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NASA Langley Research Center, Hampton, Virginia 23665

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Space Administration

Langley Research Center
Hampton, Virginia 23665

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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 nonprofit 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:

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

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

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

- Computer systems and software, especially vector and parallel computers.

ICASE reports are considered to be primarily preprints of manuscripts that have been submitted to appropriate research journals or that are to appear in conference proceedings. A list of these reports for the period October 1, 1988 through March 31, 1989 is given in the Reports and Abstracts section which follows a brief description of the research in progress.

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RESEARCH IN PROGRESS

Saul Abarbanel

Using the physical model of 2-D Couette flow it was shown that for slow flow ($M \ll 1$) the linearly perturbed compressible Navier-Stokes equations contain not only all of the eigenmodes and eigenvalues of the corresponding incompressible system but they also contain additional eigenvalues and eigenmodes which do not appear in the incompressible formulation. Work is now in progress to apply the same technique to 3-D perturbations around the steady Poiseuille flow in a pipe. The search will be for additional "compressible modes" which are not temporarily stable. Work also continued on adapting the downstream non-reflecting boundary condition (for viscous flows) to the case of uneven grids with local time stepping.

H. T. Banks

With the support of graduate students at Brown University, we have continued our collaborative efforts on several problems of interest to Langley Research Center scientists (R. Silcox, Acoustics Division and E. Armstrong, Guidance and Control Division). These include: (i) Methods for "optimal" noise suppression in spatially distributed domains; (ii) Estimation of damping in perforated structures ("plates with holes"). In addition to investigating optimal feedback controllers for state space models of a distributed acoustic pressure field for (i), we have begun efforts to determine optimal placement of sensors (microphones) and actuators (speakers). In (ii) we have pursued a Love-Kirchoff model for a plate with "holes" to develop theoretical and computational results for estimation of internal damping mechanisms (e.g., Kelvin-Voigt) from observations of acceleration. We have also begun attempts to use ideas from homogenization theory in these inverse problems.

H. T. Banks and F. Kojima

We are continuing our investigations (in collaboration with W. Winfree, M. Heath, and P. James of the Instrument Research Division, LaRC) on inverse problems arising in thermal testing of materials in space structures. Our focus for this problem is on the identification of the geometrical shape of boundaries for a thermal diffusion system. Using techniques and ideas related to the 'method of mappings', we have been able to develop a parameter estimation technique using an optimization code for the trust region algorithm (created by R.Carter). The efficacy of the proposed scheme was demonstrated through numerous computational experiments. The ideas developed are now being tested with the experimental data from the IRD laboratory.

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John Burns

We have started an effort to develop practical models and computational algorithms for control of fluid/structure interaction problems. In most of these problems the governing equations are hybrid, i.e. coupled systems of ordinary, partial and integro-differential equations. It is often necessary to use simplified models in order to develop practical control laws. We are looking at three basic problems involving structural and fluid flow systems.

We recently completed a study of the effect of state feedback on stability and shock control by using the simple Burger's equation as a model and computing optimal LQR controls using the linearized model. We discovered that not only does the linear feedback control enhance stability, it also reduces shock formation. As expected, numerical problems occur at high Reynolds numbers; however, our preliminary results have raised several interesting questions.

In collaboration with Y. R. Ou, we have developed simple mathematical models for unsteady flow over a flat plate with a control flap. This particular problem is of interest in the development of active control laws for flow separation control. We plan to investigate computational schemes for control of such systems.

We have begun to investigate the problem of controlling the noise generated in the far field by a structure vibrating in a fluid. Again, the system is hybrid. Moreover, the problem is complicated by the fact that the control law can use only measurements taken on or near the structure (i.e. no far field sensors are allowed).

Richard Carter

Because of their robust global convergence properties and fast local convergence properties, trust region algorithms for numerical optimization have become very popular, yet many questions remain concerning their application to certain classes of problems frequently encountered. One such category involves optimization/simulation problems where neither function nor gradient values can be evaluated exactly, and where the computational expense of a given evaluation rises geometrically with the required accuracy of the evaluation.

Previous tests of trust region algorithms using synthetically generated noise confirmed the general global convergence behavior predicted by theory. These tests have been extended to include real problems from the literature in order to establish profiles of cpu time versus commanded accuracy. A method for automatically estimating gradient error and simultaneously improving gradient accuracy has also been successfully tested, as well as a related technique for controlling the accuracy of finite difference gradient evaluations. The optimization code used in these tests is being distributed to researchers at Brown

University and the University of Texas for further testing and to establish portability; if no problems are encountered the code will be submitted to the ACM Transition on Mathematical Software for general distribution.

Another topic being studied is the feasibility of adaptive nonlinear rescalings in optimization algorithms. Such rescalings are attractive because natural problem formulations from an engineering point of view are often intractable to an optimization algorithm whereas alternative formulations involving inverse or logarithmic variables may be very simple to solve. The difficulty with this approach is that selecting the wrong transformation can make an easy problem almost impossible to solve.

Two versions of this idea are being investigated. The first is to pre-specify a number of candidate scalings and allow the algorithm to switch between them from iteration to iteration based on some merit scheme. The second is to define a general nonlinear rescaling equation and adjust the parameters of this rescaling at each iteration. Hybrid approaches are also under consideration.

Tom Crockett

Version 11, Release 3 of the X Window System was installed on the ICASE Suns, keeping us up-to-date with the most current release. In addition, the IBM/Carnegie-Mellon Andrew system was installed. Andrew is a second-generation workstation environment, providing a number of sophisticated tools for creating multi-media documents (which may include text, graphics, animations, etc.), as well as a powerful mail-and-message system and various other utilities which support the programming process.

Information from a number of parallel computer vendors was collected to generate comparisons between different systems. Several criteria, including price, performance, scalability, and software support, are being examined to help ICASE and Langley decide on a new parallel computer system. Some preliminary work was also done toward developing benchmarks for candidate systems.

Naomi H. Decker

Work is progressing on the analysis of multigrid as an acceleration technique for explicit time stepping schemes for finding steady solutions of the Euler equations. Experimental observations motivate the investigation and the focus is on understanding the inability of current methods to attain true multigrid efficiencies for these types of problems. Is the inefficiency due to the nonlinearity, the coupling between equations, or is it inherent in any two (or more) dimensional conservation law? The attempt to answer this question has lead to the development of improved algorithms for special problems, and will hopefully lead to a cohesive treatment of the general problem resulting in the more efficient computation

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of steady state solutions.

Naomi H. Decker and David Kamowitz

Multigrid has been successfully used to compute steady solutions to the Euler equations, yet fundamental questions remain concerning the specific roles of the relaxation and the coarse grid correction in these non-elliptic problems. Local mode analysis of the two grid multigrid algorithm gives convergence rates which are overly pessimistic relative to experimental observations for problems with inflow/outflow boundary conditions. Experiments demonstrate that the presence of boundary conditions on the coarse grid has a global effect on the fine grid, thus improving the rate of convergence. We continue to examine, theoretically and experimentally, the relationship between the convective and dissipative roles of the relaxation, especially for two and higher dimensional problems where issue of inconsistency of the viscosity terms and the possibility of non-alignment dominate (and severely limit) the behavior of multigrid.

Robert E. Fennell

Current research involves the development of theoretical and numerical methods for the design and analysis of robust control laws for a broad class deterministic and stochastic systems. Eigenspace methods are being used to develop robust control law design and analysis methods for linear multivariable systems and the methods are being applied to a symmetric flutter suppressional/gust load alleviation problem for an aeroelastic vehicle (joint effort with William M. Adams, Guidance and Control Division). In addition, reproducing Hilbert space methods being used to develop simulation, control design and analysis methods for stochastic hereditary systems.

James Geer

Work is progressing on a hybrid perturbation/Galerkin method to determine how the method might be applied to some exterior boundary value problems for elliptic PDE's when the boundary of the domain D_0 has an irregular shape. The basic idea is to treat D_0 as a perturbation of a simple domain d_1 (e.g. a circle or an ellipse) by embedding it in a one parameter family of domains D_ε, where $0 \leq \varepsilon \leq 1$. Then, first, we use a regular (or singular) perturbation method to construct an approximate solution in the form of a perturbation solution, using ε as the perturbation parameter. We then use the perturbation coordinate functions generated in this way as trial functions for a Galerkin type approximation, where the amplitudes of the trial functions are determined by applying the Galerkin condition to the boundary condition. Currently, we are applying the method to some eigenvalue problems for irregularly shaped domains and to some problems of flows

about geometrically complicated bodies. In addition, we are combining our method with some homotopy methods to further enhance the accuracy of the results we obtain. In particular, we hope this will lead to a new extension of slender body theory. So far, the preliminary results have been very encouraging. Work on the method itself is being done with Carl Andersen of the College of William and Mary, while possible applications are being discussed with Eddie Liu (Low-Speed Aerodynamics Division) and Mike Hemsch (Applied Aerodynamics Division).

Investigations are also continuing concerning some fundamental properties (both from theoretical and computational points of view) of a class of "almost" singular integral equations of the first kind which are useful in representing solutions to certain elliptic exterior boundary value problems. These equations typically have the property that the domain of integration R is a proper subset of the domain of validity D of the equation. Special consideration is being given to the idea of analytically continuing the solution into the domain D. In fact, this has now been done for a large class of one-dimensional integrals, such as those which occur in the representation of solutions involving a body of revolution. For this special class, a characterization of R in terms of certain properties of the analytic continuation of the kernel has been obtained, which leads to a simple numerical procedure to determine R and helps to circumvent some of the stability problems inherent in solving integral equations of the first kind. Application of the results to several two and three dimensional problems involving slender or thin bodies are being carried out. The symbolic manipulation system MACSYMA has been used in some of the preliminary investigations.

We have started to study approximation theory for the optimal linear-quadratic control of linear thermoelastic systems. These systems consist of a coupled second order equation of elasticity and the first order heat equation. In general, the presence of the heat dissipation provides light damping for the mechanical system. Of particular interest is how thermoelastic damping affects control design in both the presence and absence of other forms of dissipation, for example Kelvin-Voigt or structural. We are especially interested in looking at the subsequent performance of a control law designed without regard to thermoelastic effects; for example, could instability result, or are thermoelastic effects so small that they can be disregarded in control synthesis.

T. L. Jackson and C. E. Grosch

An understanding of the stability characteristics of reacting compressible mixing layers is of fundamental interest and is also extremely important in view of the projected use of the scramjet engine for the propulsion of hypersonic aircraft. In a recent report (ICASE Rep. No. 89-18) we presented the results of a study of the inviscid spatial stability of a parallel compressible mixing layer in which a flame sheet is embedded.

We are currently carring out an analysis of the stability of the compressible mixing layer using various models of the thermodynamics. We hope to determine the sensitivity of the growth rates, etc. to the assumptions of the model. We have also begun a study of the stability of the reacting mixing layer using a finite thickness flame.

Fumio Kojima

Work is continuing on the development of parameter estimation techniques based on the boundary integral equation approach. With the background knowledge of the output least square identification (OLSI), the inverse problems for the two- dimensional Laplace equation with Robin type or the mixed boundary condition have been considered. These boundary value problems are reduced to the equivalent integral equations of the first and/or second kind. We developed the computational technique for the OLSI-method using B-spline approximations. The method is applicable to a wide range of inverse problems such as structure design in aerodynamic engineering, impedance computed tomography, soil-structure interaction problems, etc. Numerical studies are promising using the trust region algorithm created by R.Carter. To show the convergence properties for the proposed technique is our current research interest. Further investigations will involve applying the method developed to the inverse problem arising in free boundary value problems

Jacques Liandrat

Our work is based on the study of the Wavelet Transform and some of its first applications to fluid mechanics and numerical analysis of partial differential equations. First, different algorithms for solving the regularized (viscous) Burgers equation with periodic boundary conditions, using wavelet decomposition for spatial approximation, have been implemented. After comparison with classical numerical methods (finite difference, spline approximation, Fourier spectral methods) it appears that the wavelet algorithms can be very useful to approach solutions where localized strong gradient develop. In collaboration with David Gottlieb, we are working on the numerical analysis of our methods and on their optimization in term of numerical efficiency and precision.

The wavelet transform can also be considered as a post processing tool for fluid mechanics or turbulence simulations. In collaboration with Gordon Erlebacher (Fluid Mechanics Division), we are trying to extract from the wavelet decomposition of numerically simulated 2D compressible turbulence flows, physical information concerning shocks and vorticity dynamics. Comparison with classical tools is in progress.

Dimitri Mavriplis

Work has mainly focused on the solution of the steady-state compressible Navier Stokes equations on unstructured triangular meshes. A multigrid method for solving laminar

viscous flow problems on unstructured meshes has been developed and validated for single airfoil and flat-plate configurations, resulting in a paper presented at the 27th AIAA Aerospace Sciences Meeting in Reno, Nevada, in January 1989. Current work is focused on the implementation of a suitable turbulence model for use on unstructured meshes. In a first phase, an algebraic Baldwin-Lamax model has been implemented with the present multigrid solver on structured triangular meshes, in order to verify the efficiency of the scheme in computing turbulent flows. The implementation of a more general two-equation field model is planned for the future.

Work has also progressed on the investigation of methods which combine in an optimal manner adaptive meshing strategies and multigrid methods in the context of unstructured meshes. Two such methods have been developed. The first makes use of global coarse meshes and employs zonal fine meshes on the high grid levels of the multigrid sequence in the regions where adaptive refinement takes place. The second method makes use of a global fine mesh and a series of zonal coarse-grid accelerator meshes which lie under the regions of the fine mesh which have been adaptively refined. Both schemes were found to produce similar convergence rates when applied to the Euler equations and provide increased solution efficiency due to the use of zonal rather than global meshes in the various levels of the multigrid sequence. This work is summarized in a paper presented at the Fourth Copper Mountain Conference on Multigrid Methods at Copper Mountain, Colorado in April 1989.

Piyush Mehrotra and John Van Rosendale

Programming distributed memory machines requires a careful distribution of data and computation so as to effectively utilize the machine. The main focus of our research, for the last six months, has been new language independent programming constructs which allow the user to specify algorithms at a high level while retaining control over performance critical issues such as data distribution and load balancing. We have been investigating algorithms and heuristics that the compiler can utilize to automatically generate a set of independently executing processes from the high level specification. The compiler is also responsible for generating all the low-level but complex details of the communications required to actually share data between the tasks.

Tobias Orloff

Work has proceeded in two main areas. First an interactive 3D modeling system has been designed and implemented under the X Windows standard (X11.3). The software is a practical implementation and extension of Kajiya's ideas on "generative models", and allows rapid interactive prototyping of many common, complex three dimensional objects. (In the simplest case, the software allows the user to interactively sketch out a "cross sectional curve" and a "spine curve" and then the program can generate the surface of an object by sweeping the cross section along the spine.) For use with this program, several graphics tools have been implemented on the new Titan graphics computer. These include interactive 3D display software and animation tools. Using these programs a short video was produced. The video demonstrates some of the modeling capabilities and also a new animation technique allowing the animator to smoothly change the shape of irregularly shaped objects.

This work has also led to more general consideration of software environments in which to do modeling and animation. A complete system for this would necessarily include many different types of tools, such as modeling, viewing, texturing, animating, compositing, anti-aliasing, etc. and each of these may actually be several different types of tools themselves. For example, animation may be produced by in-betweening key frames, by modeling physical forces on objects, or techniques such as those used in the video mentioned above, which produce animations based on the way the objects are modeled. One can imagine that new methods and ideas will continue to develop, and for this reason it is impractical to try to implement all these techniques in one "monolithic" program. Yet, when they are implemented separately, for example by having each program read and write to files of specified formats, there is a great deal of effort in getting the pieces to work together. The X Window system offers a standardized environment in which separate interactive, graphical programs may communicate with one another. The programs may even be running on different computers connected by a standard network. Therefore, work has proceeded in designing a simple specification for software which will allow the user to run several programs at once and, if some of the programs share an interest in a particular data structure (for example, the output of a 3D modeler would be of interest to a rendering program), then the user may graphically connect the output from one to the input of the other. From then on a change in the output of one is reflected by a change of the input of the other. Important features of this are that the separate programs need have no knowledge of each other (except to agree on common data structures), and the user may add as many or few components as necessary for his needs. Also, new programs can easily be introduced into this system. It is envisioned that such an environment would

be of use not only in computer graphics and animation, but in many areas of scientific research as well.

Tobias Orloff and Tom Crockett

A joint project was started to develop a parallel graphical renderer to generate high quality real-time animations of geometrically-described scenes. Current high-end graphics workstations typically render at a peak rate of about 100,000 Gouraud-shaded triangles per second. Our preliminary calculations suggest that rates approaching 1,000,000 triangles per second will be attainable on next-generation general purpose parallel computers. An initial version of a parallel renderer is being developed for the Intel iPSC/2 hypercube to evaluate parallel rendering algorithms. Other versions, in particular an SIMD implementation, are being planned. A significant goal is to exploit both geometric-level parallelism for shading and transforming the scene, and pixel-level parallelism for converting the geometric representation to a raster image.

Yuh-Roung Ou

One major open problem is the global well posedness of the initial boundary value problem associated with three dimensional (time dependent) fluid flow. A practically important regularized form of the Navier-Stokes equations has been analyzed. For this system we are able to prove global existence and uniqueness for the weak as well as strong solutions. As a continuation of previous work (ICASE report 89-14), research is being conducted on establishing a theorem for the convergence of the solution of regularized system to the solution of the conventional Navier-Stokes system as the regularization parameter approaches zero. This work is being done in collaboration with S. S. Sritharan of University of Southern California.

Recently we have begun our research on the active control of separated flow. Our attention will center on the optimal control problem arising in the nonstationary viscous flow past an obstacle. At present, a model problem based on employing an oscillating flap mechanism is being investigated. The main goal here is to reduce the reattachment length and increase the local lift. This is a joint work with John Burns and H. T. Banks.

Merrell L. Patrick and Mark W. Jones

Development of algorithms for solving the generalized eigenvalue problem is continuing. An algorithm based on the Lanczos method has been implemented and tested on the Convex and Cray 2 computers. Performance of this algorithm is being compared with that of the eigensolver module, EIG, in the structural analysis testbed system running on the Convex and Cray 2 systems. For all problems tested the performance of our implementation of Lanczos's method is superior to that of the EIG module in the testbed system.

Our approach required the development of a routine for solving indefinite linear systems of equations. Such systems might arise because shifting is required to improve convergence rates of the Lanczos iterations. A good shifting strategy was also required for optimal performance of the algorithm. A routine based on the Bunch-Kaufman algorithm for solving indefinite systems was implemented and shown to perform better than a LINPACK algorithm based on LU factorization. A shifting strategy has been defined and is being tested for robustness.

Parallel versions of the algorithm will also be implemented using the Force language due to Harry Jordan and it's performance will be compared to that of the non-Force version. This work is being done in collaboration with Olaf Storaasli (Structural Mechanics Division).

Merrell L. Patrick and Terrence W. Pratt

Methods for porting existing FORTRAN based applications codes to new parallel architectures are the focus of this study. The NASA LAURA code (Langley Aerothermodynamic Upwind Relaxation Algorithm), developed by Peter Gnoffo (Space Systems Division) is being studied as a test case. We are looking at both spatial and temporal partitioning methods for parallel execution of this code on various architectures, including the Intel iPSC/2, NCUBE/ten and BBN Butterfly Plus or GP-1000.

Doug Peterson

A second Sun 3/180 file server, with an 892MB disk, has been installed. Each of the two file servers has been configured to support one laser printer and a maximum of 12 diskless workstations. To improve overall performance, each server and its associated diskless clients are on segregated ethernets. The ethernets are joined by a Digital LANbridge 100, which isolates local ethernet traffic, but permits traffic between to entities on either net when neccessary. This arrangement allows simultaneous communication between clients and servers when the client-server pairs are on different ethernets. The network is further reconfigured to allow direct communication by all nodes with the Proteon gateway which connects the ICASE network to other nets. The gateway function performed by the orignal file server has been deleted.

ICASE.EDU is now a registered SURANET site, with direct access (currently 56kb) to the SURANET backbone site at CBAF. Addtionally, ICASE.EDU also has full connectivity with all sites at Langley and Ames, via LaRCNET and NASNET. It is anticipated that the 56kb link to CBAF will be upgraded to T1 soon.

The migration of the business office functions from the NBI word processors to Sun workstations is essentially complete in that all current NBI-based functions can be sup-

ported on the Sun system. The public domain software package 'rolo' has been used to provide an on-line master address file and an on-line card catalog for the ICASE library.

Terrence W. Pratt

PISCES 3 is a parallel programming environment for scientific and engineering applications that is being implemented for both shared and distributed memory parallel computers. The goal is to provide a convenient parallel programming environment that allows large applications codes to be run on various parallel computer architectures without reprogramming.

PISCES 3 is based on the PISCES 2 environment that has been running on the 20-processor NASA FLEX/32 system since 1987. PISCES 3 retains the major elements of the PISCES 2 system, including the user interface, tasks, asynchronous message passing, forces, shared variables and the FORTRAN extensions to provide access to these facilities. In addition, PISCES 3 will provide: (1)   A C interface to the PISCES virtual machine, so that applications programs may use C, FORTRAN, or a combination of both languages. (2)   A new "loosely synchronous" communication style, based on the use of "stencils" to define local communication topologies. (3)   Direct read/write access to arbitrary portions of large data arrays stored on multiple parallel disks.

Implementation of PISCES 3 is currently underway for the Intel iPSC/2 at the University of Virginia Institute for Parallel Computation. An implementation for the BBN GP-1000 is planned.

Peter Protzel

Work is continuing on the application of Artificial Neural Networks (ANNs) in the area of reliable computing. Together with D. Palumbo (Information Systems Division) we are investigating the characteristics of a certain class of 'programmable' ANNs that can be used to generate close-to optimal solutions for a broad range of optimization problems very quickly. The key benefits of these ANNs when implemented in hardware is their speed and fault-tolerance, which make them interesting for real-time control applications. We are specifically looking at the problem of dynamically reconfiguring the interconnection network of a fault-tolerant multi-processor system by using an ANN to control the reconfiguration.

Since the ANN would become a critical component from a reliability viewpoint when used in this application, we started to investigate the fault-tolerance characteristics of the ANN itself by simulating the performance of the ANN under the presence of injected faults. The results of this experiment, which are described in ICASE Report No. 89-12, show an

extreme fault-tolerance, even under the simultaneous presence of multiple faults, which is partly due to the particular characteristics of the model problem used. Interestingly, this fault-tolerance is inherent in the operation of the ANN and is not achieved by using redundant components as in conventional fault-tolerant systems. Further fault-injection experiments are planned for different model problems in order to evaluate the dependency between the fault-tolerance characteristics and the specific problem representation.

I. Gary Rosen and C. Wang

We have been looking at the convergence of the solutions to the discrete-time operator Riccati differential and algebraic equations to the solutions of the corresponding continuous time equations as the length of the sampling interval tends toward zero. Not surprisingly this investigation required that we also consider the relationship between discrete and continuous time system theoretic concepts such as controllability, observability, stabilizability, and detectability. We have carried out both theoretical and numerical studies that will be reported in a nearing completion.

Joel Saltz and David Nicol

We are examining the problem of automating the mapping, at run-time of sparse matrix, computations onto distributed memory architectures. These types of codes generally defeat any parallelizing compiler, because the data dependencies are unknown until the problem particulars are known at run-time.

Sutanu Sarkar

We are involved in the development of turbulence models within the framework of second-order closures. A nonlinear model for the pressure-strain term, which occurs in the Reynolds stress transport equations, has been developed in collaboration with Charles Speziale and Tom Gatski (Fluid Mechanics Division). This nonlinear model has been compared with current models in return-to-isotropy experiments and in various homogeneous turbulent shear flows. Some generic features of pressure-strain models of this class were also brought to light in this study.

An investigation of compressible turbulence is underway. Direct numerical simulations of homogeneous turbulence at high Mach number are being studied in order to elucidate purely compressible effects on the statistical moments.

The supersonic mixing layer is being studied in collaboration with L.Balakrishnan. A Reynolds stress closure has been implemented and a numerical investigation of the mixing layer at high Mach numbers is in progress.

Jeffrey S. Scroggs

Research continues in the area of physically motivated domain decomposition methods suitable for parallel processing. The method is based on solving hyperbolic (inviscid) equations in regions of smooth flow, and solving the parabolic (viscous) equations in regions of large gradients, such as shocks and boundary layers.

The hyperbolic equations may be solved via an iterative method formed by linearizing the equations over the whole temporal-spatial domain. The method is suitable for parallel processing. Convergence for the iterative method has been proven for a multidimensional nonlinear reaction-convection equation. Convergence for a system of equations in multiple dimensions is being explored.

Sharon Seddougui

The effect of significantly cooling the wall temperature on the compressible triple-deck structure for three-dimensional disturbances is jointly being investigated with Frank Smith. A new flow structure has been found and unstable modes of instability are currently being calculated for two-dimensional and three-dimensional flows and for subsonic, supersonic and hypersonic Mach numbers.

The nonlinear breakdown of wavy Görtler vortices is jointly being investigated with Andrew Bassom. We are considering small wavelength Görtler vortices with disturbances confined to the shear layers which trap the vortices. Unstable modes of instability have been found and the effect of increasing the size of the disturbance amplitude is currently in progress. This work is the nonlinear extension of the work of Hall and MacKerrell (ICASE Report No. 87-71).

Charles Speziale

Work was conducted in collaboration with S. Sarkar and T. B. Gatski (Fluid Mechanics Division) on the development of improved second-order closure models for compressible as well as incompressible turbulent flows. A major portion of this research effort was focused on the development of better models for the pressure-strain correlation. A simple quadratic nonlinear model was derived that was shown to better capture the physics of the return to isotropy problem and to better account for the effect of rotational as well as irrotational strains in rotating shear flows. This should allow for the more accurate calculation of the turbulent shear flows of aerodynamic interest which can have considerable streamline curvature. An analysis of RNG based turbulence models was also done. It is envisioned that these models may play a useful role in the integration of the turbulent flow field to a solid boundary without the need for empirical wall functions.

Research was conducted on the large-eddy simulation of transitional flows with Ugo

Piomelli, M. Y. Hussaini, and T. A. Zang (Fluid Mechanics Division). Several subgrid scale models have been correlated against direct numerical simulation data bases for transitional boundary layers and channel flow. A more direct testing of these models in actual large-eddy simulations is currently underway.

Shlomo Ta'asan

Research is being conducted in developing multigrid methods for inverse problems. Identification and design problems are the focus of our research. In the first subject the focus is on identification problems governed by elliptic partial differential equations, with boundary observations. Unknown coefficients appearing in the differential equation are to be estimated from the observed data. The attempt is to develop an adaptive approach in which the regularization for the problem is part of the solution process. Basic processes in the multigrid like the relaxation will incorporate a regularization, by rejecting changes in the coefficients that introduce negligible changes on the boundary measurements. Based on the above an adaptive discretization for the coefficients and probably also for the solution will be used.

In the other subject we focus on a design problem related to airfoil design. The purpose of the research is to develop an algorithm that solves the full design problem directly rather than iterating on a gradient type algorithm, suggested by optimal control theory. The key element of the new algorithm is a relaxation process for the airfoil which is truely local. That is, it involves changes in the airfiol that result in local changes only in the solution, thus obtaining a solution very efficiently.

Hillel Tal-Ezer

The problem of wave propagation in a linear viscoelastic medium can be stated mathematically as an exponential evolution operator of the form e^{Ft} acting on a vector representing the initial conditions, where F is a spatial operator matrix and t is the time variable. Techniques like temporal differencing by finite differences, for instance, are based polynomial interpolation of e^{zt} where z belongs to the domain D in the complex plane including the isotropic viscoelastic equation of motion. Examples of one and two-dimensional wave propagation test the accuracy and efficiency of the method compared with second-order temporal differencing and the Chebychev expansion technique. The results demonstrate the advantage of the new algorithm.

In the research described above we had an apriori knowledge on the domain D which includes the eigenvalues of F. This information is not always at our disposal. For this more general case, given a matrix A, vector v and a function $f(z)$, it is frequently desirable to obtain $w = [f(a)]v$. Many algorithms designed to approximate w can be written as $w_m =$

$[P_m(A)]v$ where $P_m(z)$ approximates $f(z)$ in a domain including all the eigenvalues of A. In the present research we have developed an algorithm based on polynomial interpolation of $f(z)$. The interpolating points are computed by the algorithm itself in some optimal way based on residual minimization. Implementing the scheme for the numerical solution of a system of O.D.E's or P.D.E's is described. The scheme which results is genuinely nonlinear. It's coefficients depend on the solution itself and are changing every time step. The result is an highly efficient method to solve time dependent problems.

Saleh Tanveer

Over the last six months, progress has been made in several different areas. In the area of two phase flow in a Hele-Shaw cell, analytic theory for the determination of velocity (ICASE Report No. (89-28)) and linear stability (ICASE report No. (89-29)) have been constructed. In the area of dendritic crystal growth, a rationa analytic theory has been constructed for the prediction of velocity and shape of a needle crystal in two dimensions at arbitrary Peclet number (ICASE report No. (89-31)). With Dan Meiron at Caltech, an analytic theory for the linear stability of the 2-D needle crystal is being constructed with the final goal of finding a proper theory for the prediction of side branching wavelength in a dendrite. With Greg Baker and Steve Cowley, a study of evolution of an interface subject to Kelvin-Helmholtz instability is being undertaken with an idea to study the formation of singularity and its regularization by introduction of surface tension or other effects. With Philip Saffman at Caltech, a rational theory for the prediction of cellular wavelength in directional solidification is being attempted.

Sherryl Tomboulian

Work continued on a spectral method solution for solving incompressible Navier-Stokes equations on the Connection Machine. This work was done in conjuction with Michele Macaraeg and Craig Street (Fluid Mechanics Division). The result was presented at the 1989 Supercomputing Conference held in November. It is published as part of the proceedings and also appears as an ICASE technical report.

Research in the area of extensions of SIMD architectures has proceeded. The latest research appears as an ICASE report and was presented at the Fifth Annual Computer Science Symposium on Massively Parallel Processor, April 7-8 1989, University of South Carolina.

Bram van Leer

Nonlinear algorithms for preventing numerical oscillations, commonly referred to as limiters, are known to slow down the convergence of implicit solution procedures. V. Venkatakrishnan (Analytical Services and Materials) found that a full Newton method applied to a third-order non-oscillatory discretization of the Euler equations has such a small attraction sphere that one must march along a path generated by a parameter that slowly switches on the higher- order terms, in order to reach the desired solution. One cause of non-convergence is that limiters tend to switch on and off in a random pattern in regions where the flow is almost uniform. A remedy is to use limiters with a built-in threshold, by which it is sensed whether a numerical oscillation is significant or insignificant. The limiter thus is no longer scale-free, and the threshold value introduces an undesirable degree of freedom, but the attraction range of the Newton method is considerably enlarged. This work is done jointly with V. Venkatakrishnan and J. L. Thomas (Fluid Mechanics Division), with some interaction with D. Gottlieb.

REPORTS AND ABSTRACTS

Decker, Naomi H. and Shlomo Ta'asan: *A simplified analysis of the multigrid V-cycle as a fast elliptic solver.* ICASE Report No. 88-56, November 3, 1988, 18 pages. Submitted to Math. Comp.

For special model problems, Fourier analysis gives exact convergence rates for the two-grid multigrid cycle and, for more general problems, provides estimates of the two-grid convergence rates via local mode analysis. A method is presented for obtaining multigrid convergence rate estimates for cycles involving more than two grids – using essentially the same analysis as for the two-grid cycle.

For the simple case of the V-cycle used as a fast Laplace solver on the unit square, the k-grid convergence rate bounds obtained by this method are sharper than the bounds predicted by the variational theory. Both theoretical justification and experimental evidence are presented.

Nicol, D. M., D. R. Shier, R. K. Kincaid, D. S. Richards: *A multistage linear array assignment problem.* ICASE Report No. 88-57, November 16, 1988, 33 pages. Submitted to Operations Research.

Implementation of certain algorithms on parallel computing architectures can involve partitioning contiguous elements into a fixed number of groups, each of which is to be handled by a single processor. It is desired to find an assignment of elements to processors that minimizes the sum of the maximum workload experienced at each stage. This problem can be viewed as a multi- objective network optimization problem. Polynomially-bounded algorithms are developed for the case of two-stages, whereas the associated decision problem (for an arbitrary number of stages) is shown to be NP-complete. Heuristic procedures are therefore proposed and analyzed for the general problem. Computational experience with one of the exact problems, incorporating certain pruning rules, is presented for a variety of test problems. Empirical results also demonstrate that one of the heuristic procedures is especially effective in practice.

Nicol, D. M. and J. C. Townsend: *Accurate modeling of parallel scientific computations.* ICASE Report No. 88-58, November 30, 1988, 13 pages. Submitted to the 1989 Sigmetrics Conference.

Scientific codes are usually parallelized by partitioning a grid among processors. To achieve top performance it is necessary to partition the grid so as to balance workload and minimize communication/synchronization costs. This problem is particularly acute when the grid is irregular, changes over the course of the computation, and is not known until load-time. Critical mapping and remapping decisions rest on our ability to accurately predict performance, given a description of a grid and its partition. This paper discusses one approach to this problem, and illustrates its use on a one- dimensional fluids code. The

models we construct are shown empirically to be accurate, and are used to find optimal remapping schedules.

Maday, Yvon, Cathy Mavriplis, and Anthony Patera: *Nonconforming mortar element methods: Application to spectral discretizations.* ICASE Report No. 88-59, October 19, 1988, 28 pages. Submitted to the Proceedings of the Second International Conference on Domain Decomposition Methods for PDE.

Spectral element methods are p-type weighted residual techniques for partial differential equations that combine the generality of finite element methods with the accuracy of spectral methods. We present here a new nonconforming discretization which greatly improves the flexibility of the spectral element approach as regards automatic mesh generation and non- propagating local mesh refinement. The method is based on the introduction of an auxiliary "mortar" trace space, and constitutes a new approach to discretization-driven domain decomposition characterized by a clean decoupling of the local, structure-preserving residual evaluations and the transmission of boundary and continuity conditions. The flexibility of the mortar method is illustrated by several nonconforming adaptive Navier-Stokes calculations in complex geometry.

Scroggs, Jeffrey S. and Danny C. Sorensen: *An asymptotic induced numerical method for the convection-diffusion-reaction equation.* ICASE Report No. 88-60, October 21, 1988, 33 pages. Submitted to Mathematics for Large Scale Computing, Julio C. Diaz (editor).

A parallel algorithm for the efficient solution of a time dependent reaction convection diffusion equation with small parameter on the diffusion term will be presented. The method is based on a domain decomposition that is dictated by singular perturbation analysis. The analysis is used to determine regions where certain reduced equations may be solved in place of the full equation. Parallelism is evident at two levels. Domain decomposition provides parallelism at the highest level, and within each domain there is ample opportunity to exploit parallelism. Run-time results demonstrate the viability of the method.

Scroggs, Jeffrey S.: *A physically motivated domain decomposition for singularly perturbed equations.* ICASE Report No. 88-62, November 1, 1988, 15 pages. Submitted to the SIAM J. Numer. Anal.

A domain decomposition algorithm suitable for the efficient and accurate solution of a parabolic reaction convection diffusion equation with small parameter on the diffusion term is presented. Convergence is established via maximum principle arguments. The equation arises in the modeling of laminar transonic flow. Decomposition into subdomains is accomplished via singular perturbation analysis which dictates regions where certain reduced equations may be solved in place of the full equation, effectively preconditioning the problem. This paper concentrates on the theoretical basis of the method, establishing local and global a priori error bounds.

Rostand, Philippe: *Algebraic turbulence models for the computation of two- dimensional high speed flows using unstructured grids*. ICASE Report No. 88-63, November 4, 1988, 43 pages. Submitted to the Numerical Methods in Fluids.

The incorporation of algebraic turbulence models in a solver for the 2D compressible Navier-Stokes equations using triangular grids is described. A practical way to use the Cebeci Smith model, and to modify it in separated regions, is proposed. The ability of the model to predict high speed, perfect gas boundary layers is investigated from a numerical point of view.

Andersen, Carl M. and James F. Geer: *Investigating a hybrid perturbation-Galerkin technique using computer algebra*. ICASE Report No. 88-65, November 17, 1988, 26 pages. Submitted to the Proc. of Computer Algebraic Integration and the Solution of Differential Equations.

A two-step hybrid perturbation-Galerkin method is presented for the solution of a variety of differential equations type problems which involve a scalar parameter. The resulting (approximate) solution has the form of a sum where each term consists of the product of two functions. The first function is a function of the independent field variable(s) x, and the second is a function of the parameter λ. In step one the functions of x are determined by forming a perturbation expansion in λ. In step two the functions of λ are determined through the use of the classical Bubnov- Galerkin method. The resulting hybrid method has the potential of overcoming some of the drawbacks of the perturbation and Bubnov-Galerkin methods applied separately, while combining some of the good features of each. In particular, the results can be useful well beyond the radius of convergence associated with the perturbation expansion. The hybrid method is applied with the aid of computer algebra to a simple two-point boundary value problem where the radius of convergence is finite and to a quantum eigenvalue problem where the radius of convergence is zero. For both problems the hybrid method apparently converges for an infinite range of the parameter λ. The results obtained from the hybrid method are compared with approximate solutions obtained by other methods, and the applicability of the hybrid method to broader problem areas is discussed.

Kamowitz, David: *Some observations on boundary conditions for numerical conservation laws*. ICASE Report No. 88-67, November 22, 1988, 13 pages. Submitted to SIAM J. Sci. Statist. Comput.

In this note, four choices of outflow boundary conditions are considered for numerical conservation laws. All four methods are stable for linear problems. For nonlinear problems, examples are presented where either a boundary layer forms or the numerical scheme, together with the boundary condition, is unstable due to the formation of a reflected shock. A simple heuristic argument is presented for determining the suitability of the boundary conditions.

Jackson, T. L. and C. E. Grosch: *Effect of heat release on the spatial stability of a supersonic reacting mixing layer*. ICASE Report No. 88-68, November 23, 1988, 12 pages. Submitted to the Third International Conference on Numerical Combustion.

We have begun a numerical study of the stability of compressible mixing layers in which a diffusion flame is embedded. In this study, we have approximated the mean velocity profile by a hyperbolic tangent profile and taken the limit of infinite activation energy which reduces the diffusion flame to a flame sheet. The addition of combustion in the form of a flame sheet was found to have important, and complex, effects on the flow stability.

Bernardi, Christine, Claudio Canuto, Yvon Maday, and Brigitte Metivet: *Single-grid spectral collocation for the Navier-Stokes equations.* ICASE Report No. 88-69, November 25, 1988, 49 pages. Submitted to IMA J. Numer. Anal.

The aim of the paper is to study a collocation spectral method to approximate the Navier-Stokes equations: only one grid is used, which is built from the nodes of a Gauss-Lobatto quadrature formula, either of Legendre or of Chebyshev type. The convergence is proven for the Stokes problem provided with in homogeneous Dirichlet conditions, then thoroughly analyzed for the Navier-Stokes equations. The practical implementation algorithm is presented, together with numerical results.

Rosen, I. G.: *On Hilbert-Schmidt norm convergence of Galerkin approximation for operator Riccati equations.* ICASE Report No. 88-71, November 30, 1988, 18 pages. Submitted to the Proc. of the Fourth International Conference on the Control and Identification of Distributed Parameter Systems.

An abstract approximation framework for the solution of operator algebraic Riccati equations is developed. The approach taken is based upon a formulation of the Riccati equation as an abstract nonlinear operator equation on the space of Hilbert-Schmidt operators. Hilbert-Schmidt norm convergence of solutions to generic finite dimensional Galerkin approximations to the Riccati equation to the solution of the original infinite dimensional problem is argued. The application of the general theory is illustrated via an operator Riccati equation arising in the linear-quadratic design of an optimal feedback control law for a one dimensional heat/diffusion equation. Numerical results demonstrating the convergence of the associated Hilbert-Schmidt kernels are included.

Saltz, Joel H. and Ravi Mirchandaney: *Run-Time parallelization and scheduling of loops.* ICASE Report No. 88-70, December 1988, 34 pages. Submitted to Transactions on Computers.

In this paper, we extend the class of problems that can be effectively compiled by parallelizing compilers. This is accomplished with the do consider construct which would allow these compilers to parallelize many problems in which substantial loop-level parallelism is available but cannot be detected by standard compile-time analysis. We describe and experimentally analyze mechanisms used to parallelize the work required for these types of loops. In each of these methods, a new loop structure is produced by modifying the loop to be parallelized. We also present the rules by which these loop transformations may be automated in order that they be included in language compilers. The main application

area of our research involves problems in scientific computations and engineering. The workload used in our experiments includes a mixture of real problems as well as synthetically generated inputs. From our extensive tests on the Encore Multimax/320, we have reached the conclusion that for the types of workloads we have investigated, self- execution almost always performs better than pre-scheduling. Further, the improvement in performance that accrues as a result of global topological sorting of indices as opposed to the less expensive local sorting, is not very significant in the case of self-execution.

Maday, Yvon and Rafael Munoz: *Spectral element multigrid. Part 2: Theoretical justification.* ICASE Report No. 88-73, December 7, 1988, 30 pages. Submitted to J. Sci. Comput.

We analyze here a multigrid algorithm used for solving iteratively the algebraic system resulting from the approximation of a second order problem by spectral or spectral element methods. The analysis, performed here in the one dimensional case, justifies the good smoothing properties of the Jacobi preconditioner that has been presented in the part 1 of this paper.

Tomboulian, Sherryl: *Spectral solution of the incompressible navier-stokes equations on the connection machine2.* ICASE Report No. 89-1, January 2, 1989, 12 pages. Proc. of Supercomputing 1988, November 1988, Orlando, Florida.

This paper addresses the issue of solving the time-dependent incompressible Navier-Stokes equations on the Connection Machine2, for the problem of transition to turbulence of the steady flow in a channel. The spectral algorithm used serially requires $O(N4)$ operations when solving the equations on an N x N x N grid; using the massive parallelism of the CM, it becomes an $O(N2)$ problem. Preliminary timings of the code, written in LISP, are included and compared with a corresponding code optimized for the CRAY-2 for a 128 x 128 x 101 grid.

Speziale, Charles G.: *On the freestream matching condition for stagnation point turbulent flows.* ICASE Report No. 89-2, December 27, 1988, 19 pages. Submitted to ASME J. Fluids Engineering.

The problem of plane stagnation point flow with freestream turbulence is examined from a basic theoretical standpoint. It is argued that the singularity which arises when the standard model is used is not due to a defect in the model but results from the use of an inconsistent freestream boundary condition. The inconsistency lies in the use of a production equals dissipation equilibrium hypothesis in conjunction with a freestream mean velocity field that corresponds to homogeneous plane strain - a turbulent flow which does not reach such as equilibrium. Consequently, the adjustment that has been made in the constants of the -transport equation to eliminate this singularity is not self-consistent since it is tantamount to artificially imposing an equilibrium structure on a turbulent flow which is known to not to have one.

Banks, H. T.; C. K. Lo; Simeon Reich, and I. G. Rosen: *Numerical studies of identification in nonlinear distributed parameter system.* ICASE Report No. 89-3, January 6, 1989, 19 pages.

An abstract approximation framework and convergence theory for the identification of first and second order nonlinear distributed parameter systems developed previously by the authors and reported on in detail elsewhere are summarized and discussed. The theory is based upon results for systems whose dynamics can be described by monotone operators in Hilbert space an an abstract approximation theorem for the resulting nonlinear evolution system. The application of the theory together with numerical evidence demonstrating the feasibility of the general approach are discussed in the context of the identification of a first order quasi-linear parabolic model for one dimensional heat conduction/mass transport and the identification of a nonlinear dissipation mechanism (i.e. damping) in a second order one dimensional wave equation. Computational and implementational considerations, in particular, with regard to supercomputing, are addressed.

Banks, H. T. and C. Wang: *Optimal feedback control of infinite dimensional parabolic evolution systems: approximation techniques.* ICASE Report No. 89-4, January 6, 1989, 59 pages.

We present a general approximation framework for computation of optimal feedback controls in linear regular problems for nonautonomous parabolic distributed parameter systems. This is done in the context of a theoretical framework using general evolution systems in infinite dimensional Hilbert spaces. We discuss conditions for preservation under approximation of stabilizability and detectability hypotheses on the infinite dimensional system. The special case of periodic systems is also treated.

Quarteroni, Alfio: *Domain decomposition methods for systems of conservation laws: spectral collocation approximations.* ICASE Report No. 89-5, January 24, 1989, 35 pages. SIAM J. Scientific and Statistical Computing.

We consider hyperbolic systems of conservation laws which are discretized in space by spectral collocation methods and advanced in time by finite difference schemes. At any time-level we introduce a domain decomposition method based on an iteration-by-subdomain procedure yielding at each step a sequence of independent subproblems (one for each subdomain) that can be solved simultaneously. The method is set for a general nonlinear problem in several space variables. The convergence analysis, however, is carried out only for a linear one-dimensional system with continuous solutions.

Jones, Mark T.; Patrick, Merrell L.; and Robert G. Voigt: *A language comparison for scientific computing on mimd architectures.* ICASE Report No. 89-6, January 24, 1989, 39 pages. Proceedings of the IFIP Working Conference on Aspects of Computation on Asynchronous Parallel Processors.

Choleski's method for solving banded symmetric, positive definite systems is implemented on a multiprocessor computer using three FORTRAN based parallel programming languages, the Force, PISCES and Concurrent FORTRAN. The capabilities of the language for expressing parallelism and their user friendliness are discussed, including readability of the code, debugging assistance offered, and expressiveness of the languages. The performance of the different implementations is compared. It is argued that PISCES, using the Force for medium-grained parallelism, is the appropriate choice for programming Choleski's method on the multiprocessor computer, Flex/32.

Crowley, Kay; Saltz, Joel; Mirchandaney and Berryman, Harry: *Run-time scheduling and execution of loops on message passing machines*. ICASE Report No. 89-7, January 31, 1989, 25 pages. Submitted to International Conf. Supercomputing 1989.

Sparse system solvers and general purpose codes for solving partial differential equations are examples of the many types of problems whose irregularity can result in poor performance on distributed memory machines. Often, the data structures used in thes problems are very flexible. Crucial details concerning loop dependencies are encoded in these structures rather than being explicitly represented in the program. Good methods for parallelizing and partitioning these types o problems require one to assign computations in rather arbitrary ways.

Naive implementations of programs on distributed memory machines requiring general loop partitions can be extremely inefficient. Instead, the scheduling mechanism needs to capture the data reference patterns of the loops in order to partition the problem. Once this partition is obtained, a pre- processing step is required. First, the indices assigned to each processor must be locally numbered. Next, it is necessary to precompute what information is needed by each processor at various points in the computation. The precomputed information is then used to generate an execution template designed to carry out th computation, communication and partitioning of data, in an optimized manner.

In this paper, we present the design of a general preprocessor and schedule executor, the structures of which do not vary, even though the details of the computation and of the type of information are problem dependent. We draw the following conclusions from this work: it should be possible to solve a whole variety of sparse and adaptive problems using a single mechanism for the setup phase of the problem These mechanisms can then be incorporated into automated compilers for distributed memory machines as well as explicit language extensions. We also present results that illustrate the performance benefits that accrue from effective preprocessing.

Geer, James F. and Andersen, Carl M.: *A Hybrid-perturbation-galerkin technique which combines multiple expansions*. ICASE Report No. 89-8, January 31, 1989, 21 pages. Submitted to SIAM J. Appl. Math.

A two-step hybrid perturbation-Galerkin method for the solution of a variety of differential equations type problems is found to give better results when multiple perturbation expansions are employed. The method assumes that there is a parameter in the problem formulation and that a perturbation method can be used to construct one or more expansions in this parameter. An approximate solution is constructed in the form of a sum of perturbation coefficient functions multiplied by computed amplitudes. In step one, regular and/or singular perturbation methods are used to determine the perturbation coefficient functions. The results of step one are in the form of one *or more* expansions each expressed as a sum of perturbation coefficient functions multiplied by a *priori* known gauge functions. In step two the the classical Bubnov-Galerkin method uses the perturbation coefficient functions computed in step one to determine a set of amplitudes which replace and improve upon the gauge functions. The hybrid method has the potential of overcoming some of the drawbacks of the perturbation and Galerkin methods as applied separately, while combining some of their better features. In this study the proposed method is applied, with two perturbation expansions in each case, to a variety of model ordinary differential equations problems including: a family of linear two-point boundary-value problems, a nonlinear two-point boundary-value problem, a quantum mechanical eigenvalue problem and a nonlinear free oscillation problem. The results obtianed from the hybrid method are

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comapred with approximate solutions obtained by other methods, and the applicability of the hybrid method to broader problem areas is discussed.

Zang, Thomas A.; Krist, Steven E. and Hussaini, M. Yousuff: *Resolution Requirements for Numerical Simulations of Transition.* ICASE Report No. 89-9, January 31, 1989, 25 pages. Submitted to J. Scientific Computing.

The resolution requirements for direct numerical simulations of transition to turbulence are investigated. A reliable resolution criterion is determined from the results of several detailed simulations of channel and boundary-layer transition.

Sarkar, Sutanu and Charles G. Speziale: *A simple nonlinear model for the return to isotropy in turbulence.* ICASE Report No. 89-10, February 9, 1989, 18 pages. The Physics of Fluids.

A quadratic nonlinear generalization of the linear Rotta model for the slow pressure-stain correlation of turbulence is developed. The model is shown to satisfy realizability and to give rise to no stable non-trivial equilibrium solutions for the anisotropy tensor in the case of vanishing mean velocity gradients. The absence of stable non-trivial equilibrium solutions is a necessary condition to ensure that the model predicts a return to istropy for all relaxational turbulent flows. Both the phase space dynamics and the temporal behavior of the model are examined and compared against experimental data for the return to isotropy problem. It is demonstrated that the quadratic model successfully captures the experimental trends which clearly exhibit nonlinear behavior. Direct comparisons are also made with the predictions of the Rotta model and the Lumley model.

Mavriplis, Dimitri, A. Jameson and L. Martinelli: *Multigrid solution of the navier-stokes equations on triangular meshes.* ICASE Report No. 89-11, February 9, 1989, 13 pages. Submitted to AIAA Journal.

A new Navier-Stokes algorithm for use on unstructured triangular meshes is presented. Spatial discretization of the governing equations is achieved using a finite-element Galerkin approximation, which can be shown to be equivalent to a finite-volume approximation for regular equilateral triangular meshes. Integration steady-state is performed using a multi-stage time-stepping scheme, and convergence is accelerated by means of implicit residual smoothing and an unstructured multigrid algorithm. Directional scaling of the artificial dissipation and the implicit residual smoothing operator is achieved for unstructured meshes by considering local mesh stretching vectors at each point. The accuracy of the scheme for highly stretched triangular meshes is validated by comparing computed flat-plate laminar boundary-layer results with the well known similarity solution, and by comparing laminar airfoil results with those obtained from various well-established structured quadrilateral-mesh codes. The convergence efficiency of the present method is also shown to be competitive with those demonstrated by structured quadrilateral-mesh algorithms.

Protzel, P.; D. Palumbo and M. Arras: *Fault-tolerance of a neural network solving the traveling salesman problem.* ICASE Report No. 89-12, February 16, 1989, 14 pages. Intern. Joint Conf. on Neural Networks.

This study presents the results of a fault-injection experiment that stimulates a neural network solving the Traveling Salesman Problem (TSP). The network is based on a modified version of Hopfield's and Tank's original method. We define a performance characteristic for the TSP that allows an overall assessment of the solution quality for different city-distributions and problem sizes. Five different 10-, 20-, and 30-city cases are sued for the injection of up to 13 simultaneous stuck-at-"0" and stuck-at-"1" faults. The results of more than 4000 simulation-runs show the extreme fault-tolerance of the network, especially with respect to stuck-at-"0" faults. One possible explanation for the overall surprising result is the redundancy of the problem representation.

Zang, Thomas A.; Craig Streett and M. Yousuff Hussaini: *Spectral methods for CFD.* ICASE Report No. 89-13, February 17, 1989, 70 pages. Submitted to von Karman Institute Lecture Survey on Computation Fluid Dynamics March 6-10, 1989.

One of the objectives of these notes is to provide a basic introduction to spectral methods with a particular emphasis on applications to computational fluid dynamics. Another objective is to summarize some of the most important developments in spectral methods in the last two years. The fundamentals of spectral methods for simple problems will be covered in depth, and the essential elements of several fluid dynamical applications will be sketched.

Ou, Yuh-Roung and S. S. Sritharan: *Analysis of regularized navier-stokes equations - II.* ICASE Report No. 89-14, February 17, 1989, 65 pages. Submitted to Pacific J. of Mathematics.

A practically important regularization of the Navier-Stokes equations have been analyzed. As a continuation of the previous work, we study in this paper the structure of the attractors characterizing the solutions. Local as well as global invariant manifolds have been found. Regularity properties of these manifolds are analyzed.

Erlebacher, Gordon and M. Y. Hussaini: *Non-linear evolution of a second mode wave in supersonic boundary layers.* ICASE Report No. 89-15, February 28, 1989, 40 pages. Submitted to Applied Numerical Mathematics.

The non-linear time evolution of a second mode instability in a Mach 4.5 wall-bounded flow is computed by solving the full compressible, time-dependent Navier-Stokes equations. High accuracy is achieved by using a Fourier- Chebyshev collocation algorithm. Primarily inviscid in nature, second modes are characterized by high frequency and high growth rates compared to first modes. Time evolution of growth rate as a function of distance from

the plate suggests this problem is amenable to the Stuart-Watson perturbation theory as generalized by Herbert.

Banks, H. T., Reich, Rosen, I. G.: *Estimation of nonlinear damping in second order distributed parameter stystems.* ICASE Report No. 89-16 (in preparation).

Nicol, David: *Parallel solution of sparse one-dimensional dynamic programming problems.* ICASE Report No. 89-17, February 23, 1989, 21 pages. Submitted to ORSA Journal on Computing.

Parallel computation offers the potential for quickly solving large computational problems. However, it is often a non-trivial task to effectively use parallel computers. Solution methods must sometimes be reformulated to exploit parallelism; the reformulations are often more complex than their slower serial counterparts. We illustrate these points by studying the parallelization of *sparse* one-dimensional dynamic programming problems, those which do not obviously admit substantial parallelization. We propose a new method for parallelizing such problems, develop analytic models with which help us to identify problems which parallelize well, and compare the performance of our algorithm with existing algorithms on a multiprocessor.

Jackson, T. L. and C. E. Grosch: *Inviscid spatial stability of a compressible mixing layer part II. the flame sheet model.* ICASE Report No. 89-18, March 20, 1989, 31 pages. Submitted to Journal of Fluid Mechanics.

We report the results of an inviscid spatial stability calculation for a compressible reacting mixing layer. The limit of infinite activation energy is taken and the diffusion flame is approximated by a flame sheet. Results are reported for the phase speeds of the neutral waves and maximum growth rates of the unstable waves as a function of the parameters of the problem: the ratio of the temperature of the stationary stream to that of the moving stream, the Mach number of the moving stream, the heat release per unit mass fraction of the reactant, the equivalence ratio of the reaction, and the frequency of the disturbance. These results are compared to the phase speeds and growth rates of the corresponding nonreacting mixing layer. We show that the addition of combustion has important, and complex, effects on the flow stability.

Duck, Peter: *The inviscid axisymmetric stability of the supersonic flow along a circular cylinder.* ICASE Report No. 89-19, January 3, 1989, 39 pages. Submitted to Journal of Fluid Dynamics.

The supersonic flow past a thin straight circular cylinder is investigated. The associated boundary layer flow (i.e. the velocity and temperature field) is computed; the asymptotic, far downstream solution is obtained, and compared with the full numerical results.

The inviscid, linear, axisymmetric (temporal) stability of this boundary layer is also studied. A so called "doubly generalized" inflexion condition is derived, which is a condition for the existence of so called "subsonic" neutral modes. The eigenvalue problem (for the complex wavespeed) is computed for two freestream Mach numbers (2.8 and 3.8), and this reveals that curvature has a profound effect on the stability of the flow. The first unstable inviscid mode is seen to rapidly disappear as curvature is introduced, whilst the second (and generally the most important) mode suffers a substantially reduced amplification rate.

Mehrotra, Piyush and John Van Rosendale: *Compiling high level constructs to distributed memory architectures.* ICASE Report No. 89-20, March 7, 1989, 8 pages. Submitted to Proceedings of Hypercube Multiprocessors.

Current languages for nonshared memory architectures provide a relatively low-level programming environment. In this paper we describe a set of language primitives which allow the programmer to express data-parallel algorithms at a higher level, while also permitting control over those aspects of the program critical to performance, such as load balance and data distribution. Given such a program specification, the compiler automatically generates a distributed program containing send and receive constructs to perform interprocess communication.

Malik, M. R. and M. Y. Hussaini: *Numerical simulation of görtler/tollmein-schlichting wave-interaction.* ICASE Report No. 89-21, March 22, 1989, 29 pages. Submitted to Journal of Fluid Mechanics.

The problem of nonlinear development of Görtler vortices and interaction within the framework of incompressible Navier-Stokes equations which are solved by a Fourier-Chebyshev spectral method. It is shown that two-dimensional waves can be excited in the flow modulated by Görtler vortex wavelength. Interaction is also considered of oblique waves with spanwise wavelength twice that of Görtler vortices.

ICASE INTERIM REPORTS

Ortega, James M., Robert G. Voigt, and Cherles H. Romine: *A bibliography on parallel and vector numerical algorithms* <u>ICASE Interim Report No. 8</u>, July 5, 1989, 89 pages.

Since parallel and vector computation is expanding rapidly, we hope that the references we have collected over the years will be of some value to researchers entering the field. Although we make the usual caveat that we do not claim completeness, we have in fact listed everything of which we are aware. Our apologies in advance to authors whose works we have missed. (Please send us your references.) It is our intent to keep this bibliography up to date. For further information about access to the bliograpy send email to either rome@ms.epm.ornl.gov or rgv@icase.edu.

Although this is a bibliography on numerical methods, we have included a number of other references on machine architecture, programming languages, and other topics of interest to scientific computing.

ICASE COLLOQUIUM

October 1, 1988 - March 31, 1989

Name/Affiliation/Title	Date
Professor Abdel Zebib, Rutgers University "Natural and Mixed Convection in a Circular Pipe"	October 11
Professor Serge Gauthier, CEA, Centre d'Etudes de Limeil-Valenton "Pseudo-Spectral Collocation Method for Compressible Convection: Sub and Supersonic Stationary Solutions"	October 28
Professor Suresh A. Deshpande, Indian Institute of Science "A Method of Characteristics for Multidimensional, Unsteady Gasdynamics"	November 3
Professor Frederic Bisshop, Brown Univeristy "A Method of Characteristics for Multidimensional, Unsteady Gasdynamics"	November 4
Dr. Robert Walters, VPI&SU, "CFD Research in the Aerospace Department at VPI&SU"	November 8
Professor S. Tsuge, University of Tsukuba, Japan "A Solitan-Like Solution of the Navier-Stokes Equation Relevant to Longitudinal Vortices"	November 18
Dr. Helena Wisniewski, Advanced Computer and Software Applications "A Science and Engineering Profile for Lockheed"	November 22
Dr. Sharon Newman, Massachusetts Institute of Technology "Transition Modeling for Turbomachinery Design"	December 1
Dr. Peter Protzel, ICASE "Information Processing in Artificial Neural Networks"	December 8
Professor Lawrence Sirovich, Brown University "Low Dimensional Characterization of Chaotic Fluid Flows"	December 12
Dr. Bernadette Palmerio, INRIA, France "Recent Works Related to Mesh Adaption at INRIA, Sophia-Antipolis"	December 12

Name/Affiliation/Title	Date
Professor Richard Pelz, Rutgers University "Pseudospectral Methods on Hypercubes"	January 23
Mr. Charles R. Johnson, College of William and Mary "Matrix Completion Problems: A Status Report"	January 31
Dr. Arlene Louise Perkins, University of California at Davis "Parallel Heterogeneous Mesh Refinement for Multidimensional Convection-Diffusion Equations Using an Euler-Lagrange Method"	January 20
Ms. Elizabeth Ong, University of Washington "The 3D Linear Hierarchical Basis Preconditioner and Its Shared Memory Parallel Implementation"	Febuary 1
Professor John Gero, University of Sydney, Australia "A Basis for Knowledge-Based Design in Engineering"	February 10
Ms. Kirsten Morris, University of Waterloo, Canada "A Comparison of Different Models for Beam Vibrations from the Standpoint of Controller Design"	January 30
Professor R. A. Nicolaides, Carnegie-Mellon University "Unstructured Mesh Techniques for Viscous Incompressible Flows"	February 6
Professor Saul Abarbanel, Tel-Aviv University "Are Compressible Modes More or Less Stable Then Incompressible Ones"	February 8
Dr. Steven T. Zalesak, Naval Research Laboratory "Non-Clipping, Very High Order and Pseudospectral Shock-Capturing Schemes"	February 13
Professor Wayne Dyksen, Purdue University "Pipelined Iterative Techniques for Shared Memory Machines"	February 16
Professor Peyman Givi, State University of New York at Buffalo "Evaluation of Single-Point PDF Closures in Reacting Homogeneous Turbulence: Direct Numerical Simulations"	March 31

Name/Affiliation/Title	Date
Dr. Jacques Liandrat, Institut de Mecanique Statistique de la Turbulence, France "The Wavlet Transform: First Applications to Turbulence and Computational Fluid Dynamics"	March 10
Professor Roger Peyret, Universite de Nice, France "Spectral Methods for Variable Density Flows With Application to Convection"	March 27
Professor Stephen Lundstrom, Stanford University "Performance Prediction of Applications on Highly-Concurrent Systems"	March 6
Professor George Dulikravich, Penn State University "Theory of Compressible Irrotational Flows Including Heat Conductivity and Longitudinal Viscosity"	March 15
Dr. Seunghwan Kim, The Institute for Advanced Study "Dynamics of Competing Periods"	March 16
Professor Brian E. Launder, UMIST, England "Status and Prospects of Second-Moment Closure"	March 28

ICASE STAFF

I. ADMINISTRATIVE

Robert G. Voigt, Director Ph.D., Mathematics, University of Maryland, 1969 Numerical and Algorithms for Parallel Computers

Linda T. Johnson, Office and Financial Administrator

Etta M. Blair, Personnel/Bookkeeping Secretary

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Tony Chan, Professor, Department of Mathematics, University of California at Los Angeles.

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Anita Jones, Chairman, Department of Computer Science, University of Virginia.

Robert MacCormack, Professor, Department of Aeronautics and Astronautics, Stanford University.

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Burton Smith, Tera Computer Company, Seattle, WA.

Robert G. Voigt, Director, Institute for Computer Applications in Science and Engineering, NASA Langley Research Center.

III. ASSOCIATE MEMBERS

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

H. Thomas Banks, Professor, Division of Applied Mathematics, Brown University.

David Gottlieb, Professor, Division of Applied Mathematics, Brown University.

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

Merrell L. Patrick, Professor, Department of Computer Science, Duke University.

IV. CHIEF SCIENTIST

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

V. SENIOR STAFF SCIENTIST

Charles G. Speziale - Ph.D., Aerospace and Mechanical Sciences, Princeton University, 1978. Fluid Dynamics with Emphasis on Turbulence Modeling and the Transition Process. (September 1987 to September 1990)

VI. SCIENTIFIC STAFF

Richard G. Carter - Ph.D., Numerical Analysis, Rice University, 1986. Numerical Methods for Optimization Problems. (September 1987 to September 1990)

Thomas W. Crockett - B.S., Mathematics, College of William and Mary, 1977. Parallel Systems Research. (February 1987 to February 1991)

Naomi Decker - Ph.D., Mathematics, University of Wisconsin-Madison, 1987. Multigrid Method Applied to Hyperbolic Equations. (September 1987 to September 1989)

David Kamowitz - Ph.D., Computer Science, University of Wisconsin, Madison, 1986. Iterative Methods for Numerical Solutions of Partial Differential Equations. (September 1986 to September 1989)

Fumio Kojima - Ph.D., Control Theory, Kyoto University, Japan, 1985. Probabilistic and Stochastic Methods for Optimal Control Problems. (September 1986 to September 1989)

Dimitri Mavriplis - Ph.D., Mechanical and Aerospace Engineering, Princeton University, 1988 Grid Techniques for Computational Fluid Dynamics. (February 1987 to February 1990)

David J. Middleton - Ph.D., Computer Science, University of North Carolina, 1986. Design of Parallel Computing Systems. (November 1986 to November 1989)

Vijay K. Naik - M.S., Mechanical Engineering, University of Florida, 1982. AM., Computer Science, Duke University, 1984. Parallel Processing, Computational Fluid Dynamics. (August 1984 to November 1988)

Tobias B. Orloff - Ph.D., Mathematics, Princeton University, 1983. High Performance Graphics. (September 1988 to September 1990)

Yuh-Roung Ou - Ph.D., Aerospace Engineering, University of Southern California, 1988. Control Systems for Fluid Dynamics. (November 1988 to November 1990)

Douglas H. Peterson, Jr. - M.S., Computer Science, College of William and Mary, 1987. Computer Systems and Networking. (October 1985 to September 1989)

Peter W. Protzel - Ph.D., Electrical Engineering, Technical University of Braunschweig, Germany, 1987. Reliability of Computing Systems. (March 1987 to September 1990)

Sutanu Sarkar, - Ph.D., Mechanical and Aerospace Engineering, Cornell University, 1988. Fluid Dynamics, Turbulence Modeling, Compressible Turbulence. (September 1988 to September 1990)

Jeffrey S. Scroggs, - Ph.D., Computer Science, University of Illinois at Urbana, 1988. Domain Decomposition for Differential Equations. (July 1988 to July 1990)

Sharon O. Seddougui, - Ph.D., Applied Mathematics, University of Exeter, England, 1988. Compressible Fluid Dynamics. (June 1988 to June 1990)

Sherryl J. Tomboulian - Ph.D., Computer Science, Duke University, 1986. Dynamic Graph Embedding Algorithms. (September 1986 to October 1988)

VII. 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. (January to December 1989)

Charles-Henri Bruneau - Ph.D., Numerical Analysis, Universite Paris-Sud, Orsay, France, 1980. Assistant Professor, Department of Mathimatics, Universite Paris-Sud, France. Navier-Stokes Equations. (March to May 1989)

Peter W. Duck - Ph.D., Fluid Mechanics, Univeristy of Southampton, United Kingdom, 1975. Lecturer in Mathematics, Department of Mathematics, University of Manchester, United Kingdom. Numerical Solution of Unsteady Boundary Layer Equations. (January 1989)

T. Leonard Freeeman - Ph.D., Numerical Analysis, University of Liverpool, England, 1974. Lecturer in Mathematics, Department of Mathematics, University of Manchester, United Kingdom. Parallel Quasi-Newton Algorithms. (March to May 1989)

Philip Hall - Ph.D., Mathematics, Imperial College, England, 1973. Professor, Department of Applied Mathematics, University of Exeter, England. Computational Fluid Dynamics. (November 1988)

Jacques Liandrat - Ph.D., Fluid Mechanics-Numerical Simulations, University of Toulouse, France, 1986. Research Scientist, I.M.S.T., Marseille, France. Turbulence Simulation. (October 1988 to August 1989)

Piyush Mehrotra - Ph.D., Computer Science, University of Virginia, 1982. Assistant Professor, Department of Computer Science, Purdue University. Programming Languages for Multiprocessor Systems. (January to April 1989)

Hillel Tal-Ezer - Ph.D., Applied Mathematics, Tel-Aviv University, 1985. Instructor, Department of Mathematics, Tel-Aviv University, Israel. Spectral Methods for Partial Differential Equations. (August to October 1988)

John Van Rosendale - Ph.D., Computer Science, University of Illinois, 1980. Supercomputing Research Center. Parallel Programming Languages. (February 1988 to January 1989) ·

VIII. CONSULTANTS

Loyce M. Adams - Ph.D., Applied Mathematics, University of Virginia, 1983. Associate Professor, Department of Applied Mathematics, University of Washington. Numerical Methods for Parallel Computing Systems.

Ivo Babuska - Ph.D., Technical Sciences, Tech University, Prague, Czechoslovakia, 1952; Mathematics, Academy of Sciences, 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.

Alvin Bayliss - Ph.D., Mathematics, New York University, 1975. Associate Professor, Technological Institute, Northwestern University. Numerical Methods for Partial Differential Equations.

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

Achi Brandt - Ph.D., Mathematics, Weizmann Institute of Science, 1965. Professor, Applied Mathematics Department, Weizmann Institute of Science, Israel. Multigrid Methods.

Dennis W. Brewer - Ph.D., Mathematics, University of Wisconsin, Madison, 1975. Associate Professor, Department of Mathematical Sciences, University of Arkansas. Methods for Parameter Identification and Estimation.

John A. Burns - Ph.D., Mathematics, University of Oklahoma, 1973. Professor, Virginia Polytechnic Institute and State University. Numerical Methods in Feedback Control and Parameter Estimation.

Stephen H. Davis - Ph.D., Mathematics, Rensselaer Polytechnic Institute, 1964. Professor of Engineering Sciences and Applied Mathematics, Northwestern University. Theory of Hydrodynamic Stability.

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

Robert E. Fennell - Ph.D., Mathematics, University of Iowa, 1969. Professor, Department of Mathematical Sciences, Clemson University. Control Theory for Multivariable Systems.

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.

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

James F. Geer - Ph.D., Applied Mathematics, New York University, 1967. Professor, Systems Science and Mathematical Sciences, Watson School of Engineering, Applied Science and Technology, SUNY-Binghamton. Perturbation Methods and Asymptotic Expansions of Solutions to Partial Differential Equations.

J. Steven Gibson - Ph.D., Engineering Mechanics, University of Texas at Austin, 1975. Associate Professor, Department of Mechanical, Aerospace and Nuclear Engineering, 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 Computer Science and Slover Professor, Department of Oceanography, Old Dominion University. Hydrodynamic Stability, Computational Fluid Dynamics, Unsteady Boundary Layers and Algorithms for Array Processors.

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

Amiram Harten - Ph.D., Mathematics, New York University, 1974. Associate Professor, Department of Mathematics, Tel-Aviv University, Israel. Numerical Solution for Partial Differential Equations.

Thorwald Herbert - Ph.D., Aerospace Engineering, University of Stuttgart, Germany 1978. Professor, Department of Mechanical Engineering, Ohio State University. Fluid Dynamics.

Kazufumi Ito - Ph.D., Systems Science and Mathematics, Washington University, 1981. Assistant Professor, Division of Applied Mathematics, Brown University. Control Theory.

Thomas L. Jackson - Ph.D., Mathematics, Rensselaer Polytechnic Institute, 1985. Assistant Professor, Department of Mathematics, Old Dominion University. Numerical and Analytical Methods for Chemically Reacting Flows.

Antony Jameson - Ph.D., Magnetohydro-Dynamics, Cambridge University, England, 1963. James S. McDonnell Distinguished Professor, Department of Mechanical and Aerospace Engineering, Princeton University. Computational, Fluid Dynamics.

Charles R. Johnson - Ph.D., Mathematics and Economics, California Institute of Technology, 1972. Professor, Mathematics Department, College of William and Mary. Numerical Linear Algebra.

Harry F. Jordan - Ph.D., Physics, University of Illinois, 1977. Professor Department of Electrical and Computer Engineering, University of Colorado at Boulder. Parallel Computation.

Ashwani K. Kapila - Ph.D., Theoretical and Applied Mechanics, Cornell University, 1975. Associate Professor, Department of Mathematical Sciences, Rensselaer Polytechnic Institute. Ordinary and Partial Differential Equations, Asymptotic Methods.

Stephen L. Keeling - Ph.D., Mathematics, University of Tennessee, 1986. Assistant Professor, Vanderbilt University. Analysis of Mathematical Models for Problems Arising in Acoustics.

David E. Keyes - Ph.D., Applied Mathematics, Harvard University, 1984. Assistant Professor, Mechanical Engineering, Yale University. Parallelizaton of Numerical Procedures Appropriate for the Study of Combustion.

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

William D. Lakin - Ph.D., Applied Mathematics, University of Chicago, 1968. Eminent Professor, Department of Mathematical Sciences, Old Dominion University. Fluid Mechanics and Elastic Vibrations.

Randall J. LeVeque - Ph.D., Computer Science, Stanford University, 1982. Assistant Professor Department of Mathematics, University of Washington. Numerical Solution of Partial Differential Equations.

John L. Lumley - Ph.D., Aeronautics, John Hopkins University, 1957. Professor, Department of Mechanical and Aerospace Engineering, Cornell University. Mathematical Aspects of Turbulence.

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

Mark V. Morkovin -Ph.D., Applied Mathematics, University of Wisconsin, 1942. Professor Emeritus, Department of Mechanical and Aerospace Engineering, Illinois Institute of Technology. Transition Process in Aerodynamics.

David M. Nicol - Ph.D., Computer Science, University of Virginia, 1985. Professor, Department of Computer Science, College of William and Mary. Mapping Algorithms onto Parallel Computing Systems.

Roy A. Nicolaides - Ph.D., Mathematics, University of London, 1972. Professor, Department of Mathematics, Carnegie-Mellon University. Numerical Solution of Partial Differential Equations.

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

Stanley J. 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.

Ugo Piomelli - Ph.D., Mechanical Engineering, Stanford University 1987. Professor, Department of Mechanical Engineering, University of Maryland. Subgrid Scale Reynold's Stress Modelling and Large Eddy Simulation of Turbulent Flows.

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

Daniel A. Reed - Ph.D., Computer Science, Purdue University, 1983. Assistant Professor, Department of Computer Science, University of Illinois. Parallel Processing.

Helen L. Reed - Ph.D., Engineering Mechanics, Virginia Polytechnic Institute and State University, 1981. Associate Professor, Department of Mechanical Engineering, Arizona State University. Computional Fluid Dynamics.

Eli Reshotko - Ph.D., Aeronautics and Physics, California Institute of Technology, 1960. Interim Dean, Case Western Reserve University. High Speed Aerodynamics with an Emphasis on Transition, Turbulence and Combustion.

Paul F. Reynolds - Ph.D., Computer Science, University of Texas at Austin, 1979. Assistant Professor, Department of Computer Science, The University of Virginia. Parallel Computing Systems.

I. Gary Rosen - Ph.D., Applied Mathematics, Brown University, 1980. Assistant Professor, Department of Applied Mathematics, University of Southern California. Numerical Methods for Problems in Control Systems.

Joel H. Saltz - Ph.D., Computer Science, Duke University, 1985. Assistant Professor, Yale University. Parallel Computing.

Paul E. Saylor - Ph.D., Mathematics, Rice University, 1986. Associate Professor, Computer Science Department, University of Illinois, Urbana. Iterative Solution of Linear Algebraic Equations and Algorithms for Parallel Computers.

Chi-Wang Shu - Ph.D., Mathematics, University of California, Los Angeles, 1986. Assistant Professor, Division of Applied Mathematics, Brown University. Partial Differential Equations.

Edward A. Spiegel - Ph.D, Astronomy, University of Michigan, 1958. Rutherford Professor of Astronomy, Department of Astronomy and Astrophysics, Columbia University. Mathematical Aspects of Turbulence.

Katepalli R. Sreenivason - Ph.D., Aeronautical Engineering, Indian Institute of Science, 1975. Professor and Chairman, Department of Mechanical Engineering, Yale University. Transition and Turbulence.

Shlomo Ta'asan - Ph.D., Applied Mathematics, Weizmann Institute, 1984. Scientist, Department of Applied Mathematics, The Weizmann Institute of Science, ISRAEL. Multigrid Methods for Partial Differential Equations.

Saleh Tanveer - Ph.D., Applied Mathematics, California Institute of Technology, 1984. Assistant Professor, Department of Mathematics, Virginia Polytechnic Institute and State University. Vortex Methods for Fluid Dynamics Simulations.

Lu Ting - Ph.D., Aeronautics, New York University, 1951. Professor, Courant Institute of Mathematical Sciences, New York University. Fluid Mechanics. Cheryl J. Tomboulian - Ph.D.,

Bram van Leer - Ph.D., Theoretical Astrophysic, Leiden State University, THE NETHER-LANDS, 1970. Professor, Department of Aerospace Engineering, University of Michigan. Computational Fluid Dynamics.

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

Shing-Tung Yau - Ph.D., University of California at Berkeley, 1971. Professor, Department of Mathematics, Harvard University. Differential Equations and Eigenvalue Problems.

IX. STUDENT ASSISTANTS

Michael Arras - Graduate student at College of William and Mary. (October 1988 to Present)

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Final Report

16. Abstract

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