1997.

McMorris, F.R. and Rasmussen, C.W., "Phi-Tolerance Upper-Bound Graphs of Partially Ordered Sets," 28th Southeastern International Conference on Combinatorics, Graph Theory, and Computing, Boca Raton, FL, March 1997.

DoD KEY TECHNOLOGY AREAS: Computing and Software, Other (Resource Allocation)

KEYWORDS: Ordered Sets, Chordal Graphs, Interval Graphs

REMOVAL OF THE ASSUMPTION OF CELLULAR TARGETS IN THE COMPUTATION OF DAMAGE AGGREGATION TO AN AREA TARGET FROM A SALVO OF N WEAPONS

I. Bert Russak, Associate Professor
T. Jayachandran, Professor
Department of Mathematics
Sponsor: Naval Postgraduate School-Institute of Joint Warfare Analysis

OBJECTIVE: To improve the accuracy of damage calculations to an area target by removing certain non-real world assumptions used in its model.

SUMMARY: Analysts who do computation of damage aggregation to a area target from a salvo of weapons sometimes use the simplifying assumption of a target consisting of cells. This often has the implicit assumption of weapons hits to the target always being at the center of a cell, which is certainly not true. The removal of this assumption provides a more accurate model with more accurate calculations of damage aggregation.

PUBLICATION:

Russak, I.B. and Jayachandran, T. "Removal of the Assumption of Cellular Targets in the Computation of Damage Aggregation to an Area Target from a Salvo of N Weapons," NPS Technical Report, NPS-MA-98-001, December 1997.

DoD KEY TECHNOLOGY AREAS: Computing and Software, Modeling and Simulation

KEYWORDS: Damage Aggregation, Area Target, Cellular Target

BI-ORTHOGONALITY RELATIONS APPLIED TO SCATTERING IN WAVEGUIDES

Clyde Scandrett, Associate Professor
Chris Frenzen, Associate professor
Department of Mathematics
Sponsor: Naval Postgraduate School

OBJECTIVE: To investigate the behavior of Scholte/Rayleigh-Lamb surface wave propagation along the interface of an elastic/poro-elastic solid underlying a fluid layer.

SUMMARY: The bi-orthogonality relationships developed for a porous/elastic-fluid layered system were implemented to determine the interfacial wave scattering from a vertical discontinuity in the medium. The dispersion relationship was found and used to determine wavenumbers for the discrete eigenfunctions of the media. Non-uniqueness of the solution led the investigators to develop compatibility conditions in the form of infinite matrix identities. The compatibility condition was obtained analytically for the case of two fluids in lateral contact. Compatibility conditions for elastic and poro-elastic media were also discussed.

PUBLICATION:

Scandrett, C. and Frenzen, C. L., "Bi-orthogonality Relationships and Scattering from Material Discontinuities," to appear in the Proceedings of the Fourth International Conference on Mathematical and Numerical Aspects of Wave Propagation, Golden, CO, 1-5 June 1998.

CONFERENCE PRESENTATION:

Scandrett, C. and Frenzen, C.L., "Bi-orthogonality Relationships," to be given at the Fourth International Conference on Mathematical and Numerical Aspects of Wave Propagation, Golden, CO, 1-5 June 1998.

DoD KEY TECHNOLOGY AREAS: Environmental Quality, Sensors

KEYWORDS: Wave Propagation, Porous Media, Bi-Orthogonality, Layered Media

INTEGRATED ASSESSMENT OF SHIP MISSILE DEFENSE EFFECTIVENESS

W. M. Woods, Professor
Department of Mathematics
Sponsor: Naval Warfare Assessment Center

OBJECTIVE: To provide technical support to NWAC (QA30) in integrated assessment of DD963 ship missile defense effectiveness for a specific threat.

DoD KEY TECHNOLOGY AREA: Conventional Weapons

KEYWORDS: Ship Missile Defense, System Effectiveness