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ABS:    Research conducted at the Institute for Computer Applications in Science
        and Engineering in applied mathematics, numerical analysis and computer
        science during the period April 1, 1983 through September 30, 1983 is
        summarized.


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INTRODUCTION

The Institute for Computer Applications in Science and Engineering (ICASE) is operated at the Langley Research Center (LaRC) of NASA by the Universities Space Research Association (USRA) under a contract with the Center. USRA is a non-profit consortium of major U. S. colleges and universities.

The Institute conducts unclassified basic research in applied mathematics, numerical analysis, and computer science in order to extend and improve problem-solving capabilities in science and engineering, particularly in aeronautics and space.

ICASE has a small permanent staff. Research is conducted primarily by visiting scientists from universities and from industry, who have resident appointments for limited periods of time, and by consultants. Members of NASA's research staff also may be residents at ICASE for limited periods.

The major categories of the current ICASE research program are:

a. Numerical methods, with particular emphasis on the development and analysis of basic numerical algorithms;

b. Control and parameter identification problems, with emphasis on effective numerical methods;

c. Computational problems in engineering and the physical sciences, particularly fluid dynamics, acoustics, structural analysis, and chemistry;

d. Computer systems and software, especially vector and parallel computers, microcomputers, and data management.

ICASE reports are considered to be primarily preprints of manuscripts that have been submitted to appropriate research journals or which are to appear in conference proceedings. A list of these reports for the period January 1, 1983, through September 30, 1983, follows a brief description of research in progress in the next section.

Presently, ICASE is operated at NASA Langley Research Center, Hampton, VA under the National Aeronautics and Space Administration, NASA Contracts No. NAS1-17070 and NAS1-17130. In the past, support has been provided by NASA Contracts No. NAS1-15810, NAS1-16394, NAS1-14101, and NAS1-14472.

RESEARCH IN PROGRESS

Loyce M. Adams

Work has focused on the XFEM activity and related issues. The XFEM activity is an attempt by several ICASERs to design a parallel system for typical structural-analysis problems and is described by Pratt, et al., in ICASE Report No. 83-41 and in the Proceedings 1983 International Conference on Parallel Processing. Using the methodology in this report, Voigt and Adams examined the parallelism in the Finite Element Process - in particular, in the substructuring technique for solving the system of linear equations.

Work is beginning with R. A. Nicolaides to devise a parallel implementation for the solution of the biharmonic equation. The first approach will include a finite element discretization of the problem domain and a direct solution of the resulting systems of equations using the substructuring technique. We plan to code and run the resulting algorithms on the Finite Element Machine and possibly the Denelcor HEP (Adams is to attend a user workshop at Los Alamos on the HEP).

Work is underway with A. Noor (George Washington University) to study the parallel solution of some nonlinear structural problems. The objectives of this work are to determine what features are needed to solve these problems efficiently for future machines (this relates to the XFEM effort) and for several parallel machines existing today, such as the Finite Element Machine and the HEP.

Loyce M. Adams, Piyush Mehrotra, Merrell L. Patrick, Terrence W. Pratt, John Van Rosendale, and Robert G. Voigt

An ongoing group effort, XFEM, has been started to design a parallel architecture for finite element analysis. A top-down design methodology is being used, wherein the entire system is considered in terms of layers of virtual machines. Each of the four layers -- (1) end user's level, (2) researcher's level, (3) operating system level, and (4) hardware -- is to be formally defined during the design process. The requirements at each level drive the design at the lower level, while the choices at the lower level have an impact on the design of the higher level. Of particular interest are the design of the operating system level and the language features and constructs to be provided to the researcher at the second level.

H. Thomas Banks

Motivated by collaboration with B. Hanks (LaRC), this research concerns problems in which large space structures such as truss-beam systems are modeled by a continuum, such as a plate or slender beam with bending and/or shearing and damping. Schemes for determining apparent parameters (stiffness and shear moduli, visco-elastic damping, etc.) in such models with spatially varying geometry and material properties are being pursued in collaboration with J. Crowley. Initial numerical results involving cubic and quintic spline based approximations appear most promising.

Two separate but related parameter estimation problems are being studied in collaboration with Patricia Daniel Lamm. For nonlinear nonautonomous differential difference equations, the inverse problem of estimating parameters (including multiple delays) from observations of the system were considered. For parabolic partial differential equations, a similar problem involving estimation of time-dependent coefficients was investigated. Convergence results for spline based schemes have been obtained, and numerical results on test examples for the delay systems support the efficacy of the methods.

This project, in collaboration with E. Armstrong (LaRC) and Patricia Daniel Lamm, involves development of computational schemes for state estimation of the antenna surface of the deployed Maypole Hoop/Column antenna. Several preliminary mathematical models have been considered and now development of ideas for static estimation in a specific model entailing an annular shaped membrane under distributed loading is underway. Theoretical and numerical results have been obtained for special cases and efforts are continuing.

Claudio Canuto

Techniques of preconditioning for elliptic problems with spectral methods were investigated in a recent ICASE report (No. 83-28) with A. Quarteroni. Those techniques have been applied to the solution of exterior problems with a Fourier-Chebyshev method, in a joint work with S. Hariharan and L. Lustman. Particular attention was devoted to the treatment of the farfield boundary condition, not to deteriorate the spectral accuracy of the scheme. The feasibility of imposing an "infinite order" farfield boundary condition was devised and tested numerically. Results will appear in a forthcoming ICASE report.

Some effects of smoothing the Fourier method for the periodic Burgers' equation have been investigated mathematically, with the aim of deriving a priori estimates on the solution. The entropy condition is also taken into account. Results will be collected in a forthcoming ICASE report.

A mathematical analysis of the treatment of some boundary conditions with Legendre pseudospectral methods for elliptic problems was carried out. The interest was focused on the "implicit" or "built-in" imposition of boundary conditions of Neumann or third type; estimates on the deviation from the exact boundary conditions have been given and cases in which the corresponding matrix is indefinite have been indicated. A forthcoming ICASE report will contain these results.

Stephen F. Davis

An ICASE report has been completed which describes a first-order upwind scheme that is designed to detect and resolve steady oblique shocks which are not aligned with the computing grid. This is accomplished by locating the angle at which a shock might be expected to cross the computing grid and then constructing separate finite difference formulas for the flux components normal and tangential to this direction. Numerical experiments show that this method works as designed. Present efforts are directed towards the development of a theory for this method, extension of the method to general systems of conservation laws, and the development of a second-order accurate version of the method.

The latest version of this method is second-order accurate in space and first-order accurate in time. Numerical experiments indicate that it resolves shocks better than the first-order method but is very sensitive to the choice of boundary conditions. An improper choice of boundary conditions will cause spurious oscillations in the solution. A study of improved boundary condition procedures is underway in the hope that they will correct this problem.

A preliminary study of the application of the biconjugate gradient method to implicit upwind difference schemes for hyperbolic equations was conducted in collaboration with T. N. Phillips. It was expected that the biconjugate gradient method would work very well on the diagonally dominant indefinite matrices that result from upwind discretizations. Numerical experiments conducted on the one-dimensional Burgers' equation and the two-dimensional linear advection equation confirmed these expectations. In the future an examination of other iterative methods for implicit upwind schemes and the use of preconditioning with the biconjugate gradient method will be undertaken.

Work has continued, in collaboration with J. Flaherty (Rensselaer Polytechnic Institute), on the adaptive finite element method that was first reported on in ICASE Report No. 81-13. In particular, a study of time-dependent algorithms for moving computing grids showed that many of the proposed algorithms for moving grid points are unconditionally unstable for parabolic equations and only neutrally stable for hyperbolic equations. Some of this work was presented at the ARO Workshop on Adaptive Numerical Methods for Partial Differential Equations. Another study showed that for certain reaction-diffusion equations which model combustion, Newton's method will not solve the implicit time-stepping equations unless very small time-steps are taken or some global modification is made to Newton's method. Preliminary numerical experiments using a backtracking strategy to improve the convergence of Newton's method have been encouraging. Next, it will be determined how this or some other global Newton strategy can be balanced against a step-cutting scheme in the overall time-stepping algorithm.

Stefan Feyock

The work on the database machine performed jointly with P. Fishwick (Kentron, Inc.), aimed toward the goal of developing a High-Level Data Abstraction (HILDA), has been completed. A query language constructed by means of the MYSTRO parser generation tool has been implemented and is operational on the iDBP.

The use of mechanical theorem-proving techniques as a programming tool is referred to as logic programming. Restricted forms of predicate calculus expressions known as Horn clauses have proven particularly useful and form the basis of the successful logic programming language Prolog.

The formal similarity between clauses and BNF productions gives rise to an intriguing possibilility: Can grammatical techniques be used as a programming and problem-solving tool in a manner analogous to logic programming? Investigations into this question are well underway and have proven extremely fruitful to date. Several small experimental expert systems have been constructed, and the feasibility of doing general programming using this approach has been demonstrated. The advantages of syntax programming over logic programming include efficiency and the possibility of writing programs possessing self-knowledge, due to their capability of inspecting the tables that drive them. Syntax programming appears to be a rich new area for research and will be investigated intensively in future work.

Dennis B. Gannon and John Van Rosendale

Though algorithms for partial differential equations contain a great deal of parallelism, this parallelism can be difficult to exploit, particularly on complex problems. We hope to exploit nearly all of this parallelism by the use of a special-purpose, data-driven parallel architecture tuned to complex partial differential equation problems. The proposed architecture requires locally regular grid structures but imposes no global constraints on the type of grids used. In particular, completely regular grids -- such as those used in global-circulation weather models -- and locally refined adaptive grids can be treated with equal ease. The complex software and performance issues arising in this work are being addressed through the use of a detailed architecture simulator of the proposed machine. A variety of adaptive and nonadaptive partial differential equation algorithms, involving both iterative and direct solution algorithms, are currently under study.

David Gottlieb

An effort has been made to quantify the theory by P. D. Lax concerning high-resolution schemes for shocked flows. Lax has argued that more information is contained in such schemes than in low-order schemes. This argument was supported by notions from information theory.

It turns out that in spectral calculations of two-dimensional oblique shocks, one can verify the above theory. The typical, steady-state solution contains oscillations in space. Based on the spectral representation for the solution, a post-processing scheme has been developed that extracts the information very accurately for shocks that separate constant states.

Chester E. Grosch

The calculation, with T. Gatski (LaRC), of the flow in a channel with a backward-facing step has been continued. Steady-state results are now available at several Reynolds numbers. The least stable eigenmode of the Orr-Sommerfeld equation (the T-S mode) of the upstream channel flow has been calculated for each of these Reynolds numbers. Next, these disturbances will be introduced at the upstream end of the channel so that they can propagate downstream. We expect that the T-S mode will be strongly amplified when it encounters the region of reversed flow behind the step. The calculation and understanding of the dynamics of the amplification of this disturbance is the ultimate goal of this study.

A two-dimensional Navier-Stokes code in elliptic-hyperbolic coordinates has been developed from the two-dimensional velocity-vorticity code in Cartesian coordinates. The new code is being used to calculate the impulsive start-up of a slender elliptic cylinder. The objective of this work is to study the time evolution of the flow past this slender, blunt-nosed body -- particularly the development in time of the separation region at the rear of the body. The results of the calculation will be compared with the predictions of classical boundary layer theory and with those of triple-deck theory. It is also planned to calculate the flow due to the interaction of vortical disturbances in the free stream ahead of the body with the blunt leading edge.

The two-dimensional Navier-Stokes code has also been adapted, with P. Hall, to polar coordinates. The code will be used to study the unsteady separation on a circular cylinder undergoing a harmonic oscillation along a diameter. The code is now being tested -- in particular for its the phase accuracy -- by calculating the flow between concentric cylinders when the outer cylinder is stationary and the inner cylinder rotates harmonically about its axis. This problem was chosen as a test because it has a known exact solution of the unsteady Navier-Stokes equations. The calculated velocity and vorticity fields will be compared with the exact solution in order to determine the accuracy of the calculation.

Max D. Gunzburger and Roy A. Nicolaides

The problem to be addressed is the accurate computation of incompressible viscous flows at moderately high Reynolds numbers by finite-element methods. Initial efforts are directed at simple geometries in two-dimensions so that the implementation and efficacy of the new algorithms can be studied and verified. Subsequently, the methods will be applied to the flow around airfoils at high angles of attack, with particular interest focused on predicting the separation of such flows. An essential feature of the methods is the accurate resolution of tangential boundary layers and tangential discontinuities in the flow, enabling the accurate prediction of the drag on the airfoil.

Philip Hall

The stability of steady and unsteady boundary layers to Görtler vortices or Tollmien-Schlichting waves has been investigated. It was shown in ICASE Report No. 83-45 that the unsteady boundary layer on an oscillating body is locally centrifugally unstable. The instability signifcantly alters the steady streaming layer on the body and can lead to premature separation of the layer. The work reported in J. Fluid Mechanics, Vol. 130, 1983, concerning the linear evolution of Görtler vortices in growing boundary layers is being extended to allow for the effect of wall suction and pressure gradient. The eigenvalue problem for Taylor vortices has been studied in some joint work with R. DiPrima (ICASE Report No. 83-57). The evolution equations for Taylor vortices which evolve in two spatial directions have been derived (ICASE Report No. 83-55). It was shown that previous derivations of the evolution equations were incorrect.

The growth to equilibrium of disturbances in steady boundary layers is being studied, with the aim of understanding the origin of certain empirical transition-prediction methods. In joint work with C. Grosch, the effect of free stream oscillations on the stability of stagnation points or Blasius boundary layers is under investigation, using triple-deck theory and Floquet theory.

M. Yousuff Hussaini

Experiments have established the dependence of the transition Reynolds number on the intensity of free stream disturbances. The semiempirical theories of transition prediction have incorporated these effects in an ad hoc fashion, with the implicit belief that certain types of transition processes may be preceded by the linear instability regime. The linkage between the free stream disturbances and the instability waves, known as the receptivity problem, is not well understood. The purpose of the present research is to use three-dimensional compressible Navier-Stokes simulation to throw some light on this gray area.

The study of shock wave turbulence interaction is continuing within the context of two-dimensional compressible Euler equations. The mechanisms of turbulence enhancement across shock waves isolated for numerical studies are: (a) amplification of incident turbulence (vorticity waves) across a shock wave, (b) generation of turbulence behind a shock wave due to incident acoustic or entropy waves, (c) unsteady focusing of vorticity behind the shock wave due to shock distortions, (d) direct transfer of mean flow energy into vorticity fluctuations by shock oscillations. The results concerning the first two mechanisms are reported in ICASE Report No. 83-10. Investigation of the last two mechanisms is underway. It is intended to use these numerical experiments as a test bed for the mathematical models of turbulence usually employed in the shock wave turbulent boundary layer interaction studies. This work is being done in collaboration with D. Bushnell and T. Zang (LaRC).

The program of research for developing spectral methods for aerodynamic problems is continued. Applications of these methods to potential equations and Euler equations are reported in ICASE Report Nos. 83-11, 83-14, and 83-46. Efforts are underway to develop these methods for the boundary layer equations, thin layer approximations of Navier-Stokes equations, and certain combustion and thermal problems. These studies are pursued in collaboration with P. Drummond, C. Streett, and T. Zang (LaRC).

Kazufumi Ito

The purpose of this research (with H. T. Banks) is to develop a computational method for linear regulator problems of a large class of systems governed by PDEs. Various approximation schemes including finite difference, spline-based finite element, Legendre-tau and Chebyshev-collocation methods are being tested, using one-dimensional advection-diffusion equations as our model problem. Our main goal is the development of algorithms to design finite-order compensator for distributed parameter systems. The study also involves the development of efficient algorithms to solve algebraic Riccati equations.

A study on the use of Legendre-based spectral method for PDEs is continuing. A report describing results on two-point boundary value problems and eigenvalue approximations is in preparation. The problem under consideration is the two-dimensional elliptic equation in irregular domains.

An iterative method for solving systems of linear equations in which the symmetric part is indefinite has been developed. The method involves the modification of Orthomin (a generalization of the conjugate residual method to nonsymmetric systems). The performance of the method is currently being investigated for a class of elliptic problems discretized using spectral methods.

David A. Kopriva

The application of spectral collocation methods to gas-dynamics problems is being continued. First, the study of filtering strategies for Fourier pseudospectral approximations to both linear and nonlinear hyperbolic problems with discontinuous solutions is being completed. The results have led to examination of the use of spectral methods in conjunction with shock-fitting methods. The need for smoothing in two-dimensional continuous gas flows using Chebyshev methods was studied recently in ICASE Report No. 83-51. For that report, a code for computing the classical Ringleb flow was completed, and this will now be used for convergence acceleration studies. Finally, a Chebyshev pseudospectral code is being developed to compute transonic flows over a circular cylinder in which the shock is fitted. This work has been done in collaboration with T. Zang (LaRC) and M. Y. Hussaini.

Research on the generation of sound in shock/vortex interactions is being continued with H. Ribner (University of Toronto). Both second- and fourth-order finite difference codes have been developed for the computations. The linear theory for this problem has been found to be inadequate. The theoretical results show features in the form of a "precursor" wave which is not evident in the computations and cannot be explained physically. Efforts are now being directed towards improving the theory. A related sound-generation problem will be attempted soon, in which the linear theory is not appropriate. If the shock is weak or the vortex is strong, a triple-point shock forms. The feasibility of fitting the second shock will be studied first and then a double-grid method will be used to compute the sound generated.

Mala Mehrotra and John Van Rosendale

Tree-searching is a fundamental computer science technique with applications in computer game-playing, robotics, combinatorial optimization, and numerical analysis. With the advent of highly parallel computers, consisting of large numbers of interconnected microprocessors, the problem of mapping tree-search algorithms onto such architectures has become important. This research looks at a number of tree-search algorithms and at a variety of strategies for distributing such algorithms across processor arrays. Among the issues currently being studied are:

1. How to maximize the amount of parallelism for different tree traversal algorithms.
2. How to effectively embed tree traversal algorithms in parallel architectures for trees of varying breadth and depth.
3. How to determine the influence of different network topologies, particularly when very high parallelism is exploited.

Though some of the issues here can be studied theoretically, most can be studied only experimentally. For this reason, an advanced multi-microprocessor simulator, written by Dennis Gannon, is currently being used to model a variety of architectures, and a number of tree traversal algorithms are being studied.

Piyush Mehrotra

A set of language concepts has been proposed to partition and distribute dense large arrays for processing on multiprocessor architectures. Extension of the constructs to multidimensional arrays and other special types of matrices was studied. The implementation of the concepts on the Intel 432 (a multiprocessor) was investigated.

Constructs needed in high-level languages for coding algorithms for multiprocessor systems are being studied. This effort is being carried out at two levels. One is as a part of the XFEM project to design a system for finite element calculations using a top-down methodology; the other is to study language constructs needed for parallel programming in general.

Many databases and dictionary systems use B*-trees as the underlying data structure. Mechanisms needed for the concurrent manipulation of such data structures were studied. The feasibility of such concurrent retrieval, addition, and deletion of records from B*-trees was investigated.

William F. Moss

A mathematical model of spin-mode acoustic radiation was developed from a thick wall duct at ICASE during the summer of 1982. Our model was based on an experimental setup designed by R. Silcox (LaRC). Our computational results are currently under comparison with experiments conducted by R. Silcox during July 1982; for example, the reflection coefficient for mode (1,0) has just been computed with $k = 3.2$, to find $R = .197$. Silcox's experimental value was $R = .196$. Our sound pressure level results are also close to the experimental results in this case. Thus here is the beginning of a verification of our code.

Timothy N. Phillips

Research on the application of the spectral multigrid method to elliptic problems with Dirichlet boundary conditions has continued. In joint work with M. Y. Hussaini and T. A. Zang (LaRC), the need for effective preconditioners was established. Preconditioners based on incomplete LU-decompositions of the corresponding finite difference matrix were found to be effective in these calculations (ICASE Report No. 83-48). In the future, extensions to incorporate Neumann boundary conditions and systems of equations will be considered. Work has begun on the mixed periodic-Dirichlet problem in which effective preconditioners must take into account the periodicity in one direction. If such a preconditioner can be constructed, it will allow treatment of the potential flow problem of transonic aerodynamics. Investigation of the development of a parameter-free method -- using, for example, the minimum residual method -- is underway.

Progress in the treatment of elliptic equations by compact finite difference schemes has been made. In joint work with M. E. Rose, a method for transforming the compact scheme to an equivalent algebraic system was devised. The reformulated system has the advantage of being amenable to many of the standard iterative methods of solution (ICASE Report No. 83-26). A study of the extension of this procedure for the equilibrium equations of elastic materials is underway.

Milton E. Rose

In preparation for extending a two-dimensional treatment of a vorticity-velocity formulation of incompressible Navier-Stokes equations to three-dimensions, a least-squares method for solving $\operatorname{div} u = \rho$, $\operatorname{curl} u = \zeta$ was studied. In joint work with G. Fix, striking similarities between finite difference and finite element methods were reported in an ICASE report.

A method for treating elliptic problems of the general form $\operatorname{div} v - f(u) = 0$, $v = g(\operatorname{grad} u, u)$ by compact finite difference schemes was initiated. With T. N. Phillips, the equation $\nabla \rho \nabla u - q^2 u = 0$ was treated and a technique, called flux elimination, was introduced in order to transform the compact scheme to an equivalent algebraic system which can be treated by standard (e.g., Gauss-Seidel or multigrid) iterative schemes. With M. Giles a similar approach was taken to study the solution $u(\nu)$ of the scalar convective-diffusion equation $f_x(u) + g_y(u) = \nu\nabla^2 u$, which models the Navier-Stokes equations, and its relationship when $\nu \to 0$ to the formal singular perturbation limit u^0 of $f_x(u^0) + g_y(u^0) = 0$, which models the Euler equations for inviscid flows. Also included in the general class of equations described above are the equilibrium equations for elastic materials. In collaboration with T. N. Phillips, a second-order accurate finite difference scheme was developed and a study of iterative methods to solve a two-dimensional isotropic material in a square is being completed.

Nancy E. Shoemaker

Over the last six months, work has been done to improve the link of the VAX as a remote batch terminal to a CY170-750 in ACD by decreasing the amount of knowledge of the CDC system required of the user of the link. Work on improving the reliability of the link continues, but it is hoped that the link will be augmented by a separate network connection to the central complex in the near future.

Work has also been done to integrate the VAX news systems with the rest of the Langley complex. A news group has been established for the Langley VAX Users' Group: the news is accessible through a special account on the VAX, and the news items are periodically distributed in newsletter form. Conversely, the Computer Bulletins published by ACD are retrieved from the central complex and added to the VAX news system. (F. Meissner (LaRC), provided a modified version of BULLET to aid in the retrieval.)

A new printer was added to the system during the summer. Work is in progress to facilitate the use of the printer for report output.

Experimentation over the summer with the TRAN access to the system has led to the conclusion that in order for phone network connections to the VAX to be reliable, a modem directly connected to the VAX is necessary. This modem is being ordered, and a full range of network connections will be implemented when it arrives.

One of the difficult questions that must be resolved in a computing complex that contains a supercomputer is what functions must be done on the supercomputer and what may be off-loaded to other computers. For example, the operating system and software tools available for a VAX class machine are much richer in capability and flexibility than those provided by a state-of-the-art supercomputer. On the other hand, supercomputers have the potential to generate so much data that it may not be feasible to send it to another computer. Results from this study will be used by the Cyber 200 System Enhancement Ad Hoc Working Group in making recommendations on the operating environment for the Cyber 203 upgrade to be installed at LaRC in FY ´84.

Sivaguru S. Sritharan

Four different projects are currently active. The first one is an almost-completed project of designing shock-free delta wings. The design method has been validated for simple cases, and a report is in preparation. The results will be presented in the forthcoming American Physical Society Meeting in Houston, Texas (November, 1983).

The grid generation method of Thomson, Thames, and Mastin for two-dimensional multiply connected bodies, the Gaussian Method of three-dimensional grid generation by Warsi, and also the grid generation problem in certain analytic surfaces can be studied from a unified point of view by considering certain harmonic mapping problems on an analytic Riemannian manifold. This project is in collaboration with P. Smith (Old Dominion University).

The plausibility of developing a code to compute incompressible unsteady fluid motion in a bounded but arbitrary domain is being studied, in collaboration with A. Hassan (Arizona State University). A finite difference formulation of the fractional step type (related to the methods of Chorin and

Temam) is being considered for the equations in primitive variables. Efficient ways to handle various geometrical terms in order to save time and storage are being investigated.

The invariant manifold method is being developed for certain hydrodynamic problems where a symmetry group is present. Based on the works of Sattinger, Ruelle, and Ritchmyer, a computational method is being developed, adapted to the consequences of the symmetries in the equations.

Eli Turkel

Work has continued on a fast solver for the Euler equations. With M. Salas (LaRC), work was completed in comparing uniqueness properties of the Euler and potential equations, and an AIAA paper has been accepted. Theoretical work on ways to accelerate the convergence to a steady state is continuing -- including enthalpy damping, residual smoothing, and multistep Runge-Kutta methods. An ICASE report is being written.

There has been further work, in collaboration with B. van Leer, on incorporating a one-sided scheme within the framework of the Runge-Kutta algorithm. The code has been debugged, and comparisons of central and upwind difference schemes are being conducted. We have also found the optimal scheme for a Runge-Kutta K state algorithm when central differences are used. Applications to multigrid are presently being considered.

Additionally, there has been a project to find fast and efficient methods to solve the Helmholtz equation. This has been a continuing effort with A. Bayliss. We are presently working on a preconditioned conjugate gradient technique. Several preconditionings are being considered -- including ADI, SSOR, and multigrid. Theoretical and computational comparisons on a variety of applications are being made. A paper appeared in the Conference on Elliptic Equations in Monterey, California, January 1983.

Research is also continuing on the theory and application of spectral methods to partial differential equations. Several new stability proofs have been developed, and a review paper was completed with D. Gottlieb.

John Van Rosendale

The reliability of communications networks whose nodes or links are subject to random, stochastically independent failures is an important problem in network design. This problem may be approached by Monte Carlo methods or by the inclusion-exclusion formula. The latter gives the reliability in terms of the set of all paths or cutsets on the network, of all pairs or cutsets, of all triples, and so on. A new topological algorithm using equivalence classes of paths or cutsets has been derived. This algorithm is efficient on sparse graphs, where the fanout per node is small. Application of this algorithm to problems of practical importance is currently underway.

Robert G. Voigt

A description of a substructuring technique for solving systems of linear equations using concepts developed jointly with L. Adams was reported at the NATO Advanced Research Workshop on High Speed Computation (Julich, West Germany) and appears in ICASE Report No. 83-33.

The review of numerical techniques appropriate for the parallel solution of partial differential equations has continued in collaboration with J. Ortega (University of Virginia). Both direct and iterative techniques for a variety of architectures are being considered and an extensive bibliography is being prepared.

In November the 1983 Fall SIAM meeting will be held in Norfolk with R. Voigt serving as general chairman. The three-day meeting will feature invited speakers on three themes: control, stabilization and optimization in distributed systems, computational aerodynamics and parallel processing. Following the meeting there will be a special two-day symposium on parallel processing with R. Voigt again serving as general chairman.

J. Christian Wild

During this period, a report reviewing the Finite Element Machine (FEM) software effort was written and submitted to members of the FEM effort (T. Crockett, J. Knott, O. Storaasli, and R. Fulton). K. McLemore, a graduate student under my supervision, submitted a report on his work to interconnect the VAX 11/780 to the FEM controller over a 9600 bps communication line. Using this facility, it is now possible to login to the VAX system and through the VAX system to login and use the FEM controller. In this mode the terminal user appears to be connected directly to the FEM controller. In addition to this remote terminal facility, McLemore also implemented a file transfer facility between the VAX and FEM machines. Although the file transfer is operational, further effort should be done to increase its performance and reliability.

During this period, an area of research was started to investigate the feasibility of using automatic programming technology in the production of Ultra-reliable Computing Systems. A preliminary resource search is underway. In connection with this work, a graduate student has been assigned a master's project of building a prototype automatic programming system to participate in an ongoing experiment in n-version programming being conducted at RTI by J. Dunham.

To complement work on an expert system for fault-monitoring and fault-diagnosis in commercial air transport (work done this summer by M. Ali), a proposal has been submitted to build a causal model of the airplane subsystems. This model will be used to test the monitoring and diagnosis system and will also be used to build a knowledge base of fault/symptom pairs to be used in a real-time pattern recognition system. Furthermore this model can be used to investigate the effects of the time delays of fault propagation on the monitoring and diagnosis function.

REPORTS AND ABSTRACTS

January 1, 1983 through September 30, 1983

Phillips, Timothy N.: *Numerical solution of a coupled pair of elliptic equations from solid state electronics.* ICASE Report No. 83-1, January 12, 1983, 18 pages. To appear J. Comput. Phys.

Iterative methods are considered for the solution of a coupled pair of second order elliptic partial differential equations which arise in the field of solid state electronics. A finite difference scheme is used which retains the conservative form of the differential equations. Numerical solutions are obtained in two ways - by multigrid and dynamic alternating direction implicit methods. Numerical results are presented which show the multigrid method to be an efficient way of solving this problem.

Phillips, Timothy N.: *Natural convection in an enclosed cavity.* ICASE Report No. 83-2, February 24, 1983, 24 pages. To appear J. Comput. Phys.

We are concerned with the problem of buoyancy driven flow in a vertical, rectangular cavity whose vertical sides are at different temperatures and whose horizontal sides are insulated. An application of the dynamic A.D.I. method to obtain numerical solutions to this problem is described. For large non-dimensional temperature differences characterized by the Rayleigh number the flow patterns develop strong boundary layers. These boundary layers are resolved by applying the D.A.D.I. method to the discretization of this problem on a non-uniform grid.

Dahlburg, Russell B., Thomas A. Zang, David Montgomery and M. Yousuff Hussaini: *Viscous, resistive MHD stability computed by spectral techniques.* ICASE Report No. 83-3, March 1, 1983, 28 pages. To appear Proc. Nat. Acad. Sci.

Expansions in Chebyshev polynomials are used to study the linear stability of one-dimensional magnetohydrodynamic (MHD) quasi-equilibria, in the presence of finite resistivity and viscosity. The method is modeled on the one used by Orszag in accurate computation of solutions of the Orr-Sommerfeld equation. Two Reynolds-like numbers involving Alfven speeds, length scales, kinematic viscosity, and magnetic diffusivity govern the stability boundaries, which are determined by the geometric mean of the two Reynolds-like numbers. Marginal stability curves, growth rates versus Reynolds-like numbers, and growth rates versus parallel wave numbers are exhibited. A numerical result which appears general in that instability has been found to be associated with inflection points in the current profile, though no general analytical proof has emerged. It is possible that nonlinear subcritical three-dimensional instabilities may exist, similar to those in Poiseuille and Couette flow.

Fix, George J. and Milton E. Rose: *A comparative study of finite element and finite difference methods for Cauchy-Riemann type equations.* ICASE Report No. 83-4, March 28, 1983, 22 pages. Submitted to SIAM J. Numer. Anal.

A least squares formulation of the system $\mathrm{div}\,\underline{u} = \rho$, $\mathrm{curl}\,\underline{u} = \underline{\zeta}$ is surveyed from the viewpoint of both finite element and finite difference methods. Closely related arguments are shown to establish convergence estimates.

Dunn, Mark H. and Subramaniya I. Hariharan: *Numerical computations on one-dimensional inverse scattering problems.* ICASE Report No. 83-5, April 13, 1983, 15 pages. To appear J. Comput. Phys.

In this note we present an approximate method to determine the index of refraction of a dielectric obstacle. For simplicity we treat one-dimensional models of electromagnetic scattering. The governing equations yield a second order boundary value problem, in which the index of refraction appears as a functional parameter. The availability of reflection coefficients yield two additional boundary conditons. We approximate the index of refraction by a k-th order spline which can be written as a linear combination of B-splines. For N distinct reflection coefficients, the resulting N boundary value problems yield a system of N non-linear equations in N unknowns which are the coefficients of the B-splines.

Flaherty, Joseph E. and Robert E. O'Malley, Jr.: *Numerical methods for stiff systems of two-point boundary value problems.* ICASE Report No. 83-6, April 7, 1983, 43 pages. To appear SIAM J. Sci. Statist. Comput.

We develop numerical procedures for constructing asymptotic solutions of certain nonlinear singularly perturbed vector two-point boundary value problems having boundary layers at one or both endpoints. The asymptotic approximations are generated numerically and can either be used as is or to furnish a general purpose two-point boundary value code with an initial approximation and the nonuniform computational mesh needed for such problems. The procedures are applied to a model problem that has multiple solutions and to problems describing the deformation of a thin nonlinear elastic beam that is resting on an elastic foundation.

Chen, Goong and Quan Zheng: *N-Person differential games part I: Duality-finite element methods.* ICASE Report No. 83-7, April 14, 1983, 67 pages. Submitted to SIAM J. Control Optim.

Standard theory of differential games focuses the study on two-person zero-sum games, and treat N-person games separately and differently. In this paper we present a new equivalent formulation of the Nash equilibrium strategy for N-person differential games. Our contributions are the following:

1) Our min-max formulation unifies the study of two-person zero-sum with that of the general N-person non zero-sum games. Indeed, it opens a new avenue of systematic research for differential games.
2) We are successful in applying the finite element method to compute solutions of linear-quadratic N-person games. We have also established numerical error estimates. Our calculations, which are based upon the dual formulation, are very efficient.
3) We are able to establish global existence and uniqueness of solutions of the Riccati equation in our form, which is important in synthesis. This, to our knowledge, has not been done elsewhere by any other researchers.

This paper's particular emphasis is on the duality approach, which is motivated by computational needs and is done by introducing N + 1 Language multipliers: one for each player and one "joint multiplier" for all players. For N-person linear quadratic games, we show that under suitable conditions the primal min-max problem is equivalent to its dual min-max problem, which is actually a saddle point and is then computed by finite elements. Numerical examples are presented in the last section.

Chen, Goong, Wendell H. Mills, Quan Zheng and Wan-Hua Shaw: *N-Person differential games part II: The penalty method.* ICASE Report No. 83-8, April 15, 1983, 52 pages. Submitted to SIAM J. Control Optim.

The equilibrium strategy for N-person differential games can be found by studying a min-max problem subject to differential systems constraints [4]. In this paper, we penalize the differential constraints and use finite elements to compute numerical solutions. Convergence proof and error estimates are given. We have also included numerical results and compared them with those obtained by the dual method in [4].

Adams, Loyce: *M-Step preconditioned conjugate gradient methods.* ICASE Report No. 83-9, April 16, 1983, 29 pages. To appear SIAM J. Sci. & Statis. Comput.

This paper describes preconditioned conjugate gradient methods for solving sparse symmetric and positive definite systems of linear equations. Necessary and sufficient conditions are given for when these preconditioners can be used and an analysis of their effectiveness is given. Efficient computer implementations of these methods are discussed and results on the CYBER 203 and the Finite Element Machine under construction at NASA Langley Research Center are included.

Zang, Thomas A., M. Yousuff Hussaini and Dennis M. Bushnell: *Numerical computations of turbulence amplification in shock wave interaction.* ICASE Report No. 83-10, April 28, 1983, 33 pages. To appear AIAA J.

Numerical computations are presented which illustrate and test various effects pertinent to the amplification and generation of turbulence in shock wave-turbulent boundary layer interactions. Several fundamental physical mechanisms are identified. Idealizations of these processes are examined by nonlinear numerical calculations. The results enable some limits to be placed on the range of validity of existing linear theories.

Street, Craig, Thomas Zang and M. Yousuff Hussaini: *Spectral multigrid methods with applications to transonic potential flow.* ICASE Report No. 83-11, April 29, 1983, 53 pages. Submitted to J. Comput. Phys.

Spectral multigrid methods are demonstrated to be a competitive technique for solving the transonic potential flow equation. The spectral discretization, the relaxation scheme, and the multigrid techniques are described in detail. Significant departures from current approaches are first illustrated on several linear problems. The principal applications and examples, however, are for compressible potential flow. These examples include the relatively challenging case of supercritical flow over a lifting airfoil.

Zang, Thomas A., Yau S. Wong and M. Yousuff Hussaini: *Spectral multigrid methods for elliptic equations II.* ICASE Report No. 83-12, May 3, 1983, 32 pages. To appear J. Comput. Phys.

A detailed description of spectral multigrid methods is provided. This includes the interpolation and coarse-grid operators for both periodic and Dirichlet problems. The spectral methods for periodic problems use Fourier series and those for Dirichlet problems are based upon Chebyshev polynomials. An improved preconditioning for Dirichlet problems is given. Numerical examples and practical advice are included.

Banks, H. Thomas and James M. Crowley: *Parameter identification in continuum models.* ICASE Report No. 83-13, May 4, 1983, 5 pages. Proc. of 1983 American Control Conference, June 22-24, 1983, San Francisco, CA.

We discuss approximation techniques for use in numerical schemes for estimating spatially varying coefficients in continuum models such as those for Euler-Bernoulli beams. The techniques are based on quintic spline state approximations and cubic spline parameter approximations. Both theoretical and numerical results are presented.

Zang, Thomas A., David A. Kopriva and M. Yousuff Hussaini: *Pseudospectral calculation of shock turbulence interactions.* ICASE Report No. 83-14, May 16, 1983, 11 pages. Proc. of Numerical Methods Conference, August 8-11, 1983, Seattle WA.

A Chebyshev-Fourier discretization with shock fitting is used to solve the unsteady Euler equations. The method is applied to shock interactions with plane waves and with a simple model of homogeneous isotropic turbulence. The plane wave solutions are compared to linear theory.

Tadmor, Eitan: *The large-time behavior of the scalar, genuinely nonlinear Lax-Friedrichs scheme.* ICASE Report No. 83-15, June 13, 1983, 30 pages. To appear Math. Comp.

We study the Lax-Friedrichs scheme, approximating the scalar, genuinely nonlinear conservation law $u_t + f_x(u) = 0$, where $f(u)$ is, say, strictly convex, $\ddot{f} \geq \dot{a}_* > 0$. We show that the divided differences of the numerical solution at time t do not exceed $2(t\dot{a}_*)^{-1}$. This one-sided Lipschitz boundedness is in complete agreement with the corresponding estimate one has in the differential case; in particular, it is independent of the initial amplitude in sharp contrast to linear problems. It guarantees the entropy compactness of the scheme in this case, as well as providing a quantitive insight into the large-time behavior of the numerical computation.

Tadmor, Eitan: *Entropy functions for symmetric systems of conservation laws.* ICASE Report No. 83-16, June 14, 1983, 7 pages. Submitted to Bull. Amer. Math. Soc.

Using a simple symmetrizability criterion, we show that symmetric systems of conservation laws are equipped with a one-parameter family of entropy functions.

Ito, Kazifumo and Russell Teglas: *Legendre-Tau approximations for functional differential equations.* ICASE Report No. 83-17, June 14, 1983, 43 pages. Submitted to SIAM J. Control Optim.

In this paper we consider the numerical approximation of solutions to linear functional differential equations using the so-called Legendre-tau method. The functional differential equation is first reformulated as a partial differential equation with a non-local boundary condition involving time-differentiation. The approximate solution is then represented as a truncated Legendre series with time varying coefficients which satisfy a certain system of ordinary differential equations. The method is very easy to code and yields very accurate approximations. Convergence is established, various numerical examples are presented, and comparison between the latter and cubic spline approximations is made.

Teglas, Russell: *On the control canonical structure of a class of scalar input system.* ICASE Report No. 83-18, June 14, 1983, 36 pages. To appear SIAM J. Control Optim. Replaces ICASE Report No. 81-40.

In this paper, we demonstrate the equivalence of a scalar input system $\dot{x} = \mathcal{A}x + u$, for which the eigenvalues of the generator $\mathcal{A}$ coincide with the roots of the entire function

$$p(\omega) = e^{\omega T} + a_1 e^{\omega(T-\theta_1)} + \cdots + a_m + \int_0^T a(\theta)e^{\omega(T-\theta)}d\theta,$$

with the controlled scalar functional equation

$$y(t) + a_1 y(t-\theta_1) + \cdots + a_m y(t-T) + \int_0^T a(\theta)y(t-\theta)d\theta = u(t).$$

The theory of nonharmonic Fourier series is then employed to investigate the placement of eigenvalues in the closed-loop system with continuous state feedback.

Banks, H. Thomas and George Majda: *Modeling of flexible surfaces: a preliminary study.* ICASE Report No. 83-19, June 14, 1983, 23 pages. To appear Math. Modeling.

We give a careful derivation of the 1-dimensional classical scalar "string" equation which involves linearization about a horizontal reference or equilibrium position. We then derive a model for "small motion" about a nonhorizontal reference. The implications of our findings to modeling of flexible antenna surfaces such as that in the Maypole Hoop/Column antenna are discussed.

Tadmor, Eitan: *Numerical viscosity and the entropy condition for conservative difference schemes.* ICASE Report No. 83-20, June 14, 1983, 26 pages. To appear Math. Comp.

Consider a scalar, nonlinear conservative difference scheme satisfying the entropy condition. It is shown that difference schemes containing more numerical viscosity will necessarily converge to the unique, physically relevant weak solution of the approximated conservative equation. In particular, entropy satisfying convergence follows for E schemes -- those containing more numerical viscosity than Godunov's scheme.

Sritharan, Sivaguru S. and A. Richard Seebass: *Finite area method for nonlinear supersonic conical flows.* ICASE Report No. 83-21, June 15, 1983, 34 pages. To appear AIAA J.

A fully conservative numerical method for the computation of steady inviscid supersonic flow about general conical bodies at incidence is described. The procedure utilizes the potential approximation and implements a body conforming mesh generator. The conical potential is assumed to have its best linear variation inside each mesh cell; a secondary interlocking cell system is used to establish the flux balance required to conserve mass. In the supersonic regions the scheme is desymmetrizied by adding artificial viscosity in conservation form. The algorithm is nearly an order of a magnitude faster than present Euler methods and predicts known results accurately and qualitative features such as nodal point lift off correctly. Results are compared with those of other investigators.

Tadmor, Eitan: *Finite-difference, spectral and Galerkin methods for time-dependent problems.* ICASE Report No. 83-22, June 15, 1983, 53 pages. Submitted to SIAM Rev.

We survey finite-difference, spectral and Galerkin methods for the approximate solution of time-dependent problems. A unified discussion on their accuracy, stability and convergence is given. In particular, the dilemma of high accuracy versus stability is studied in some detail.

Adams, Loyce: *An M-step preconditioned conjugate gradient method for parallel computation.* ICASE Report No. 83-23, June 15, 1983, 8 pages. Proc. of IEEE International Conference on Parallel Processing, August 23-26, 1983, Bellaire, MI.

This paper describes a preconditioned conjugate gradient method that can be effectively implemented on both vector machines and parallel arrays to solve sparse symmetric and positive definite systems of linear equations. The implementation on the CYBER 203/205 and on the Finite Element Machine is discussed and results obtained using the method on these machines are given.

Fleming, Peter: *CAD of control systems: application of nonlinear programming to a linear-quadratic formulation.* ICASE Report No. 83-24, June 22, 1983, 7 pages. Submitted to Automatica.

The familiar suboptimal regulator design approach is recast as a constrained optimization problem and incorporated in a CAD package where both design objective and constraints are quadratic cost functions. This formulation permits the separate consideration of, for example, model-following errors, sensitivity measures and control energy as objectives to be minimized or limits to be observed. Efficient techniques for computing the interrelated cost functions and their gradients are utilized in conjunction with a nonlinear programming algorithm. The effectiveness of the approach and the degree of insight into the problem which it affords is illustrated in a helicopter regulation design example.

Banks, H. Thomas, Patricia L. Daniel and Ernest S. Armstrong: *A spline-based parameter and state estimation technique for static models of elastic surfaces.* ICASE Report No. 83-25, June 28, 1983, 61 pages.

We discuss parameter and state estimation techniques for an elliptic system arising in a developmental model for the antenna surface in the Maypole Hoop/Column antenna. A computational algorithm based on spline approximations for the state and elastic parameters is given and numerical results obtained using this algorithm are summarized.

Phillips, Timothy N. and Milton E. Rose: *A compact finite difference scheme for* $\mathrm{div}(\rho\ \mathrm{grad}\ u) - q^2 u = 0$. ICASE Report No. 83-26, June 29, 1983, 20 pages. Submitted to SIAM J. Numer. Anal.

A representative class of elliptic equations is treated by a dissipative compact finite difference scheme and a general solution technique by relaxation methods is discussed in detail for the Laplace equation.

Phillips, Timothy N.: *A preconditioned formulation of the Cauchy-Riemann equations.* ICASE Report No. 83-27, June 29, 1983, 13 pages. Submitted to IMA J. Numer. Anal.

A preconditioning of the Cauchy-Riemann equations which results in a second-order system is described. This system is shown to have a unique solution if the boundary conditions are chosen carefully. This choice of boundary condition enables the solution of the first-order system to be retrieved. A numerical solution of the preconditioned equations is obtained by the multigrid method.

Canuto, Claudio and Alfio Quarteroni: *Preconditioned minimal residual methods for Chebyshev spectral calculations.* ICASE Report No. 83-28, June 29, 1983, 31 pages. Submitted to J. Comput. Phys.

The problem of preconditioning the pseudospectral Chebyshev approximation of an elliptic operator is considered. The numerical sensitiveness to variations of the coefficients of the operator are investigated for two classes of preconditioning matrices: one arising from finite differences, the other from finite elements. The preconditioned system is solved by a conjugate gradient type method, and by a DuFort-Frankel method with dynamical parameters. The methods are compared on some test problems with the Richardson method [12] and with the minimal residual Richardson method [17].

Van Rosendale, John: *Algorithms and data structures for adaptive multigrid elliptic solvers.* ICASE Report No. 83-29, June 29, 1983, 31 pages. To appear Appl. Math. Comput.

With the advent of multigrid iteration, the large linear systems arising in numerical treatment of elliptic boundary value problems can be solved quickly and reliably. This frees the researcher to focus on the other issues involved in numerical solution of elliptic problems: adaptive refinement, error estimation and control, and grid generation. Progress is being made on each of these issues and the technology now seems almost at hand to put together general purpose elliptic software having reliability and efficiency comparable to that of library software for ordinary differential equations. This paper looks at the components required in such general elliptic solvers and suggests new approaches to some of the issues involved. One of these issues is adaptive refinement and the complicated data structures required to support it. These data structures must be carefully tuned, especially in three dimensions where the time and storage requirements of algorithms are crucial. Another major issue is grid generation. The options available seem to be curvilinear fitted grids, constructed on iterative graphics systems, and unfitted Cartesian grids, which can be constructed automatically. On several grounds, including storage requirements, the second option seems preferrable for the well behaved scalar elliptic problems considered here. A variety of techniques for treatment of boundary conditions on such grids have been described previously and are reviewed here. A new approach, which may overcome some of the difficulties encountered with previous approaches, is also presented.

Dadfar, Mohammad B., James Geer and Carl M. Andersen: *Perturbation analysis of the limit cycle of the free van der Pol equation.* ICASE Report No. 83-30, June 29, 1983, 31 pages. To appear SIAM J. Appl. Math.

A power series expansion in the damping parameter ϵ of the limit cycle $U(t;\epsilon)$ of the free van der Pol equation $\ddot{U} + \epsilon(U^2-1)\dot{U} + U = 0$ is constructed and analyzed. Coefficients in the expansion are computed up to $O(\epsilon^{24})$ in exact rational arithmetic using the symbolic manipulation system MACSYMA and up to $O(\epsilon^{163})$ using a FORTRAN program. The series is analyzed using Pade′ approximants. The convergence of the series for the maximum amplitude of the limit cycle is limited by two pair of complex conjugate singularities in the complex ϵ-plane. A new expansion parameter is introduced which maps these singularities to infinity and leads to a new expansion for the amplitude which converges for all real values of ϵ. Amplitudes computed from this transformed series agree very well with reported numerical and asymptotic results. For the limit cycle itself, convergence of the series expansion is limited by three pair of complex conjugate branch point singularities. Two pair remain fixed throughout the cycle, and correspond to the singularities found in the maximum amplitude series, while the third pair moves in the ϵ-plane as a function of t from one of the fixed pairs to the other. The limit cycle series is transformed using a new expansion parameter, which leads to a new series that converges for larger values of ϵ.

Hussaini, M. Yousuff, Manuel D. Salas and Thomas A. Zang: *Spectral methods for inviscid, compressible flows.* ICASE Report No. 83-31, July 14, 1983, 39 pages. To appear in book "Advances in Computational Transonics," W. G. Habashi, ed., Pineridge Press, Swansea, United Kingdom, 1983.

Recent developments in the application of spectral methods to two-dimensional compressible flows are reviewed. A brief introduction to spectral methods -- their history and especially their implementation -- is provided. The stress is on those techniques relevant to transonic flow computation. The spectral multigrid iterative methods are discussed with application to the transonic full potential equation. Discontinuous solutions of the Euler equations are considered. The key element is the shock fitting technique which is briefly explained.

Hariharan, Subramaniya I. and Alvin Bayliss: *Radiation of sound from unflanged cylindrical ducts.* ICASE Report No. 83-32, July 14, 1983, 28 pages. To appear SIAM J. Sci. Statist. Comput.

In this paper we present calculations of sound radiated from unflanged cylindrical ducts. The numerical simulation models the problem of an aero- engine inlet. The time-dependent linearized Euler equations are solved from a state of rest until a time harmonic solution is attained. A fourth-order accurate finite difference scheme is used. Solutions are obtained from a fully vectorized Cyber-203 computer program. Cases of both plane waves and spin modes are treated. Spin modes model the sound generated by a turbofan engine. Boundary conditions for both plane waves and spin modes are treated. Solutions obtained are compared with experiments conducted at NASA Langley Research Center.

Adams, Loyce and Robert G. Voigt: *A methodology for exploiting parallelism in the finite element process.* ICASE Report No. 83-33, September 9, 1983, 36 pages. Proc. of NATO Advanced Research Workshop on High Speed Computation, June 1983, Julich, West Germany.

In most efforts to design parallel computing systems the hardware is fixed before consideration is given to the requirements of the applications that are to be executed on that hardware. This paper describes a methodology for developing a parallel system using a top down approach taking into account the requirements of the user. Substructuring, a popular technique in structural analysis, is used to illustrate this approach.

Banks, H. Thomas and Karl Kunisch: *The linear regulator problem for parabolic systems.* ICASE Report No. 83-34, July 24, 1983, 28 pages. Submitted to SIAM J. Control Optim.

We present an approximation framework for computation (in finite dimensional spaces) of Riccati operators that can be guaranteed to converge to the Riccati operator in feedback controls for abstract evolution systems in a Hilbert space. It is shown how these results may be used in the linear optimal regulator problem for a large class of parabolic systems.

LeVeque, Randall J. and Lloyd N. Trefethen: *On the resolvent condition in the Kreiss matrix theorem.* ICASE Report No. 83-35, July 24, 1983, 12 pages. Submitted to BIT.

The Kreiss Matrix Theorem asserts the uniform equivalence over all $N \times N$ matrices of power boundedness and a certain resolvent estimate. We show that the ratio of the constants in these two conditions grows linearly with N, and we obtain the optimal proportionality factor up to a factor of 2. Analogous results are also given for the related problem involving matrix exponentials e^{At}. The proofs make use of a lemma that may be of independent interest, which bounds the arc length of the image of a circle in the complex plane under a rational function.

Van Rosendale, John: *Minimizing inner product data dependencies in conjugate gradient iteration.* ICASE Report No. 83-36, July 24, 1983, 10 pages. Proc. of IEEE International Conference on Parallel Processing, August 23-26, 1983, Bellaire, MI.

The amount of concurrency available in conjugate gradient iteration is limited by the summations required in the inner product computations. The inner product of two vectors of length N requires time c*log(N), if N or more processors are available. This paper describes an algebraic restructuring of the conjugate gradient algorithm which minimizes data dependencies due to inner product calculations. After an initial start up, the new algorithm can perform a conjugate gradient iteration in time c*log(log(N)).

Davis, Stephen F.: *A rotationally biased upwind difference scheme for the Euler equations.* ICASE Report No. 83-37, July 24, 1983, 50 pages. To appear J. Comput. Phys.

The upwind difference schemes of Godunov, Osher, Roe and van Leer are able to resolve one-dimensional steady shocks for the Euler equations within one or two mesh intervals. Unfortunately, this resolution is lost in two dimensions when the shock crosses the computing grid at an oblique angle. To correct this problem, we develop a numerical scheme which automatically locates the angle at which a shock might be expected to cross the computing grid and then constructs separate finite difference formulas for the flux components normal and tangential to this direction. We present numerical results which illustrate the ability of this new method to resolve steady oblique shocks.

Van Leer, Bram: *Computational methods for ideal compressible flow.* ICASE Report No. 83-38, July 25, 1983, 32 pages. Lecture notes for Lecture Series 1983-04 on Computational Fluid Dynamics, Von Karman Institute for Fluid Dynamics, Rhode-St-Genese, Belgium, 1983.

Lectures presented at the Von Karman Institute for Fluid Dynamics, Rhode-St-Genese, Belgium, in Lecture Series 1983-04 on Computational Fluid Dynamics.

1. Conservative dissipative difference schemes p. 1
2. The recognition and representation of discontinuities p. 13
3. Multi-dimensional methods p. 18

Gannon, Dennis and John Van Rosendale: *Parallel architectures for iterative methods on adaptive, block structured grids.* ICASE Report No. 83-39, August 15, 1983, 14 pages. Proc. of Elliptic Problem Solvers Conference, January 1983, Monterey, CA., Academic Press.

This paper proposes a parallel computer architecture well suited to the solution of partial differential equations in complicated geometries. Algorithms for partial differential equations contain a great deal of parallelism. But this parallelism can be difficult to exploit, particularly on complex problems. One approach to extraction of this parallelism is the use of special purpose architectures tuned to a given problem class. The architecture proposed here is tuned to boundary value problems on complex domains. An adaptive elliptic algorithm which maps effectively onto the proposed architecture is considered in detail. Two levels of parallelism are expolited by the proposed architecture. First, by making use of the freedom one has in grid generation, one can construct grids which are locally regular, permitting a one to one mapping of grids to systolic style processor arrays, at least over small regions. All local parallelism can be extracted by this approach. Second, though there may not be a regular global structure to the grids constructed, there will still be parallelism at this level. One approach to finding and exploiting this parallelism is to use an architecture having a number of processor clusters connected by a switching network. The use of such a network creates a highly flexible architecture which automatically configures to the problem being solved.

Daniel, Patricia L.: *An approximation technique for estimating discontinuous coefficients in distributed systems.* ICASE Report No. 83-40, August 15, 1983, 12 pages. Proc. of Inverse Scattering: Theory and Application Conference, eds., J. B. Bednar, R. Redner, E. Robinson and A. Weglein, SIAM, Philadelphia, PA 1983.

We discuss the problem of estimating spatially-varying coefficients (related to porosity, permeability, etc.) that appear in distributed pressure or flow equations for porous media problems. A special feature of our approach is the formulation of a relatively simple spline-based numerical algorithm that not only determines the shape of the coefficients but locates points of spatial discontinuity as well. Theoretical results and representative numerical findings are presented.

Pratt, Terrence W., Loyce M. Adams, Piyush Mehrotra, John Van Rosendale, Robert G. Voigt and Merrell Patrick: *The FEM-2 design method.* ICASE Report No. 83-41, August 15, 1983, 10 pages. Proc. of IEEE International Conference on Parallel Processing, August 23-26, 1983, Bellaire, MI.

The FEM-2 parallel computer is being designed using methods differing from those ordinarily employed in parallel computer design. The major distinguishing aspects are: (1) a top-down rather than bottom-up design process, (2) the design considers the entire system structure in terms of layers of virtual machines, and (3) each layer of virtual machine is defined formally during the design process. The result is a complete hardware/software system design. The basic design method is discussed and the advantages of the method are considered. A status report on the FEM-2 design is included.

Berger, Marsha J.: *Stability of interfaces with mesh refinement.* ICASE Report No. 83-42, August 24, 1983, 24 pages. Submitted to Math. Comp.

We study the stability of mesh refinement in space and time for several different interface equations and finite difference approximations. First, we derive a root condition which implies stability for the initial boundary value problem for this type of interface. From the root condition, we prove the stability of several interface equations using the maximum principle. In some cases, the final verification steps can be done analytically; in other cases, a simple computer program has been written to check the condition for values of a parameter along the boundary of the unit circle. Using this method, we prove stability for Lax-Wendroff with all the interface conditions considered, and for Leapfrog with interpolation interface conditions when the fine and coarse grids overlap.

Hariharan, Subramaniya I. and Richard C. MacCamy: *Low frequency acoustic and electromagnetic scattering.* ICASE Report No. 83-43, August 25, 1983, 26 pages. Submitted to SIAM J. Appl. Math.

This paper deals with two classes of problems arising from acoustics and electromagnetics scattering in the low frequency situations. The first class of problem is solving Helmholtz equation with Dirichlet boundary conditions on an arbitrary two-dimensional body while the second one is an interior-exterior interface problem with Helmholtz equation in the exterior. Low frequency analysis show that there are two intermediate problems which solve the above problems accurate to $O(k^2 \log k)$ where k is the frequency. These solutions greatly differ from the zero frequency approximations. For the Dirichlet problem numerical examples are shown to verify our theoretical estimates.

Gunzburger, Max D., Roy A. Nicolaides and Chen-Huei Liu: *New discretization and solution techniques for incompressible viscous flow problems.* ICASE Report No. 83-44, August 26, 1983, 21 pages. Proc. of 6th AIAA Computational Fluid Dynamics Conference, July 13-15, 1983, Danvers, MA.

This paper considers several topics arising in the finite element solution of the incompressible Navier-Stokes equations. Specifically, the question of choosing finite element velocity/pressure spaces is addressed, particularly from the viewpoint of achieving stable discretizations leading to convergent pressure approximations. Following this, the role of artificial viscosity in viscous flow calculations is studied, emphasising recent work by several researchers for the anisotropic case. The last section treats the problem of solving the nonlinear systems of equations which arise from the discretization. Time marching methods and classical iterative techniques, as well as some recent modifications are mentioned.

Hall, Philip: *On the stability of the unsteady boundary layer on a cylinder oscillating transversely in a viscous fluid.* ICASE Report No. 83-45, August 26, 1983, 43 pages. Submitted to J. Fluid Mech.

The stability of the two-dimensional flow induced by the tranverse oscillation of a cylinder in a viscous fluid is investigated in both the linear and weakly nonlinear regime. The major assumption that is made to simplify the problem is that the oscillation frequency is large in which case an unsteady boundary layer is set up on the cylinder. The basic flow induced by the motion of the cylinder depends on two spatial variables and is periodic in time. The stability analysis of this flow to axially periodic disturbances therefore leads to a partial differential system dependent on three variables. In the high frequency limit the linear stability problem can be reduced to a system dependent only on a radial variable and time. Furthermore, the coefficients of the differential operators in this system are periodic in time so that Floquet theory can be used to further reduce this system to a coupled infinite system of ordinary differential equations together with uncoupled homogeneous boundary conditions. The eigenvalues of this system are found numerically and predict instability entirely consistent with the experiments with circular cylinders performed by Honji [1981]. Results are given for cylinders of elliptic cross section and it is found that for any given eccentricity the most dangerous configuration is when the cylinder oscillates parallel to its minor axis. Some discussion of nonlinear effects is also given and for the circular cylinder it is shown that the steady streaming boundary layer of the basic flow is significantly altered by the instability.

Hussaini, M. Yousuff, Craig L. Streett and Thomas A. Zang: *Spectral methods for partial differential equations.* ICASE Report No. 83-46, August 29, 1983, 62 pages. Proc. of First Army Conference on Applied Mathematics and Computing, May 9-11, 1983, Washington, D. C.

Origins of spectral methods, especially their relation to the Method of Weighted Residuals, are surveyed. Basic Fourier, Chebyshev, and Legendre spectral concepts are reviewed, and demonstrated through application to simple model problems. Both collocation and tau methods are considered. These techniques are then applied to a number of difficult, nonlinear problems of hyperbolic, parabolic, elliptic, and mixed type. Fluid-dynamical applications are emphasized.

Giles, Michael: *Eigenmode analysis of unsteady one-dimensional Euler equations.* ICASE Report No. 83-47, August 29, 1983, 16 pages. Submitted to AIAA J.

The initial boundary value problem describing the evolution of unsteady linearized perturbations of a steady, uniform subsonic flow is analyzed. The eigenmodes and eigenfrequenices of the system are derived and several examples are presented to illustrate the effect of different boundary conditions on the exponential decay rate of the eigenmodes. The resultant implications for the stability and convergence rates of finite difference computations are discussed.

Phillips, Timothy N., Thomas A. Zang and M. Yousuff Hussaini: *Preconditioners for the spectral multigrid method.* ICASE Report No. 83-48, September 2, 1983, 31 pages. Submitted to IMA J. of Numer. Anal.

The systems of algebraic equations which arise from spectral discretizations of elliptic equations are full and direct solutions of them are rarely feasible. Iterative methods are an attractive alternative because Fourier transform techniques enable the discrete matrix-vector products to be computed with nearly the same efficiency as is possible for corresponding but sparse finite difference discretizations. For realistic Dirichlet problems preconditioning is essential for acceptable convergence rates. A brief description of Chebyshev spectral approximations and spectral multigrid methods for elliptic problems is given. A survey of preconditioners for Dirichlet problems based on second-order finite difference methods is made. New preconditioning techniques based on higher order finite differences and on the spectral matrix itself are presented. The preconditioners are analyzed in terms of their spectra and numerical examples are presented.

Osher, Stanley and Sukumar Chakravarthy: *High resolution schemes and the entropy condition.* ICASE Report No. 83-49, September 7, 1983, 62 pages. Submitted to SIAM J. Numer. Anal.

A systematic procedure for constructing semidiscrete, second order accurate, variation diminishing, five point band width, approximations to scalar conservation laws, is presented. These schemes are constructed to also satisfy a single discrete entropy inequality. Thus, in the convex flux case, we prove convergence to the unique physically correct solution. For hyperbolic systems of conservation laws, we formally use this construction to extend the first author's first order accurate scheme, and show (under some minor technical hypotheses) that limit solutions satisfy an entropy inequality. Results concerning discrete shocks, a maximum principle, and maximal order of accuracy are obtained. Numerical applications are also presented.

Goldberg, Moshe and Eitan Tadmor: *Convenient stability criteria for difference approximations of hyperbolic initial-boundary value problems.* ICASE Report No. 83-50, September 19, 1983, 28 pages.

New convenient stability criteria are provided in this paper for a large class of finite difference approximations to initial-boundary value problems associated with the hyperbolic system $\mathbf{u}_t = A\mathbf{u}_x + B\mathbf{u} + \mathbf{f}$ in the quarter plane $x \geq 0$, $t \geq 0$. Using the new criteria, stability is easily established for numerous combinations of well known basic schemes and boundary conditions, thus generalizing many special cases studied in recent literature.

Kopriva, David A., Thomas A. Zang, Manuel D. Salas and M. Yousuff Hussaini: *Pseudospectral solution of two-dimensional gas-dynamic problems.* ICASE Report No. 83-51, September 23, 1983, 15 pages. Proc. 5th GAMM Conference on Numerical Methods in Fluid Dynamics, October 5-7, 1983, Rome, Italy.

Chebyshev pseudospectral methods are used to compute two-dimensional smooth compressible flows. Grid refinement tests show that spectral accuracy can be obtained. Filtering is not needed if resolution is sufficiently high and if boundary conditions are carefully prescribed.

Giles, Michael B. and Milton E. Rose: *A numerical study of the steady scalar convective diffusion equation for small viscosity.* ICASE Report No. 83-52, September 27, 1983, 28 pages. Submitted to J. Comp. Phys.

The equation $\nu \nabla^2 u = f_x(u) + g_y(u)$ is studied by means of a compact finite difference scheme and numerical solutions are compared to the analytic inviscid $(\nu = 0)$ solutions. The correct internal and external boundary layer behaviour is observed, due to an inherent feature of the scheme which automatically produces upwind differencing in inviscid regions and the correct viscous behaviour in viscous regions.

Banks, H. Thomas, Kazufumi Ito and Katherine A. Murphy: *Computational methods for estimation of parameters in hyperbolic systems.* ICASE Report No. 83-53, September 28, 1983, 14 pages. Proceedings of Conference on Inverse Scattering, May 1983, University of Tulsa, Tulsa, OK.

We discuss approximation techniques for estimating spatially varying coefficients and unknown boundary parameters in second order hyperbolic systems. Methods for state approximation (cubic splines, tau-Legendre) and approximation of function space parameters (interpolatory splines) are outlined and numerical findings for use of the resulting schemes in model "1-D seismic inversion" problems are summarized.

OTHER ACTIVITIES

The summer program for 1983 included the following visitors:

NAME/AFFILIATION	DATE OF VISIT	AREA OF INTEREST
Abarbanel, Saul Tel-Aviv University	6/20 - 9/5	Computational Fluid Dynamics
Banks, H. Thomas Brown Univ. and Southern Methodist Univ.	6/10 - 6/21	Numerical Methods for Control Systems
Berger, Marsha J. Courant Institute	7/15 - 8/15	Numerical Solution of PDE's
Bokhari, Shahid Pakistan Inst. of Engrg	6/20 - 8/30	Distributed Computing
Canuto, Claudio Instituto de Analisi Numerica	4/1 - 9/30	Spectral Methods for PDE's
Chavent, Guy Institut National de Recherche en Informatique et en Automateque, France	6/11 - 7/15	Control Theory
Crowley, James M. U. S. Air Force Academy	6/20 - 7/15	Control Theory
Daniel, Patricia L. Southern Methodist University	6/12 - 6/21	Control Theory
Gannon, Dennis B. Purdue University	8/8 - 8/12	Algorithms for Parallel Computers
Gibson, J. Steven University of California, LA	6/25 - 7/2	Control Theory
Giles, Michael B. Massachusetts Institute of Tech.	6/15 - 8/31	Computational Fluid Dynamics
Gunzburger, Max D. Carnegie-Mellon University	5/11 - 5/28	Numerical Solution of PDE's
Jacobs, Marc Q. University of Missouri	6/20 - 6/25	Control Theory
Kunisch, Karl University of Graz, Austria	6/18 - 6/30	Control Theory

NAME/AFFILIATION	DATE OF VISIT	AREA OF INTEREST
Lueze, Michael Vanderbilt University	5/31 - 6/10 8/8 - 8/12	Numerical Methods for Parallel Computers
LeVeque, Randall J. Courant Institute	7/10 - 8/26	Numerical Solution of PDE's
Mulder, William A. Delft University of Technology Netherlands	7/1 - 9/1	Computational Fluid Dynamics
Napolitano, Michele Universita Degli Studi di Bari Instituto di Macchine, Italy	7/1 - 8/30	Computational Fluid Dynamics
Oliger, Joseph E. Stanford University	7/17 - 7/22	Numerical Solution of PDE's
Patrick, Merrell L. Duke University	5/2 - 7/1	Algorithms for Parallel Computers
Pratt, Terrence W. University of Virginia	5/30 - 6/3 6/13 - 7/1	Programming Languages
Quarteroni, Alfio Instituto di Analisi Numerica del C.N.R., Italy	6/1 - 6/30	Spectral Methods for PDE's
Rosen, I. Gary Bowdoin College	6/25 - 7/8	Numerical Methods for Problems in Control Systems
Strikwerda, John C. University of Wisconsin, Madison	7/18 - 7/29	Numerical Methods for PDE's
Trefethan, Lloyd N. Courant Institute	6/9 - 8/5	Numerical Methods for PDE's
Turkel, Eli Tel-Aviv University	7/9 - 8/30	Computational Fluid Dynamics
van Leer, Bram Delft University of Technology Netherlands	7/1 - 9/1	Computational Fluid Dynamics
White, Luther W. University of Oklahoma	7/2 - 7/8	Control Theory

WORKSHOP ACTIVITIES

A Workshop on Grid Methods was held September 26-27, 1983. The purpose of this workshop was to help clarify the properties of numerical schemes which make general grids useful, and to review generation techniques being employed or being proposed. The speakers and their topics are listed below:

Peter Eiseman, Columbia University: *General Adaptive Grid Methods*

Mac Hyman, Los Alamos Scientific Laboratory: *Adaptive Grids that Track Fronts and Surfaces*

Frank Thames, NASA Langley Research Center: *Elliptic Grid Generation and Experiences with the B-S Method*

Jeffrey Saltzman, Los Alamos National Lab: *Generating Adaptive Meshes on General Surfaces in Three Dimensions*

Sri Sritharan, ICASE: *Grid Generation on Curved Surfaces*

Robert E. Smith, NASA Langley Research Center: *Algebraic Grid Methods in CFD*

William Henshaw, California Institute of Technology: *Overlapping Grid Methods*

Joe Oliger, Stanford University: *Component Grid Methods for Computations in Fluid Dynamics*

Marsha Berger, Courant Institute: *Conservation and Stability Properties at Interfaces Between Grids*

Ivo Babuska, University of Maryland: *Adaptive Construction of Optimal Meshes*

Mohammed Hafez, NASA Langley Research Center: *Cartesian Grid Methods for Compressible Fluids*

Milton Rose, ICASE: *Cartesian Grid Methods for Elastic Materials*

Michael Bieterman, National Institute of Health: *Regridding Strategies for Parabolic PDE*

Mary Wheeler, Rice University: *Grid Refinement for Problems in Reservoir Engineering*

Steve McCormick, Colorado State University: *Multigrid Adapted Discretizations*

ICASE STAFF

April 1, 1983 through September 30, 1983

I. ADMINISTRATIVE

Milton E. Rose, Director
Ph.D., Mathematics, New York University, 1953
Numerical Methods

Robert G. Voigt, Associate Director
Ph.D., Mathematics, University of Maryland, 1969
Numerical and Computational Techniques

Linda T. Johnson, Administrative Assistant

Georgia Ballance, Technical Typist/Housing

Barbara Rohrbach, Office Assistant (Part-time)

Susan Ruth, Personnel/Accounting Secretary

Emily Todd, Visitor Coordinator/Correspondence Secretary

II. SCIENCE COUNCIL

Bruce Arden, Chairman and Arthur Doty Professor, Department of Electrical Engineering and Computer Science, Princeton University.

Richard C. DiPrima, Professor and Chairman, Department of Mathematical Sciences, Rensselaer Polytechnic Institute.

Michael J. Flynn, Professor, Department of Electrical Engineering, Computer Systems Laboratory, Stanford University.

Bernard Galler, Professor, Department of Computer and Communication Sciences and Associate Director of the Computer Center, University of Michigan.

C. William Gear, Professor, Department of Computer Science, University of Illinois at Urbana.

Anthony Hearn, Department Head, Department of Information Sciences, Rand Corporation.

Seymour Parter, Professor, Department of Mathematics, University of Wisconsin.

III. ASSOCIATE MEMBERS

Herbert E. Keller, Professor, Department of Applied Mathematics, California Institute of Technology.

Peter D. Lax, Director, Courant Institute of Mathematical Sciences, New York University.

William R. Sears, Professor, Department of Aerospace and Mechanical Engineering, University of Arizona.

Saul Abarbanel, Professor, Department of Applied Mathematics, Tel-Aviv University, Israel.

IV. SENIOR STAFF SCIENTISTS

David Gottlieb - Ph.D., Numerical Analysis, Tel-Aviv University, Israel, 1972. Professor, Department of Applied Mathematics, Tel-Aviv University. Numerical Methods for Partial Differential Equations. (July 1974 to January 1987)

M. Yousuff Hussaini - Ph.D., Mechanical Engineering, University of California, 1970. Computational Fluid Dynamics. (April 1978 to January 1987)

V. SCIENTIFIC STAFF

Loyce Adams - Ph.D., Applied Mathematics, University of Virginia, 1983. Parallel Numerical Algorithms. (October 1982 to October 1984)

Stephen F. Davis - Ph.D., Applied Mathematics, Rensselaer Polytechnic Institute, 1980. Numerical Methods for Partial Differential Equations. (February 1982 to February 1984)

Subramaniya I. Hariharan - Ph.D., Mathematics, Carnegie-Mellon University, 1980. Numerical Methods for Partial Differential Equations. (August 1980 to August 1983)

Kazufumi Ito - Ph.D., Systems Science and Mathematics, Washington University, 1981. Control Theory. (August 1981 to August 1984)

David A. Kopriva - Ph.D., Applied Mathematics, University of Arizona, 1982. Computational Fluid Dynamics. (July 1982 to July 1984)

Piyush Mehrotra - Ph.D., Computer Science, University of Virginia, 1982. Language Concepts for Parallel and Distributed Systems. (July 1983 to July 1985)

Timothy Phillips - Ph.D., Numerical Analysis, Oxford University, United Kingdom, 1983. Numerical Solution of Elliptic Partial Differential Equations. (October 1982 to October 1984)

Nancy E. Shoemaker - Ph.D., Mathematics, Rensselaer Polytechnic Institute, 1977. Computer Systems, particularly UNIX. (February 1982 to February 1984)

Sivaguru S. Sritharan - Ph.D., Applied Mathematics, University of Arizona, 1982. Computational Fluid Dynamics. (July 1982 to July 1984)

Eitan Tadmor - Ph.D., Applied Mathematics, Tel-Aviv University, Israel, 1979. Numerical Analysis of Partial Differential Equations, Numerical Linear Algebra and Matrix Theory. (July 1982 to September 1983)

Russell G. Teglas - Ph.D., Mathematics, University of Wisconsin, 1981. Control Theory. (September 1981 to September 1983)

John Van Rosendale - Ph.D., Computer Science, University of Illinois, 1980. Numerical Solution of Partial Differential Equations. (June 1981 to June 1984)

VI. VISITING SCIENTISTS

Saul S. Abarbanel - Ph.D., Theoretical Aerodynamics, Massachusetts Institute of Technology, 1959. Professor, Department of Applied Mathematics, Tel-Aviv University, Israel. Numerical Analysis of Partial Differential Equations. (February to December 1983)

Marsha J. Berger - Ph.D., Numerical Analysis, Stanford University, 1982. Research Associate, Courant Institute of Mathematical Sciences. Numerical Solution of Partial Differential Equations. (July to August 1983)

Shahid H. Bokhari - Ph.D., Electrical Computer Engineering, University of Massachusetts, Amherst, 1978. Associate Professor, Department of Electrical Engineering, University of Engineering and Technology, Pakistan. Parallel Processing, Distributed Computing and Computer Architecture. (June to August 1983)

Claudio Canuto - Ph.D., Mathematics, University of Torino, Italy, 1975. Researcher, Istituto Di Analisi Numerica, C.N.R. - Pavia, Italy. Numerical Analysis of Partial Differential Equations. (October 1982 to September 1983)

Guy J. Chavent - These d'Etat in Applied Mathematics, Paris, France, 1971. Professor, University of Paris-Dauphine (Paris IX), France; Professor, Department of Applied Mathematics, Ecole Polytechnique, France; and Scientific Director at Institut National de Recherche d'Informatique et d'Automatique, France. Control Theory. (June to July 1983)

James M. Crowley - Ph.D., Applied Mathematics, Brown University, 1982. Assistant Professor, Department of Mathematics, (Captain), U.S. Air Force Academy. Identification for Distributed Parameter Systems. (June to July 1983)

Peter J. Fleming - Ph.D., Engineering Mathematics, Queen's University, Belfast, Ireland, 1973. Lecturer, School of Electronic Engineering Science, University College of North Wales, United Kingdom. Control System Design. (January to June 1983)

Philip Hall - Ph.D., Mathematics, Imperial College, London, England, 1973. Lecturer, Department of Mathematics, Imperial College. Computational Fluid Dynamics. (March 1983 to September 1984)

Marc Q. Jacobs - Ph.D., Mathematics, University of Oklahoma, 1966. Professor, Department of Mathematics, University of Missouri. Control Theory. (June 1983)

Karl Kunisch - Ph.D., Mathematics, University of Graz, Austria, 1978. Associate Professor, Technical University of Graz; Visiting Associate Professor, University of Oklahoma and Visiting Associate Professor, Lefschetz Center for Dynamical Systems, Brown University. Control Theory. (June 1983)

Randall J. LeVeque - Ph.D., Computer Science, Stanford University, 1982. Assistant Professor, Department of Mathematics, University of California at Los Angeles. Numerical Solution of Partial Differential Equations. (July to September 1983)

Michele Napolitano - Ph.D., Aerospace Engineering, University of Cincinnati, 1978. Professor, Istituto di Macchine, University of Bari, Italy. Computational Fluid Dynamics. (July to September 1983)

Merrell L. Patrick - Ph.D., Mathematics, Carnegie-Mellon University, 1964. Professor, Department of Computer Science, Duke University. Parallel Numerical Algorithms and Architectures. (May to June 1983)

Terrence W. Pratt - Ph.D., Mathematics/Computer Science, University of Texas at Austin, 1965. Professor, Department of Computer Science, University of Virginia. Programming Languages. (May to July 1983)

Alfio Quarteroni - Ph.D., Mathematics, University of Pavia, Italy, 1975. Researcher, National Council of Research of Pavia. Numerical Approximation of Partial Differential Equations by Spectral Methods. (June to July 1983)

Lloyd N. Trefethen - Ph.D., Computer Science, Stanford University, 1982. NSF Fellow/Adjunct Assistant Professor, Courant Institute of Mathematical Sciences. Numerical Analysis. (June to August 1983)

Eli Turkel - Ph.D., Applied Mathematics, New York University, 1970. Associate Professor, Department of Mathematics, Tel-Aviv University, Israel. Numerical Fluid Dynamics. (February to December 1983)

Bram van Leer - Ph.D., Theoretical Astrophysics, Leiden University, Leiden, Netherlands, 1970. Research Leader, Department of Mathematics and Computer Science, Delft University of Technology, Delft, Netherlands. Computational Fluid Dynamics. (July to August 1983)

Luther W. White - Ph.D., Mathematics, University of Illinois at Urbana, 1977. Associate Professor, Department of Mathematics, University of Oklahoma. Control Theory and Identification. (July 1983)

VII. CONSULTANTS

Ivo Babuska - Ph.D., Technical Science, University Tech, Prague, Czechoslovakia, 1952; Mathematics, Academy of Science, Prague, 1956; D.Sc., Mathematics, Academy of Science, Prague, 1960. Professor, Institute for Physical Science and Technology, University of Maryland. Numerical Methods for Partial Differential Equations.

H. Thomas Banks - Ph.D., Applied Mathematics, Purdue University, 1967. Professor, Department of Mathematics, Brown University and Southern Methodist University. Control Theory, Mathematical Biology, and Functional Differential Equations.

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Marsha J. Berger - Ph.D., Numerical Analysis, Stanford University, 1982. Research Associate, Courant Institute of Mathematical Sciences. Numerical Solution of Partial Differential Equations.

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Robert W. Collins - Ph.D., Mathematics, University of Massachusetts-Amherst, 1971. Associate Professor, Department of Mathematics and Computer Science and Director of Applied Science, College of William and Mary. Programming Languages, Simulation and Automated Tools.

James M. Crowley - Ph.D., Applied Mathematics, Brown University, 1982. Assistant Professor, Department of Mathematics, (Captain), U.S. Air Force Academy. Identification for Distributed Parameter Systems.

Peter R. Eiseman - Ph.D., Mathematics, University of Illinois, 1970. Associate Research Scientist, Department of Applied Physics and of Nuclear Engineering, Columbia University. Computational Fluid Dynamics.

Stefan Feyock - Ph.D., Computer Science, University of Wisconsin, 1971. Associate Professor, Department of Mathematics and Computer Science, College of William and Mary. Artificial Intelligence.

George J. Fix - Ph.D., Mathematics, Harvard University, 1968. Professor and Chairman, Department of Mathematics, Carnegie-Mellon University. Numerical Methods for Partial Differential Equations.

Joseph E. Flaherty - Ph.D., Applied Mathematics, Polytechnic Institute of Brooklyn, 1969. Associate Professor, Department of Mathematics, Rensselaer Polytechnic Institute. Singular Perturbations, Numerical Analysis and Applied Mathematics.

Dennis B. Gannon - Ph.D., Computer Science, University of Illinois, 1980. Assistant Professor, Department of Computer Science, Purdue University. Numerical Methods and Software and Architecture Design.

James F. Geer - Ph.D., Applied Mathematics, New York University, 1967. Associate Professor, Department of Department of Systems Science, SUNY-Binghamton. Asymptotic Expansions of Solutions to Partial Differential Equations.

J. Steven Gibson - Ph.D., Engineering Mechanics, University of Texas at Austin, 1975. Assistant Professor, Department of Mechanics and Structures, University of California at Los Angeles. Control of Distributed Systems.

Chester E. Grosch - Ph.D., Physics - Fluid Dynamics, Stevens Institute of Technology, 1967. Professor, Department of Mathematics and Slover Professor, Department of Oceanography, Old Dominion University. Hydrodynamic Stability, Computational Fluid Dynamics, Algorithms for Array Processor and Unsteady Boundary Layers.

Max D. Gunzburger - Ph.D., Mathematics, New York University, 1969. Associate Professor, Department of Mathematics, Carnegie-Mellon University. Fluid Dynamics and Numerical Methods for Partial Differential Equations.

Subramaniya I. Hariharan - Ph.D., Mathematics, Carnegie-Mellon University, 1980. Professor, University of Tennessee Space Institute. Numerical Methods for Partial Differential Equations.

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Heinz-Otto Kreiss - Ph.D., Mathematics, Royal Institute of Technology, Sweden 1960. Professor, Department of Applied Mathematics, California Institute of Technology. Numerical Analysis.

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Patricia Daniel Lamm - Ph.D., Applied Mathematics, Brown University, 1980. Assistant Professor, Department of Mathematics, Southern Methodist University. Control and Identification of Partial Differential Equations.

Richard C. MacCamy - Ph.D., Mathematics, University of California-Berkeley, 1956. Professor, Department of Mathematics, Carnegie-Mellon University. Partial Differential and Internal Equations.

Robert W. MacCormack - M.S., Mathematics, Stanford University. Associate Professor, Department of Aeronautics and Astronautics, University of Washington. Computational Fluid Dynamics and Numerical Analysis.

David Montgomery, Ph.D., Physics, Princeton, 1959. Professor, Department of Physics, College of William and Mary. Plasma Physics, Turbulence Theory and Magnetohydrodynamics.

William F. Moss - Ph.D., University of Delaware, 1974. Assistant Professor, Department of Mathematical Sciences, Old Dominion University. Integral Equation Methods for Acoustics.

Roy A. Nicolaides - Ph.D., Mathematics, University of London, 1972. Professor, Department of Mathematics, Carnegie-Mellon University. Numerical Solution of Partial Differential Equations and Finite Difference/Element Methods.

Joseph E. Oliger - Ph.D., Numerical Analysis, Uppsala University, Sweden, 1973. Associate Professor, Department of Computer Science, Stanford University. Methods for the Numerical Analysis of Partial Differential Equations.

James E. Ortega - Ph.D., Mathematics, Stanford University, 1962. Professor and Chairman, Department of Applied Mathematics and Computer Science, University of Virginia. Numerical Methods for Partial Differential Equations.

Stanley Osher - Ph.D., Functional Analysis, New York University, 1966. Professor, Department of Mathematics, University of California at Los Angeles. Methods for the Numerical Analysis of Partial Differential Equations.

Merrell L. Patrick - Ph.D., Mathematics, Carnegie-Mellon University, 1964. Professor, Department of Computer Science, Duke University. Parallel Numerical Algorithms and Architectures.

Terrence W. Pratt - Ph.D., Mathematics/Computer Science, University of Texas at Austin, 1965. Professor, Department of Computer Science, University of Virginia. Programming Languages.

Werner C. Rheinboldt - Ph.D., Applied Mathematics, University of Freiburg, Germany, 1955. Andrew W. Mellon Professor, Department of Mathematics, University of Pittsburgh. Numerical Analysis and Computational Solution of Nonlinear Problems.

I. Gary Rosen - Ph.D., Applied Mathematics, Brown University, 1980. Technical Staff, Charles Stark Draper Laboratory, Inc. Numerical Methods for Problems in Control Systems.

Jacob T. Schwartz - Ph.D., Mathematics, Yale University, 1953. Professor, Department of Computer Science, Courant Institute for Mathematical Sciences. Programming Languages, Parallel Computing and Artificial Intelligence.

John C. Strikwerda - Ph.D., Mathematics, Stanford University, 1976. Assistant Professor, Department of Computer Science, University of Wisconsin. Numerical Methods for Partial Differential Equations.

J. Christian Wild - Ph.D., Rutgers University, 1977. Assistant Professor, Department of Computer Science, Old Dominion University. Concurrent Computing Systems.

VIII. STUDENT ASSISTANTS

Mark H. Dunn - Graduate Student at Old Dominion University. (November 1980 to present)

Robert S. Fennema - Graduate student at Old Dominion University. (June 1982 to June 1983)

Jeanette B. Hariharan - Graduate student at the College of William and Mary. (June 1982 to August 1983)

Mala Mehrotra - Graduate student at the College of William and Mary. (July 1983 to present)

Peter L. Spence - Graduate student at Old Dominion University. (June 1982 to present)

GRADUATE FELLOWS

Michael B. Giles - Student at Massachusetts Institute of Technology. (June to August 1983)

William A. Mulder - Student at Leiden University Observatory, Netherlands. (July to September 1983)

ICASE SEMINAR PROGRAM

April 1, 1983 through September 30, 1983

April 25 — **Professor Andrzej Manitius**, Rensselaer Polytechnical Institute: *Linear and Nonlinear Feedba-' Controllers for a Wind Tunnel Model Involving a Delay: Analytical Design and Numerical Simulations*

April 26 — **Professor Achi Brandt**, The Weizmann Institute of Science and Colorado State University: *Algebraic Multigrid*

May 12 — **Professor Stanley Osher**, University of California, Los Angeles: *Entropy Condition Satisfying Difference Approximations to the Full Potential Equation*

May 16 — **Dr. Kenneth G. Stevens, Jr.**, NASA Ames Research Center: *Studies in Concurrent Processing at NASA Ames Research Center*

May 19 — **Professor Stephen B. Pope**, Cornell University: *PDF Methods for Turbulent Flows*

May 20 — **Dr. Manmohan M. Rai**, NASA Ames Research Center: *A Zonal Approach to Grid Generation*

June 3 — **Dr. Milton E. Rose and Dr. Timothy N. Phillips**, ICASE: *Solution of* $(\mathrm{div}\ \rho\ \mathrm{grad} - q^2)u = 0$

June 14 — **Dr. Joel E. Dendy, Jr.**, Los Alamos National Laboratory: *Multigrid Semi-Implicit Hydrodynamics Revisited*

June 20 — **Professor Woo Yung Soh**, University of California, Berkeley: *Entry Flow in a Curved Pipe*

July 1 — **Professor Bernard A. Fleishman**, Rensselaer Polytechnic Institute: *Perturbation and Bifurcation in a Free Boundary Problem*

July 13 — **Professor Philip Hall**, ICASE: *Taylor Gortler Vortices in Steady and Oscillatory Flows*

July 14 — **Professor Shahid H. Bokhari**, Pakistan University of Engineering & Technology, Lahore: *Reducing the Diameters of Arrays*

July 18 — **Professor Nick Trefethen**, Courant Institute and ICASE: *Stability of Finite Difference Models with One or Two Boundaries*

July 19 — **Professor Shahid H. Bokhari**, Pakistan University of Engineering & Technology, Lahore: *New Heuristics for the Mapping Problem*

July	20	**Professor Egon Krause,** Aerodynamisches Institut der RWTH Aachen: *A Numerical Study of Flows with Large Vortices*
July	21	**Professor Ir. Charles Hirsch,** Vrije Universiteit Brussel: *A Class of Central Bidiagonal Schemes with Implicit Boundary Conditions for the Solution of Euler's Equations*
July	22	**Professor H. Hollanders,** Onera, France: *Extension of a Class of Implicit Inviscid Schemes to the Solution of the Complete Navier-Stokes Equation for Compressible Flows*
July	22	**Professor A. Lerat,** ENSAM Paris and Onera, France: *Implicit Euler Solvers of Second-Order Accuracy*
July	28	**Professor Russell B. Dahlburg,** College of William and Mary: *Viscous, Resistive MHD Stability Computed by Spectral Techniques*
August	5	**Professor Bram van Leer,** ICASE and Delft University of Technology: *Relaxation Methods for the Euler Equations*
August	5	**William A. Mulder,** ICASE and Leiden University Observatory: *Multigrid Relaxation for the Euler Equations*
August	8	**Michael B. Giles,** ICASE and Massachusetts Institute of Technology: *Iterative Solutions of 2D Time-Independent Scalar Convective-Diffusion Equations and their Inviscid Limits*
August	10	**Professor Frank T. Smith,** Ohio State University & Imperial College, U.K.: *An Alternative Approach to Linear and Nonlinear Stability Calculations for Boundary Layers and Channel Flows*
August	15	**Professor Randall J. LeVeque,** ICASE and Courant Institute: *A Large Timestep Generalization of Godunov's Method for Systems of Conservation Laws*
August	19	**Dr. John Van Rosendale,** ICASE: *Minimizing Inner Product Data Dependencies in Conjugate Gradient Iteration*
August	22	**Professor Norman J. Zabusky,** University of Pittsburgh: *Contour Methods in Two-Dimensional Fluid Dynamics*
August	26	**Professor Joel Ferziger,** Stanford University: *Turbulent Flow in the Channel with a Moving Wavy Wall*
August	31	**Dr. Timothy N. Phillips,** ICASE: *Preconditioners for the Spectral Multigrid Method*
September	1	**Dr. Saul Abarbanel,** Tel Aviv University and ICASE: *What!? More on Boundary Conditions*
September	15	**Professor Michele Napolitano,** Istituto di Macchine, Univ. of Bari, Italy and ICASE: *Numerical Methods for the 3D Lambda-Formulation Equations*

September 20 **Professor Peter K. Sweby,** University of California at Los Angeles: *High Resolution TVD Schemes Using Flux Limiters*

September 21 **Mr. Murshed Hossain,** College of William and Mary: *Long-Time States of Inverse Cascades in the Presence of a Maximum Length Scale*

September 28 **Dr. David Kopriva,** ICASE: *Pseudospectral Solution of Two-Dimensional Gas-Dynamic Problems*

September 29 **Professor David C. Montgomery,** College of William and Mary: *The Effect of Small-Scale MHD Turbulence on the Large-Scale Dynamics*

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15. Supplementary Notes

Langley Technical Monitor: Robert H. Tolson
Final Report

16. Abstract

This report summarizes research conducted at the Institute for Computer Applications in Science and Engineering in applied mathematics, numerical analysis and computer science during the period April 1, 1983 through September 30, 1983.

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