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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 for 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 April 1, 1990 through September 30, 1990 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

The work on "spurious" oscillations continued and it will be issued as a new ICASE report (ICASE Report No. 90-73) entitled "Spurious Frequencies as a Result of Numerical Boundary Treatments." The main new result is that the interaction between boundaries which are treated in a stable, but "uncharacteristic," fashion can cause temporally growing oscillations on any finite mesh. Another new result explains why a "characteristic" treatment at only one boundary ameliorates the problem.

The study of accelerating convergence to steady state also continues and the focus is now on hyperbolic systems which are not diagonalizable.

The above two studies are joint work with David Gottlieb.

A third topic is the stability of Initial-Boundary Value problems for high order Padè-like finite differences schemes. The stability of 4th and 6th order inflow and outflow boundary conditions was studied together with David Gottlieb and Mark Carpenter.

H. T. Banks and Fumio Kojima

We are continuing our investigations (in collaboration with W. P. Winfree of the Instrument Research Division, LaRC) on inverse problems arising in thermal tomography. We have developed a spline-based corrosion detection algorithm using thermographic data from the front surface. For the detection of macroscopic corrosions, we are testing the validity and accuracy of our thermal method with the various kinds of laboratory data. Furthermore, our method has been applied to the identification of microscopic clusters which often occur in passenger airplanes. Domain decomposition ideas as well as the method of mappings play an important role in our proposed algorithm. We have successful estimation results by our new algorithm with the simulation data.

H. T. Banks and G. Propst

Our efforts concerning the active noise suppression problem concentrate on two topics: modeling and optimal control.

Using data from experiments conducted by R. J. Silcox (Acoustics Division, LaRC) we identify least-squares optimal parameters in models for the reflection and absorption of sound. The quality of the correspondence of the models' reflection coefficients with the measured data evaluates the applicability of the models to specific physical configurations.

As models we consider dissipative boundary conditions for the wave equation that constitute mathematically well-posed systems.

As to optimal control techniques, we discretize the one-dimensional wave equation with point sources and semireflecting impedance boundary conditions. For sources that are piecewise polynomial in time we get a finite-dimensional linear quadratic tracking problem that can be solved explicitly. On the basis of this discretization we plan to investigate approximations for the optimal control of more complex sources and boundary conditions.

Stanley A. Berger

Analytical and numerical studies of vortex breakdown are being carried out. Vortex breakdown is the sudden enlargement of the core of a vortex when the swirl velocity exceeds a certain critical value. Vortex breakdown is regarded with favor when it occurs in the trailing vortices behind large commercial transports because it enhances the rate of dissipation and therefore the hazard posed to following smaller aircraft. It is regarded as a negative phenomenon when it occurs in the leading edge vortices off the leading edges of high angle of attack fighter planes because of the degradation of aerodynamic performance. There are a number of theories extant which attempt to "explain" breakdown, but none of them is universally accepted. Most recently extensive calculations have been carried out solving both the Euler and the Navier-Stokes equations. These solutions, like those in the past, exhibit a strong tendency for the breakdown to move upstream toward the initial station of the computational domain. This has led to criticism, on the part of some, of the numerical simulation of breakdown. In an attempt to get to the root of this effect, analytical and numerical studies of breakdown are being carried out. Through the inclusion in the quasi-cylindrical equations, parabolic boundary-layer like equations which have been used in the past to model breakdown, of a radial diffusion term. If the term is neglected, one can show analytically that these equations in fact exhibit an elliptic character and therefore allow upstream influence. A full consideration of these equations requires a major numerical calculation, so as a first step a simple model of these equations has been analyzed. The resulting equation is a Riccati equation, which has been solved exactly in terms of Airy functions. The solution exhibits a great sensitivity to initial and boundary conditions and to the values of the relevant parameters, and so suggests a possible source of difficulty for the full numerical simulations. A singular perturbation analysis of this equation has also been carried out.

Scott Berryman, David Nicol, Joel Saltz, and Jeff Scroggs

Adaptive methods to solve the PDEs that arise in the simulation of physical phenomena require the efficient utilization of parallel computers. Distributed and hierarchical memory architectures appear to offer the most cost effective computational power. This project examines the issues related to using adaptive-mesh algorithms in this environment.

We are using an asymptotics-induced algorithm described by Scroggs and Sorensen ("An asymptotic induced numerical method for the convection-diffusion-reaction equation," in Mathematics for Large Scale Computing, J. Diaz, ed. See also ICASE Report No. 88-60) as a model problem to examine strategies for mapping and remapping changing workload to processors. One issue we address involves deciding when the potential advantage of repartitioning outweighs the overheads incurred. Another issue involves choosing what type of mapping should be used when we repartition. This work may be regarded as a continuation of work described in the following: D. Nicol, J. Saltz, and James Townsend, "Delay point schedules for irregular parallel computations," which appeared in International Journal of Parallel Processing, D. M. Nicol and J. Saltz, "Dynamic remapping of parallel computations with varying resource demands" in IEEE Transactions in Competition, J. Saltz and D. Nicol, "Statistical methodologies for the control of dynamic remapping," in Parallel Processing and Medium Scale Multiprocessors, Arthur Wouk (ed.), SIAM publications, 1989, and J. S. Scroggs, "A parallel algorithm for nonlinear convection-diffusion equations," which is to appear in Proceedings for SIAM 1989 Conference on Domain Decomposition.

Kelly Black

Applications of domain decomposition techniques are being pursued. The main thrust of the work has been concentrated on spectral methods and the interface conditions necessary to retain spectral accuracy. Spectral methods have many disadvantages on complex geometries. Domain decomposition techniques offer one solution to the problems encountered on such domains. The application of such techniques can be used on multi-processor computers or problems on complex geometries.

Percy J. Bobbitt

An experimental/theoretical Laminar-Flow-Control (LFC) program was carried out by the LaRC during the period 1978-1988 that investigated the ability of several suction-surface concepts to provide long runs of laminar flow on a large chord airfoil. The experimental research was carried out on a specially designed 7-foot chord airfoil model in the Langley 8-foot Transonic Pressure Tunnel. A comprehensive paper detailing the background and accomplishments of the LFC program has been written including the considerations that went into the design and fabrication of a streamline liner for the tunnel walls, the associated wind-tunnel flow-quality research, features of the airfoil model design and fabrication, details of a highly complex suction system, instruments and measurement techniques employed, and results such as pressure distributions, suction requirements, boundary layer stability/transition and drag coefficients. The primary variables considered were Mach number, Reynolds number, and the level and extent of suction.

Shahid Bokhari

Investigation of the communication overhead on the IPSC-860 hypercube is continuing. Earlier research was described in ICASE Interim Report No. 10. Further results have been obtained. Detailed analysis of the "Total Exchange" algorithm, and experiments on the iPSC-860 reveal that there are several implementations, each of which is optimal over a specific range of hypercube dimension and message size. An attempt is being made to combine these algorithms into a unified multiphase algorithm.

When carrying out binary dissections on very large domains that are to be computed on in parallel, memory limitations make it impossible to use the straightforward partitioning approaches. A "virtual partitioning" approach has been developed that permits any sized domain to be partitioned with fixed memory per processor. For very large domains, this approach is only a small constant factor slower than the naive approach. An ICASE report is in preparation.

A network flow model for load balancing on circuit switched hypercubes was written up as an ICASE report. Further work in this area concentrates on generalizing this approach and demonstrating its optimality.

Kurt Bryan

Work has focused on electrical impedance tomography, the problem of recovering the internal electrical conductivity of an object by means of voltage and current flux measurements on its boundary. Numerical work has been directed at a specific case, so-called "diffraction" problems, in which the conductivity of interest is a piecewise constant perturbation of a constant (known) background conductivity. The forward problem is formulated in terms of an integral equation and a linearized version of this equation is used to recover an estimate of the conductivity by means of an output least squares procedure. Convergence results for the method have been proved and numerical results have been excellent on simulated data.

Coding is also underway for the full non-linear version of the algorithm, and convergence results are being studied.

John Burns

Two ICASE reports, Nos. 90-43 and 90-45 were completed. These papers are concerned with the application of linear quadratic regulator theory to the problem of stability enhancement for two types of partial differential equations. The first report deals with thermoelastic systems and the second report is concerned with the Burgers' equation.

During the past few years, considerable attention has been devoted to the development of smart materials and structures. One approach to this class of problems is to use shape memory alloys as actuators in active control designs. These alloys are best described by thermo-mechanical models consisting of coupled (and nonlinear) hyperbolic and parabolic partial differential equations. The development of computational algorithms for designing controllers for such systems is an immensely complex problem and the subject of several ongoing research projects. In addition to the obvious difficulties related to the nonlinearities, the basic thermo-elastic coupling often gives rise to nonstandard mathematical models and leads to several problems in developing computational algorithms for control. Therefore, the computational methods for controlling a linear thermo-elastic system may be viewed as a first step toward the ultimate nonlinear problem. With this motivation in mind, we considered the problem of controlling a class of coupled partial differential equations that describe the linearized motions of a thermo-mechanical structure. The basic approach is to combine approximation theory with state space modeling to develop convergent computational algorithms for LQR control designs. We developed a specific computational algorithm based on a combination of finite element/averaging schemes and applied this method to the LQR problem for thermoelastic materials. We established that the algorithm converges provided the internal damping model is sufficiently strong and conducted several numerical experiments for weaker (pure thermoelastic) damping models. Based on the numerical runs we conjectured that the classical thermoelastic model is stabilizable, yet standard finite element approximations do not produce convergent control designs. More work on this class of problems is needed before practical computational algorithms can be designed for the non-linear case.

The second report contains theoretical and computational results on the LQR design applied to Burgers' equation. The key feature of this problem is the quasi-linear nature of the governing partial differential equation. The results in this report show that LQR designed linear feedback can be used to enhance stability of a quasi-linear system. We are currently working on the problem of using angular rotation as a control for flow about (and in the wake of) a circular cylinder. The work on Burgers' equation is being used to guide our efforts on this problem.

Richard Carter

Further studies have been performed to investigate two alternative approaches to generating robust optimization algorithms in the presence of noise in gradient evaluations. Previous theoretical analysis and extensive numerical testing have shown algorithms based on the trust region methodology to be exceptionally robust with respect to gradient errors, while simple examples exist to demonstrate that linesearch algorithms are potentially very fragile with respect to even small errors. Nevertheless, a recent software study at Cornell found two implementations of the linesearch approach that were competitive when finite difference gradients were used. Analysis of the methodology of the study revealed that their test design inadvertently forces a restart of their algorithm after unsuccessful iterations. Without this restart, the linesearch method often fails at much lower gradient error levels than the trust region technique is able to tolerate, as predicted by theory. However, this also demonstrates that *carefully designed* linesearch algorithms should not be dismissed out of hand for noisy problems, as long as automatic restarts are attempted when certain "failure" indications arise.

The tunneling algorithm is a method for finding global rather than local solutions of nonlinear optimization problems. Some alternative approaches for defining the influence function this technique uses for escaping local basins of attraction are under investigation. One natural idea is to use scale information determined while solving the local sub-problems. Other ideas involve the use of locally supported influence functions rather than the globally defined singular influence functions used in the standard method.

Leon M. Clancy

Plans were firmed up for complete replacement of all SUN3 systems at ICASE with current technology, for example SPARCstations. Ten SPARCstations were purchased and integrated into the system during the period.

ICASE installed a Stardent GS 1000 graphics workstation. The machine will be used primarily to evaluate VISUAL 3 software that was developed at MIT. The software was designed to facilitate viewing of three dimensional aerodynamics simulations.

With the help of Tom Crockett and Mike Arras, techniques were devised to lessen the pain of supporting multiple compilations of nearly 500Mb of ICASE supported software.

"Computing at ICASE" is being completely rewritten, with the new edition expected to be ready by January 1, 1991.

Stephen Cowley

An ICASE Report, "On the instability of hypersonic flow past a flat plate," was written with Phil Hall and Nik Blackaby. In this paper we demonstrate that it is important to use the correct (Sutherland) viscosity law if the instability properties of hypersonic flow are to be correctly understood. In addition we show how the presence of a leading edge shock can significantly change the growth rate of unstable modes. We identify the crucial role played by the viscous adjustment region that is between the upper inviscid shock-layer and lower high-temperature boundary layer. Numerical Navier-Stokes solutions must be accurate in this region if the instability properties of the flow are to be correctly understood. This work if of relevence to the design of a hypersonic transport vehicle.

A review of unsteady separation (co-authors: Leon van Dommelen & Shui Lam) has now appeared as the ICASE Report "On the use of Lagrangian variable in descriptions of unsteady boundary-layer separation." In addition to reviewing earlier work, we identify a new form of marginal separation and present confirmatory numerical results. Amongst other applications, marginal separation is of relevance to pitching airfoils.

W. O. Criminale

In a general sense perturbations in shear flows were investigated using techniques developed earlier (A. D. D. Craik and W. O. Criminale, Proc. Roy. Soc. London Ser. A. **406**:13, 1986; W. O. Criminale and P. G. Drazin, Stud. Appl. Math. **83**:123, 1990). More specifically, two prototype problems have been analyzed in detail. First, the role of the continuous spectrum in the development of disturbances in laminar boundary layers has been examined with particular emphasis given to (i) viscous boundary conditions and (ii) a non-parallel mean flow. These issues are important to understanding receptivity, breakdown and ultimate transition to turbulence.

Second, the problem of compressible Couette flow has been the subject of ongoing direct numerical simulation at ICASE and certain findings have been unexplained. Extending the novel approach cited above for use in the analysis of initial-value problems to compressible fluid, a new basis to compliment the study has been established. In effect, the early period dealing with the interaction of acoustic waves in a mean shear flow can now be determined using this approach.

Thomas W. Crockett

Work continued on the MIMD parallel rendering algorithm. The experimental implementation was ported from the iPSC/2 to the iPSC/860, where it is achieving rendering rates of approximately 200,000 10 x 10 Gouraud-shaded triangles per second on 128 processors, using only scalar C code. An improved message-buffering scheme has been devised which nearly eliminates wait time due to communication bottlenecks during the object transformation phase of the rendering pipeline. A detailed experimental analysis of buffering parameters has yielded some surprising, and as yet unexplained, variations in performance with large numbers of processors. Investigations are continuing in an effort to develop an accurate, predictive analytical performance model. Simple modifications to the original distributed memory version of the algorithm were developed which adapt it to shared memory architectures. The shared memory algorithm exploits self-scheduling techniques to achieve automatic load balancing among processors. This work is in collaboration with T. Orloff (Geometry Supercomputer Project, University of Minnesota).

Efforts to understand the performance of the parallel renderer have resulted in an interesting technique for visualizing multiprocessor performance as a function of multiple variables. The method uses 3D colored surface plots to display as many as five different parameters in a single image. Side-by-side viewing of multiple images can provide easy comparison of additional parameters.

ICASE's iPSC/860 hypercube was upgraded to Release 3.2 of the system software, and an 8mm tape backup system was added to the Concurrent File System. The high-speed, high-capacity tape backup system increases the usefulness of the CFS by improving the long term integrity of data stored on it.

Wai Sun Don

Research in shock wave simulation using spectral methods has advanced considerably. Good results have been obtained in the 1-D and 2-D interaction of shock wave with vortex and entropy wave, up to Mach 8. Although the solution of the calculations exhibited oscillatory behavior due to the Gibbs phenomena, an improved solution can be recovered after postprocessing. Furthermore, the shock is captured quite well even under severe distortion as in the case of a weak shock interacting with a strong vortex. The fine structures generated by the interaction of the shock and density/entropy wave for example are well resolved. The surprising fact is that the method used in these calculations does not involve any untested idea. The only requirement is to keep the spectral scheme stable by filtering the solution and derivatives weakly when necessary. The numerical results seem to confirm the theoretical results of Gottlieb and Tadmor concerning the accuracy of the moments in linear problems and of Tadmor concerning the convergence of spectral methods for nonlinear scalar equations. Results of this research will be prepared for an ICASE report soon.

However, spectral methods for discontinuous problems still requires further refinement Work with D. Gottlieb continues on this reconstruction step in order to recover the spectrally accurate nonoscillatory solution from the highly oscillatory one. Work is also in progress for the case of an oblique shock interacting with a vortex. Future joint work with T. Zang and G. Erlebacher on the 3-D supersonic compressible homogeneous turbulence using spectral methods will is planned.

Peter Duck

Work has been continuing with R. J. Bodonyi on 2D receptivity problems, with particular emphasis on the interaction between a surface suction slot and a small amplitude unsteady freestream disturbance, the aim being to predict the amplitude of resulting Tollmien-Schlichting (TS) waves. The method has also been used, successfully, in demonstrating the cancellation of TS waves, a technique of direct relevance to active boundary-layer control. A report summarizing these results is in preparation. The three-dimensional analogue of this problem is also currently under investigation.

Work also continues with the study of curvature effects on the stability of the supersonic flow past axisymmetric bodies, this work leading on from that reported in ICASE Report Nos. 89-19 and 90-14; in particular, the effect of wall cooling and heating has been investigated. A report detailing these results is in preparation.

Work on the effects of the "trailing-line vortex" is currently underway with M. Khorrami (High Technology Corporation). This work has enabled an asymptotic description (valid at large Reynolds numbers) to be made of new modes of instability found recently by Khorrami.

Investigations have also been carried out jointly with Erlebacher and Hussaini on the stability of compressible Couette Flow. This has revealed how additional (neutral) modes (which may be described asymptotically as the limit of large Reynolds number) may occur. Further the effect of changes in boundary conditions has been shown to have a profound effect on the stability of the flow. The motivation with this work is to increase our understanding of conditions necessary in compressible flows for stability/instability.

Thomas Eidson

A study of the role of continuous wavelet transformations in the analysis of turbulent flows is underway. The first goal is to use wavelet transformations to study a transition flow in a channel calculated by direct simulation (by T. A. Zang of the Fluid Mechanics Division, LaRC). This study will be followed by the application of the wavelet data analysis to experimental flows.

The work performed to date included study of wavelet theory and the development of several codes to perform wavelet transformations and to analyze the results of those transformations. Several different types of quadrature have been tested on a variety of simple functions to determine the most accurate algorithm.

The planned analysis of turbulence is focused on attempting to define and identify events in the flow field. An event is being defined as a region of flow that can be characterized and given an identity to distinguish it from a smoother flow in its immediate surroundings. Three types of characterization are initially planned:

1. determine an average scale of the event
2. determine the local intermitency or event spacing
3. determine an equivalent homogeneous exponent (α)

The value of alpha for a homogeneous function, $f(s) = x^{\alpha}$, can be conveniently determined using wavelet transforms. A point vortex has a spatial variation as follows: velocity x^{-1} and vorticity x^{-2}. If turbulent events have a vortex character, the velocity (or vorticity) field may be assumed locally homogeneous with an alpha of -1 (or -2).

John Elliott

The nonlinear interaction between a longitudal vortex and a three-dimensional Rayleigh-wave has been considered theoretically for compressible flow in the limit of small Mach number. Here the originally very complicated problem is simplified but in such a way that still retains a strong nonlinearity. In this limit the (regular) critical layer moves towards the boundary-wall. While most of the oncoming boundary-layer flow is simply displaced, there is a nonlinear viscous region in which the mean-profile is completely altered over a streamwise length-scale that is short compared to the original $O(1)$ boundary-layer scale but is large compared with scale of the Rayleigh wave. Moreover the vortex problem is an interactive one.

The nonlinear interaction is governed by the fully nonlinear boundary-layer equations for the vortex and by a linear partial-differential system for the Rayleigh wave. A start on solving the resulting problem numerically has been made. A scheme to solve the vortex equations using a mixed spectral/finite-difference approach has been adopted. Also a scheme that finds both the position of the critical layer and calculates the wavespeed and wavenumber is in the process of being merged with the vortex code. Currently the aim is to fully account for the interaction ensuring that as the vortex develops the wave remains neutrally stable.

Gordon Erlebacher

A new graphics package capable of reconstructing three-dimensional representations of cross-sectional data was developed. The technique consists of piercing the data volume by thousands of light rays, and integrating the color of contributions along these rays as they progress towards the viewer's eye. The software runs heterogeneously on the NAS supercomputers and on the Power Series Silicon Graphics machines. It also runs on the Personal Irises. The software is capable of scanning a 64^3 database with 16000 rays in under two seconds to produce smooth, shaded three-dimensional images. The speed is sufficient for practical use in everyday work.

Work on shear flow compressible turbulence in collaboration with Sarkar, Kreiss and Hussaini is under progress. The shear flow code has been debugged and results are being analyzed. The bulk of the work has been performed by Sarkar.

The work on Mathematica algorithms applied to supersonic transition was written up for the proceedings of the Symbolic Manipulation conference in Dallas (November 1990), under the auspices of ASME. An ICASE report awaits more substantial results.

In collaboration with Drs. M. Y. Hussaini, M. Malik, and Chang, work is under progress on the Parabolized Stability formulation applied to supersonic flows over boundary-layers. A numerical algorithm for the nonlinear version of this method has been formulated, but not yet implemented.

Together with T. A. Zang, and D. Pruett (Fluid Dynamics Division, LaRC), direct numerical simulations of supersonic transitional flow over boundary-layers has continued. Time was spent modifying previous versions of the code to make it more robust and amenable to a wide variety of numerical schemes (compact, ENO, spectral). This code will be applied to cones at a free-stream Mach number close to seven.

Work with P. Duck and M. Y. Hussaini on the stability of compressible plane Couette flow has produced new types of instabilities. These are the result of special boundary conditions applied to the upper wall. One of the objectives of this research is to try to link the properties of boundary layers (semi-infinite flows), to that of couette flow (which is predominantly viscous).

Ben Fitzpatrick

This research focuses primarily on parameter identification. One area of interest is in

Bayesian statistical methods. These methods provide not only a unified framework for statistical inference, but also a systematic approach to choosing regularization parameters. Other projects include models which contain probability measures as parameters, and identification of nonlinearities in conservation laws. We are also continuing work on incorporating actuator dynamics into flexible structure control laws.

Michael Gaster

Amplitude modulation of a Tollmien-Schlichting wave train can have great influence on its evolution when the amplitudes are large enough for non-linear effects to be important. Nevertheless, we find a great deal of analytical, computational and experimental studies of pure periodic wave trains. I believe that important aspects of a natural transition process are therefore often overlooked.

The present effort involves the processing of experimental hot-wire records obtained from impulsively excited wavepackets propagating downstream in the laminar boundary layer of a flat plate. The data sets were recorded at a range of excitation amplitudes. The packet modulation generates significant quadratic non-linearity and the purpose of the signal processing is to separate out the linear, the quadratic and the cubic responses.

James F. Geer

Work is progressing on a hybrid perturbation/Galerkin method for solving a variety of problems for both ordinary and partial differential equations. For ODE's, we are currently applying the method to several classes of nonlinear vibration problems, with special emphasis on resonant frequency calculations. For PDE's, we are investigating how the method might be applied to some exterior boundary value problems for elliptic PDE's, when the boundary of the domain D_1 has an irregular shape. The basic idea is to treat D_1 as a perturbation of a simple domain D_0 (e.g., a circle or an ellipse, in two dimensions) by embedding it in a one parameter family of domains D_ϵ, where $0 \leq \epsilon \leq 1$. 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 encouraging. Work on the method itself is being done with C. Andersen of the College of William and Mary, while possible applications are being discussed with E. Liu (Low-Speed Aerodynamics Division, LaRC) and M. Hemsch (Applied Aerodynamics Division, LaRC).

The problem of describing aerodynamically generated sound from compact sources of vorticity is being studied from a perturbation point of view, with the eddy Mach number appearing as the perturbation parameter. The problem appears to be well suited to an application of a slightly modified version of the method of multiple scales. Once the perturbation solution is fully understood, the hybrid perturbation Galerkin technique will be applied to it, with the goal of extending the usefulness (and accuracy) of the solution to higher Mach numbers than is possible using the perturbation solution alone. This work is being carried out with J. Hardin (Acoustics Division, LaRC).

David Gottlieb

We have been using the Kreiss theory to verify the stability conditions of semidiscrete schemes, and to devise stable and accurate boundary conditions for the fourth and sixth order compact schemes. In particular, we have checked the existence of eigenvalues and generalized eigenvalues in order to establish the stability of the compact schemes when Runge-Kutta schemes are used for the time marching. A surprising result is that an incorrect *inflow* treatment can lead to instabilities.

We have continued our research in spectral simulations of shock waves. We have developed a one side filter based on Gegenbaur polynomials. We proved that with a careful choice of the order and number of Gegenbaur polynomials one can achieve spectral accuracy approaching the shock from one side. We have also applied a point value spectral scheme to study interactions of vortices with shocks. The results are of the same quality as one obtains from high order ENO finite difference schemes.

Philip Hall

Aspects of receptivity theory for Görtler vortices have been investigated using asymptotic and analytical approaches. Research with Denier (University of Manchester) and Seddougui on the receptivity problem for vortices induced by isolated and distributed wall roughness was reported in ICASE Report No. 90-31. It was shown that an isolated roughness element induces vortices within a wedge shaped region behind the element. Aspects of the relationship between crossflow and Görtler vortices in 3D boundary layers were investigated with Bassom (University of Exeter) (ICASE Report No. 90-72). It was shown conclusively that crossflow completely destroys the Görtler mechanism. Investigations with Horseman (ICASE Report No. 90-71) on the secondary inviscid breakdown of streamwise vortices, reproduce the key features of experimental investigations of this problem. Research with Blackaby and Cowley (ICASE Report No. 90-40) explored the inviscid instability of hypersonic boundary layers for a Sutherland Law fluid.

Amiram Harten

The Essentially Non-Oscillatory (ENO) schemes are based on an adaptive piecewise polynomial interpolation, where we assign an appropriate stencil for each computational cell. We use an hierarchial algorithm for this purpose: We start with a stencil which is just the endpoints of the cell, and at each step of the algorithm we add a point to the previous stencil, either the one to its left or the one to its right, until we arrive at the desired number of points. Originally, at step m this algorithm selected out of the two candidates the one for which the m-th derivative of the interpolating polynomial is minimal in absolute value. It is possible that this algorithm will select a stencil for which the resulting scheme is linearly unstable over a whole interval. In all our experiments we found the ENO schemes to converge to the correct solution, however in the case mentioned above,some high derivatives of the numerical solution may fail to converge; this brings about a completely unnecessary loss of accuracy. We have corrected this basic fault of the original algorithm by modifying it to give preference to a selection of a centered stencil wherever the function is smooth. This was done by replacing the comparison of the derivatives of the interpolating polynomials for the two candidates by a comparison of an estimate for the interpolation error for each of the candidates. Together with D. Gottlieb and C. W. Shu we have started a study of a new approach to spectral approximations of discontinuous data, in which we divide the data into subintervals of smoothness. We have investigated the quality of approximations that can be obtained by collocating values in a subinterval, using eigenfunctions corresponding to the whole interval. Our numerical experiments showed that indeed we get spectral accuracy this way, but the coefficient matrix is ill-conditioned. At this stage we try to overcome this difficulty.

Dan Henningson

Non-linear interaction of finite amplitude oblique waves in subcritical Poiseuille flow was considered. Preliminary numerical simulations of this type of disturbance have shown that energy rapidly propagates to higher spanwise wavenumbers, initiating the transition process. The preferred excitation of higher spanwise wavenumbers is due to a near resonance of Orr-

Sommerfeld and Squire modes along the spanwise wavenumber axis. Numerical simulations have also shown that this non-linear growth causes the disturbances to reach the transitional stage faster than comparable disturbances of secondary instability type. This transition scenario is presently being modeled using an eigenfunction expansion in Orr-Sommerfeld and Squire modes, in which non-linear interactions are incorporated.

Mohammad Ashraf Iqbal and Shahid H. Bokhari

Work is continuing on the problem of optimally partitioning the modules of a parallel program over a multiple computer systems with a given structure. Prior research has resulted in a succession of faster solutions to these problems. We describe algorithms that are better than any of the previously reported algorithms. Our approach is based on a preprocessing step that condenses the chain or tree structured task into a monotonic chain or tree. The partitioning of this monotonic task can then be carried out using fast search techniques. An ICASE report describing this work has been completed.

Further work is aimed at partitioning graphs other than chain or tree structured tasks over more general multiple computer systems. We are, for example, looking into the possibility of partitioning series - parallel graphs over a parallel machine.

In another effort, we have been extending our work on binary trees and are trying to partition k-ary trees over a number of multiple processor systems while minimizing the communication overhead. Our analysis is based on four different multiprocessor machines: two of them are derived from a full binary tree, one is a nearest neighbor array, and the last has a hypercube interconnection structure.

Kazufumi Ito

An algorithm has been developed and tested numerically for the problem of reconstructing conductivity in electrical impedance tomography using a set of boundary measurements. The algorithm is based on the augmented Lagrangian method and its use with a new regularization technique for crack identification has been successfully demonstrated.

A method of determining the optimal Tichonof-regularization parameter in nonlinear least square problems arising in the parameter estimation has been developed (jointly with K. Kunisch, Technical University of Graz). The applicability of the method has been demonstrated using an inverse problem in a one-dimensional elliptic equation.

In joint work with M. Desai (a Ph.D student of the University of Southern California) we have studied optimal control problems in the fluid flow governed by the Navier-Stokes equations. Two control problems in the driven cavity and flow through a channel with sudden expansion have been formulated and solved successfully using a numerical method based on the augmented Lagrangian method. Also, we have developed a pre-conditioning technique for the Stokes equation in the context of the mixed finite element method.

Research on a variational approach to boundary control problems in distributed parameter systems has been continued. A manuscript with H. T. Banks on a class of boundary control problems in parabolic systems has been completed. An extension of our study to elastic dynamics (e.g., the wave and Euler-Bernoulli equations) has been started. Our approach offers a systematic way of treating and formulating control problems in flexible structure dynamics.

Thomas L. Jackson and Chester E. Grosch

Our work focuses on the structure and hydrodynamic stability of compressible high speed reacting free shear flows, directly applicable to the study of supersonic diffusion flames in the context of scramjet engines. A combination of asymptotics and numerics is used to reduce complex problems to model problems, thus isolating key physical effects for analysis.

Peter A. Jacobs

The free-piston driven shock tunnel is a type of aerodynamic test facility which can provide flows with reasonably high densities and high velocities (say, $3km/s < v < 8km/s$). It is hoped that shock tunnels will be able to provide good experimental data at these high flight speeds where chemical effects are significant. However, there are difficulties encountered when trying to obtain data in a test flow for which the duration is typically of the order of 0.1 to 2.0 milliseconds. We have been investigating the effects of the transient nature of such a test flow.

With R. C. Rogers (Fluid Mechanics Division), E. H. Weidner (Fluid Mechanics Division), and R. D. Bittner (Analytical Services & Mechanics, Inc.) some of the effects of transient flow on measurements taken in scramjet combustors have been investigated by numerically simulating the flow through a two-dimensional scramjet model. The scramjet model consisted of two parallel walls forming a constant area duct and a centrally located strut installed at the entrance to the combustor duct. The simulations were performed in a "time-accurate" manner using the SPARK Navier-Stokes code and concentrated on the establishment of flow features such as the recirculation region behind the strut and the boundary layers developing along the duct walls. Only laminar, non-reacting flows were studied. The issues of fuel injection, mixing, turbulence, and chemical effects were left for the future. Results were presented at the 26th Joint Propulsion Meeting (July 1990, Orlando, Florida) in AIAA

Paper 90-2096.

As the design Mach number of the shock tunnel nozzle is increased, the starting processes in the nozzle consume more of the precious test time. Currently, we are investigating the transient flow in a Mach 8 axisymmetric nozzle designed for use on the T4 shock tunnel facility (located at the University of Queensland, Australia). The experimental calibration of this nozzle indicated that the starting processes were consuming a significant fraction of the test time and, at high test speeds, may prevent the test flow from settling within the available test time. The flow processes are being studied with a number of CFD techniques including:

- A parabolized-Navier-Stokes solver (courtesy of John Korte, Fluid Mechanics Division) used to provide information on the steady state flow.
- A quasi-one-dimensional finite volume code used to provide information on the transient nature of the flow over a range of test parameters.
- An axisymmetric version of the SPARK Navier-Stokes code (courtesy of Mark Carpenter, Fluid Mechanics Division) used to provide a transient, multidimensional simulation of the starting processes.

The results of this work will be presented at the AIAA 29th Aerospace Sciences Meeting (January 1991, Reno, Nevada) in AIAA Paper 91-0295.

Charles R. Johnson

Work was continued on singular value inequalities and on properties of real matrices related to the signs (+, -, 0) of their entries. In the latter, work was completed with Carolyn Eschenbach (Georgia State) on conditions for diagonalizability (by similarity).

Ashwani Kapila

The evolution of hydrodynamic disturbances in an exothermically reacting atmosphere is being examined, for a broad range of disturbance wavelengths. Matters of particular interest include shock formation and acceleration, reaction runaway, and transition to detonation.

David Keyes

Combustion is both a typical and a technologically important multicomponent transport phenomenon whose numerical simulation is cramped by memory capacities and processing rates of conventional supercomputers. Combustion modeling is intrinsically amenable to large-scale parallelism, however, in that the proportion of overall computational work associated with only local data dependencies (the chemical kinetics terms of the governing equations) is very high.

Long-term collaborations with combustion modeler M. D. Smooke (Yale University) and parallel computer scientist W. D. Gropp (Argonne National Laboratory) have guided the development of a parallel code running on both shared (Multimax) and distributed (iPSC) memory systems for the solution of nonlinearly implicit finite-difference discretizations of convection-diffusion-reaction systems of elliptic PDEs using Newton's method and the GMRES Krylov solver. The main research frontier is the construction of domain-decomposed preconditioning for the inner iteration that solves the linear systems for the Newton updates. We have developed a two-level preconditioner accommodating flexible locally uniform refinement within macro-elements called tiles. The vertices of the tiles comprise a coarse grid which plays a key role in obtaining algebraic convergence rates which are "near optimal" in the sense that they degrade only as the logarithm of the ratio of the tile diameter to the finest mesh spacing, as the grid is locally refined. The algorithm parallelizes well even for single-component problems. The work per iteration in multicomponent problems can and should be tuned to the strength of the intercomponent coupling relative to the spatial (convective-diffusive) coupling.

Research on multicomponent preconditioners and adaptive refinement quickly becomes problem specific. We are concentrating on axisymmetric laminar diffusion flames in a streamfunction-vorticity formulation.

Charles Koelbel and Piyush Mehrotra

The focus of our research has been the translation of high level programs for execution on distributed memory machines. In our approach, the user uses a global name space to express the algorithm along with annotations to control data and workload distribution. The compiler analyzes this high level specification and produces code capable of execution on the distributed memory environment of the target architecture. From the compiler's point of view, scientific codes can be divided into two broad classes: those that exhibit regular memory access patterns and those that use indirection for accessing data values. The compiler that we are implementing uses a single transformational model to handle both classes of codes. For the first class of codes, the compiler has enough information to generate the message passing primitives at compile-time itself. However, when the memory access patterns are based on computed values, the compiler generates runtime code which analyzes the memory references to determine the required communication. The first case is fairly efficient since the code produced by the compiler is similar to hand written code. On the other hand, there is a fair amount of overhead due to the runtime analysis in the second case and we have been investigating mechanisms to optimize this overhead. In particular, if the access pattern does not change over repeated execution of the same code, e.g., within a loop, then the cost of the runtime analysis can be easily amortized over the repeated executions. The above work has targeted static data distributions. We are currently investigating runtime support structures which allow the user to dynamically change the distribution of the data structures.

Fumio Kojima

Work is continuing on the development of parameter estimation techniques based on the boundary integral equation method. Boundary shape identification problems related to an thermal tomography have been studied. We developed a spline based technique for a Volterra integral equation of the second kind. The advantage of the proposed method is in the computational saving obtained by reducing the problem from two space dimensions to one. Our approach is applicable to the problem of estimating arbitrary corrosion shape of the material. Numerical experiments indicate the method is attractive and convergence arguments for the proposed algorithm are currently under study. Future work is aimed at investigating an inverse problem for 3-D thermal tomography.

Heinz-Otto Kreiss

Consider the compressible Navier-Stokes (N-S) equations and assume that the Mach number is small. Asymptotic expansions in terms of solutions of the linearized incompressible N-S equations and the wave equation are derived. Careful estimates are given to determine the validity of this expansion and to measure the interaction between the fast and the slow time scales.

D. Glenn Lasseigne

Our research focuses on the interactions of disturbances in the flow field with both reacting and non-reacting shocks. A combination of asymptotics and numerics is used to reduce complex problems to model problems, thus isolating key physical effects for analysis. Specific problems include: the non-linear interactions of vorticity/detonation waves, the effects of heat release on the response of an oblique detonation subjected to wedge oscillations, and the coupling of upstream disturbances and wedge oscillations on the stability of an oblique shock. Other problems include the effects of streamwise vorticity on the stagnation point flow and the effects of more general disturbances on a flame in the viscous stagnation region.

Jacques Liandrat

Work is continuing on the application of wavelet decomposition for approximation problems in fluid mechanics. Work has begun on the definition and the implementation of new numerical algorithms for the resolution of partial differential equations based on the wavelet approach. Numerical resolution of the 1D regularized Burgers equation has been performed. The main result is the possibility to derive fully adaptative methods that are required for the efficient computation of strong local gradients. Different tests on other 1D equations are underway. Numerical analysis of the basic method has been performed. Current work deals with the generalization of the algorithm to non periodic and multidimensional problems.

The work on the use of wavelets as a tool to extract substantial physical information from turbulence or transition data is also continuing. Methods to estimate the transition Reynolds number have been tested successfully on some experimental data. A study of the decomposition of signal in terms of wavelet packets that could be close to coherent structures is also underway. It should be tested on experimental or numerical data of near wall flows.

Dimitri Mavriplis

Work is continuing on the use of unstructured triangular meshes for solving turbulent viscous flow problems about arbitrary configurations in two dimensions. An algebraic turbulence model for use on unstructured grids has been developed and implemented. The model has been shown to produce good results for high Reynolds number attached flows over single and multiple element airfoil geometries (ICASE Report No. 90-30). Further work has concentrated on the incorporation of adaptive meshing techniques to enable the accurate solution of turbulent flows with highly localized gradients (ICASE Report No. 90-61). The developed computer code is currently being employed by the Computational Aerodynamics Branch of NASA Langley for predicting wind-tunnel model results in both air and heavy non-ideal gas (sulfur-hexafluoride). The development and implementation of field-equation turbulent models of the k-epsilon type is also being pursued, in order to enable the prediction of flows with massive amounts of separation.

Other work has concentrated on alternate methods for solving the Euler and Navier-Stokes equations on unstructured meshes. An ILU (incomplete LU factorization) preconditioned GMRES implicit iterative solver has been developed in conjunction with V. Venkatakrishnan (Computer Science Corporation, Moffett Field, California) for the Euler and turbulent Navier-Stokes equations on unstructured meshes. Also, in conjunction with J. Saltz, the parallel implementation of this algorithm is being studied. The method displays good convergence properties but suffers from large memory requirements which may limit its applicability in three dimensions. Further work is planned to investigate the use of alternate matrix-free type preconditioners.

Piyush Mehrotra and John Van Rosendale

Current programming languages for distributed memory machines provide very little support for expressing scientific computation. There have been several recent efforts (including ours) to provide language primitives which allow the user to specify the algorithm at a high-level. Most of these approaches have concentrated on regular data structures such as dense matrices where the compiler has enough information to transform the program for distributed execution. We have extended this work to include more dynamic data structures such as those useful for irregular and adaptive meshes. In such situations, the distribution of data may be dependent on values computed or read in at runtime. Also the workload on each processor changes as the computation progresses. The approach followed here allows the user to specify the distribution of the data based on runtime values. The user can also change the distribution in response to changing computation so as to balance the workload. Preliminary results suggest that the primitives provided to the user allow easy expression of dynamic distribution of data while still allowing the compiler to generate efficient runtime code.

Kirsten Morris

Earlier work on convergence of Galerkin approximations in the graph topology has been refined and extended. We have demonstrated uniform stabilizability of a class of partial differential equations, which includes many structural models.

Any controller with a strictly positive transfer function will stabilize a structure with a positive transfer function. This result is known as the Passivity Theorem. Unfortunately, only structures with collaborated rate sensors and force actuators have positive transfer functions. Furthermore, this result only applies to systems with equal numbers of inputs and outputs. This theorem has been extended to more general configurations, such as displacement sensors, using dissipative system theory. A stability theorem for robust, model-independent controllers of structures which lack collocated rate sensors and actuators is given. The theory is illustrated for non-square systems and systems with displacement sensors. This work was done in collaboration with J. N. Juang (Structural Dynamics Division, LaRC).

H. S. Mukunda

The work on high speed reacting mixing layer has been carried out with the three objectives of (1) exploring the role of diffusion, (2) evolving a faster algorithm of diffusion for use in computational codes like SPARK and (3) examining an equivalent single step reaction scheme to produce the temperature and product variation along the mixing layer.

The trace diffusion approximation was derived for high speed flows where pressure gradient effects are non-negligible. Implementation in SPARK 2D showed that the approximation with $(1 - x_i)$ as the associated coefficient would produce the best comparisons for peak temperature and product variation along the mixing layer. The equivalent single step producing nearly identical peak temperature and product variation along the mixing layer, as for the case of full chemistry and diffusion, could do well when the extent of heat release is dropped by a factor of six compared to what may be expected from a "naive" single step reaction. The relatively slow peak temperature increase through the mixing layer at high speeds is argued to be due to effects of stretch.

Co-workers: Mark Carpenter (Fluid Mechanics Division, LaRC); Balu Sekar (Vigyan Research Associate, Inc.).

Naomi Naik and John Van Rosendale

Multigrid algorithms are fast and inherently parallel. In general, multigrid solves elliptic problems on an n-point mesh in time $O(\log^2 n)$, using n processors. While this parallel performance is usually acceptable, there remains a basic unresolved issue:

multigrid parallel solution time is a factor of $\log n$ *worse than that of fast direct methods.*

This $\log^2 n$ estimate is a lower bound on the parallel complexity of virtually all multigrid methods, including the new Fredrickson-McBryan parallel algorithm.

We have been looking recently at the concurrent relaxation multigrid algorithm of Gannon and Van Rosendale, in which all grid levels are relaxed simultaneously. While experiments suggest that this algorithm has $O(\log n)$ parallel execution time, this has never been proven; concurrent relaxation algorithms are so complex, they have never been adequately analyzed. We discovered recently that by combining the idea of concurrent relaxation with the use of multiple coarse grids, as in the Fredrickson-McBryan algorithm, we can make an effective concurrent relaxation algorithm which can be analyzed. The use of multiple coarse grids greatly simplifies analysis, since it leads to iteration matrices which are diagonal in Fourier space. Using this fact, we believe we can show that the new combined algorithm runs in $O(\log n)$ parallel time, the first time such a bound has been established for a multigrid algorithm. While the main interest of such a result would be theoretical, especially since

$n \log n$ processors are required, it would demonstrate the efficacy of concurrent relaxation algorithms, and could lead to a family of practical concurrent relaxation algorithms.

R. Narasimha

A review of the current state of modeling the transition zone was undertaken. A draft manuscript on the subject was completed. With B. Singer (Fluid Mechanics Division) and S. Dinavahi (Fluid Mechanics Division), an assessment of two specific models, namely one from ONERA and the other from Bangalore, was made. The latest version of the Bangalore code, TRANZ 3, was handed over to Dinavahi. Simulations of a temporally evolving boundary layer during transition, carried out earlier by T. Zang (Fluid Mechanics Division), were carefully analyzed; it was found that while the spectra had too coarse a resolution to offer much additional insight into transition processes, the instantaneous wall stress revealed a definite spot-like structure during transition. A program of follow-up work in this area was formulated.

An effort was initiated with B. Singer to see whether blowing at the wall would lead to spot-like structure in a boundary layer, using a code available at ICASE.

David M. Nicol

We've shown how to extend our previously developed conservative synchronization protocol to queueing networks which have preemptive priority classes. Analysis demonstrates that good performance will be achieved on large models. In another effort, we've shown how the standard dynamic space allocation mechanism in C, `malloc()`, can lead to inflated, sometimes superlinear speedups. We developed and tested a scheme which caches dynamic blocks on the basis of their size.

David Nicol, Joel Saltz, and Adam Rifkin

We've developed and are studying an algorithm for optimally partitioning two dimensional workload in a rectangle into rectangles such that each rectangle has only one neighboring rectangle in each of the four directions (NEWS) of the compass. This property is important on parallel architectures where the cost of communicating with a non-NEWS neighbor is extremely high.

Yuh Roung Ou

In collaboration with Y. M. Chen (Fluid Mechanics Division, LaRC), unsteady flow past a rotating circular cylinder is studied by integration of a velocity/vorticity formulation of the governing equations, using an explicit finite difference/pseudo-spectral technique and a new implementation of the Biot-Savart law. Our current efforts are devoted to simulating the case of constant speed of rotation. For a Reynolds number of 200, results are obtained for several values of the angular/rectilinear speed ratio up to 3.25. For speed ratio at 3.25, our results indicate that vortex shedding does indeed occur, in contrast to the experimental conclusion of Coutanceau & Ménard.

Another effort is focused on the possibility of controlling unsteady flow separation by proper choice of a time-dependent rotation rate. The issue of whether vortex shedding can be controlled by a time-varying cylinder rotation is of considerable practical interest from the standpoint of wake modification and the reduction of flow-induced vibration. We have performed simulations of a rotationally oscillating cylinder at various oscillation frequencies. The results indicate that forces acting on the cylinder strongly depend on the oscillation frequency. Work on the mathematical formulation of an optimal control problem associated with rotating cylinder has begun in collaboration with John Burns.

Merrell L. Patrick and Mark Jones

Improvements and additions to the software package, LANZ, for solving the generalized eigenvalue problem are continuing. LANZ, based on the Lanczos method, had been implemented and tested on the Convex, Cray Y-MP, Cray 2, and SUN 3 and SUN 4 Workstations. Since the last report a parallel version using the Force has been implemented on an Encore Multimax.

Solving indefinite linear systems of equations is a computational intensive portion of the software. A sparse version of the Bunch-Kaufman algorithm has been added to the software. With that addition, the user of LANZ can now choose either a banded or sparse indefinite solver. These versions of Bunch-Kaufman factorization take advantage of high performance architectures.

In our search for efficiency, particularly for very large problems, the option of iterative methods for solving indefinite systems will be added to LANZ. Iterative methods require less storage and parallelize more easily than direct elimination methods. We have also begun to make an assessment on the appropriateness of other parallel architectures for implementing LANZ. In particular, we are considering distributed memory parallel computers such as the Intel iPSC/860.

This work is being done in collaboration with the NASA Langley CSM group.

Merrell L. Patrick and Terrence W. Pratt

Methods for porting existing Fortran applications codes to new parallel architectures are the focus of this study. A promising new method for automatic generation of an MIMD, distributed memory, parallel program from existing sequential code is being studied. The method uses a source-to-source translation of the sequential code into parallel processes, together with a small run-time library to support communication between the parallel processes. The translation generates a two-level decomposition of the original program, first, into functionally distinct components and, second, into data parallel components.

The major code used as the focus of this study is the NASA LAURA code (Langley Aerothermodynamic Upwind Relaxation Algorithm), developed by P. Gnoffo (Space Systems Division, LaRC). Initial application of the method to this code shows that the functional decomposition can be used to generate up to 100 parallel processes, and that many of these can be replicated up to N times, where N is the problem size (number of columns in the major shared arrays). Smaller decompositions may be used to limit the number of parallel processes to the number of available machine nodes and to allow static balancing of the computational and communication load between processes. Measurements of the performance of the parallel version of the LAURA code on the NASA/ICASE Intel iPSC/860 will begin soon.

Serge Petiton, Joel Saltz, and Scott Berryman

We are carrying out a detailed study of the performance effects of irregular communications patterns on the CM-2. A range of different algorithms to carry out sparse matrix vector multiplication have been defined, coded and benchmarked. Performance of these algorithms is critically dependent on the sparse matrix employed. We have developed and are employing several synthetic workloads; we are also using a number of unstructured meshes generated for aerodynamic codes. The result of our efforts is a benchmarking suite that stresses the communications capabilities of the CM-2 in a range of different ways.

Another facet of this project is the practical development of high performance kernels to be used in sparse iterative codes. We have used some of these kernels to implement conjugate gradient linear systems solvers and sparse Arnoldi projection eigenvalue solvers.

Ugo Piomelli

In large-eddy simulations (LES) of the Navier-Stokes equations the effect of the large scales is accurately computed, and only the small, subgrid scales are modeled. Since small scales tend to be more isotropic than the large ones, it should be possible to parameterize them using simpler and more universal models than standard Reynolds stress models. Thus, most subgrid scale (SGS) stress models are based on an eddy viscosity assumption, which, however, cannot account for the energy flow from small to large scales observed during transition. The simulation of transition to turbulence in plane channel flow indicates that such models give acceptable results, but that models which include more of the physical features of the flow must be developed. A one-equation subgrid scale stress model based on these ideas has been examined. It was found that the modeling of the dissipation of subgrid scale energy presents significant difficulties, and that current models would predict an initial decay of subgrid scale energy that would lead to incorrect development of the perturbations. A new model based on the velocity due to the intermediate scales (i.e., the small resolved scales) is also being examined.

Peter Protzel

Together with D. Palumbo (Information Systems Division, LaRC), we are completing an initial study of the fault-tolerance characteristics of certain Artificial Neural Networks (ANNs) that can be used to solve optimization problems by associating the energy minima of the ANN with the (local) solutions of the problem. If an ANN is used in a critical application like a flight control system, then the fault-tolerance of the ANN itself becomes an important issue. In order to study the fault- tolerance, we simulated the operation of the ANN in the presence of different types of component failures. Our results show a surprising degree of fault-tolerance with only a slight performance degradation even after multiple faults. One application that we investigated is an ANN that controls the reallocation of tasks in a fault-tolerant, distributed multiprocessor system. Partial results of these studies have been presented at two international conferences and an ICASE report with a complete description is currently in preparation. A new project has been started in cooperation with ongoing activities at NASA Ames that investigates applications of an ANN with a new unsupervised learning method to nonlinear control problems. An evaluation of the fault-tolerance and related implementation issues is planned after simulations show the feasibility of the targeted applications.

Another project in collaboration with C. Jeffries from Clemson University studies a new associative memory architecture with applications in signal processing and pattern recognition. The architecture is characterized by the use of multipliers in the feedback loops, which leads to a complex, high order, nonlinear system described by a system of nonlinear ODEs. The main feature of the model is that arbitrary binary patterns can be easily stored in the memory by determining the feedback connectivity and that these patterns constitute the only stable attractors of the dynamical system. One application is the error correction of block codes transmitted over a noisy channel. With the ability of the associative memory to converge from arbitrary (analog) initial values to the closest binary pattern stored, it is possible to perform so-called soft-decision decoding without quantizing the noisy bit-samples. Simulations have shown that this reduces the achievable bit error rate by up to two orders of magnitude in comparison to conventional hard-decision decoding with binary quantization. The same principle capabilities have been used in pattern recognition experiments in which pixel images corrupted by noise can be correctly classified by the associative memory to the degree that it outperforms human observers in extremely high noise cases.

Dan Reed

Data placement is an important facet of programming on parallel systems that lack a global address space (e.g., message-passing architectures). Currently, the application program must explicitly manage the movement of data among processors. Because different computation phases involve different algorithms, the data access pattern changes, and reconfiguration of data among the processors is often necessary. In systems with global address spaces, data placement is also important for performance reasons. Because different memories may have different access times (e.g., local, remote local, and global), data placement and migration can significantly affect application performance.

Traditionally, data placement has been managed by a single, system-imposed policy; the classic example is a paging strategy for a multi-level virtual memory system. The drawback of this simple approach is that the memory management system is completely isolated from the algorithm generating the references. Experiments have shown that insightful assignment of data objects to memory pages can significantly improve aggregate system performance, even though the execution overheads of the memory management system may be higher. However, the intellectual burdens of explicit data placement make it difficult for programmers to construct efficient yet complex programs. Instead, programming abstractions are needed that hide the details of data placement but provide sufficient control to tailor data placement to the application behavior.

We have begun investigating data placement and relocation strategies and their object-based encapsulation. Currently, we are studying the memory access patterns of individual data structures in common scientific codes. We have developed a preprocessor that performs a source to source transformation of Fortran, adding annotations to capture symbolic memory access patterns.

Our application program set includes sequential and parallel versions of the BLAS and Linpack linear algebra subroutine libraries. The decision to use scientific codes as the initial problem domain was motivated by their ready availability and the proven interactions of data placement and performance.

Paul F. Reynolds, Jr.

Recently we have identified a framework that underlies parallel simulation protocols that synchronize based on logical time (all known approaches). This framework describes a sufficient set of synchronization values that must be disseminated efficiently for a parallel simulation protocol to work efficiently, a hardware implementation based on parallel reduction networks for combining and disseminating this information efficiently and algorithms for exploiting the disseminated information. We have identified how our framework can support widely studied protocols such as Time Warp and how it can interface with and support specialized hardware such as Fujimoto's rollback chip. We have identified remaining challenges which include methods for disseminating what we call "local synchronization information." (Processes need information only from the processes that are in the transitive closure of their immediate predecessor set.) We have also determined a method for local information dissemination using parallel prefix algorithms on the reduction network. Work still remains to make this result fully general.

We estimate that such a network to support our framework could be built in units of one for a 32 node distributed memory computer (e.g., Intel iPSC/860) for approximately $7500. We are exploring joint ventures to build such a network.

From the outset, we have known that our approach applies to any parallel program that synchronizes based on the relative values of discrete counters. We refer to this class of programs as "counter programs." This class includes physical models (e.g., Ising model) and popular numerical techniques (e.g., iterative techniques with relaxation). We plan to explore this observation further in the immediate future.

Phil Roe

Novel advection schemes for two-dimensional problems have been studied. These are of interest, both in their own right, and as a foundation for possible new treatments of multidimensional hyperbolic systems of PDE's. A new scheme, applicable to either structured or unstructured meshes, has been devised which makes a highly non-linear response to the data and is an order of magnitude more effective than conventional schemes.

Joel Saltz, Scott Berryman, Janet Wu, Adam Rifkin, Seema Mirchandaney and Jeff Scroggs

In distributed memory MIMD architectures, there is typically a non-trivial communications latency or startup cost. For efficiency reasons, information to be transmitted should be collected into relatively large messages. The cost of fetching array elements can be reduced by precomputing what data each processor needs to send and to receive. In irregular problems, such as solving PDEs on unstructured meshes and sparse matrix algorithms, the communications pattern depends on the input data. This typically arises due to some level of indirection in the code. In this case, it is not possible to predict at compile time what data must be prefetched. This lack of information is dealt with by transforming the original parallel loop into two constructs called an inspector and executor . During program execution, the inspector examines the data references made by a processor, and calculates what off-processor data needs to be fetched and where that data will be stored once it is received. The executor loop then uses the information from the inspector to implement the actual computation. We have developed a suite of primitives that can be used directly by programmers to generate inspector/executor pairs. We have also developed a prototype compiler capable of automatically embedding these primitives. Primitives carry out the movement of data between processors, eliminate duplicate data fetches and store copies of off-processor data in hash tables.

There are many situations in which simple, easily specified distributed array partitions are inappropriate. If we allow an arbitrary assignment of distributed array elements to processors, the data structure used to describe the partitioning will have the same number of elements as the distributed array. In order to access an array element, we need to know where the element is stored in the memory of the distributed machine. We use a distributed translation table defined to describe the mapping. One of our primitives handles initialization of distributed translation tables, another is used to access distributed translation tables.

When a distributed translation table is used to describe array mappings, inspectors must be modified so that they access the distributed table. Using an irregular array mapping *does not alter the form of the executor.* During the past six months, we have carried out extensive performance benchmarking of codes and kernels with PARTI primitives manually inserted as well as kernels in which the ARF compiler automatically inserted primitives. Benchmarks have included kernels from unstructured mesh codes along with an adaptive partial differential equation solver that uses an asymptotics-induced algorithm described by Scroggs and Sorenson.

Most of the optimizations we have developed so far are motivated either directly or indirectly by the high communication latencies typically found in distributed memory computers. Because we can anticipate all of the interprocessor communications that will be needed in carrying out a loop, we have the information we need to schedule interprocessor communications to reduce overheads due to contention. We are modifying the scheduling carried out by our primitives to incorporate analysis of this kind. Computations can be characterized by patterns of data dependency. Procedures that partition data structures and computational work take these dependency patterns into account. It is possible to design program transformations that generate procedures which output a record of the dependency patterns in a loop nest in a a standard representation. Standardized partitioning programs that use these data structures can then be employed.

We are also extending this work to SIMD multiprocessors, and are developing a set of CM-2 PARTI primitives along with a CM-2 version of our model ARF compiler. This work has been described in ICASE report 90-41, and ICASE report 90-59; a manual for a subset of the PARTI primitives is in ICASE Interim Report 90-13. During the last six months we have submitted papers based on this work to Concurrency Practice and Experience, to the Journal of Parallel and Distributed Computing, and to the PPoPPs parallel processing conference.

Joel Saltz and D. Mavriplis

The thin layer Navier-Stokes equations are solved for two-dimensional airfoil problems by preconditioned conjugate gradient-like iterative methods. In past work, V. Venkatakrishnan (Computer Science Corporation, Moffett Field, California) has found the GMRES with incomplete LU factorization as a preconditioner is an excellent scheme for solving linear equations arising from two-dimensional airfoil flow calculations on structured meshes. We have shown that these methods are equally applicable to unstructured grids.

We have investigated a variety of issues that arise when mapping such iterative methods to vector parallel machines and have characterized their performance. The inner loop of our solver involves computation of upper and lower sparse triangular systems. These triangular matrix solutions can constitute an appreciable percentage of the operations required in the iterative portion of preconditioned Krylov space algorithms. It is consequently essential to efficiently compute these sparse triangular solves. We have performed the optimizations required to vectorize and parallelize these operations on an eight processor Cray Y/MP.

While we achieved satisfactory results in vectorizing the sparse triangular solves, our vector parallel results were still somewhat disappointing. Another approach is to partition a domain into P subdomains and carry out an ILU factorization over each sub-domain. The convergence properties of such a domain decomposition depends on precisely how the domain is subdivided. When we partition the domain in one of our model problems in a judicious manner, we are able to obtain speedups of approximately 4.4 compared to a single domain, vectorized code. There is an overhead of approximately 20% due to extra operations introduced; most of the rest of the overhead appears to be due to the fact that partitioning a problem into subdomains reduces vector lengths. We are currently carrying out further explorations of how best to partition an unstructured mesh to obtain good convergence and good load balance, and to maximize vector lengths. We have also attempted to model the Cray Y/MP performance so that we can extend our results to deal with future more highly parallel vector machines. Some of these results were presented in the Proceedings of the 12th International Conference on Numerical Methods in Fluid Dynamics, University of Oxford, England, July 1990.

Sutanu Sarkar

We are engaged in the direct simulation and Reynolds stress modeling of turbulent flows. In collaboration with G. Erlebacher and M. Y. Hussaini, we have completed the simulation of homogeneous compressible shear flows starting with a variety of initial conditions. The simulations have begun to shed light on the behavior of terms such as the pressure-dilatation which, though long known to be important in truly compressible flows, have not been amenable to experimental measurement or theoretical analysis. Our model for the compressible dissipation which had been derived earlier based on asymptotic analysis and then validated against simulations of isotropic turbulence has now been shown to apply to homogeneous shear flows as well. Reynolds-stress turbulence modeling for the NASP project is underway in collaboration with C. G. Speziale. We are continuing the application of second-order closures (using both parabolized and full Navier-Stokes algorithms) to shear layers and wall boundary layers in collaboration with L. Balakrishnan (Old Dominion University).

Jeffrey Scroggs

Research is underway to examine the basis of physically motivated domain decomposition methods. Since these methods have a strong physical basis, it is possible to derive error bounds and error estimates for the methods applied to tough problems in mathematical physics. Most recently we have shown a rigorous upper bound on the size of the shock-layer governed by a conservation law. This bound will be used in the error analysis for asymptotic-induced domain decomposition methods applied to problems with shocks.

One of the current difficult problems in asymptotic-induced domain decomposition methods is the interfacing of domains that localize some physical behavior of the solution. This typically results in *heterogeneous* domain decomposition, where different mathematical models are used in different domains to reflect the dominant physics in each of these domains. Together with L. Perkins (MIT) a workshop was organized on this topic. The outcome of the workshop was to identify the techniques currently available, and to highlight some of the important unsolved problems. An example of heterogeneous domain decomposition is the coupling of viscous and inviscid models from gas dynamics. We have demonstrated a computational approach to this problem in one dimension, but need to derive a rigorous mathematical explanation for the observed (good) behavior of the interface treatment. Extensions to multiple dimensions are also being examined.

Jeffrey Scroggs and Marc Garbey

Domain decomposition methods that are the result of the symbiosis of asymptotics and numerical analysis generate methods that are both accurate and computationally efficient. We have demonstrated asymptotic-induced methods for the numerical solution of hyperbolic conservation laws with or without viscosity. The methods consist of multiple stages. The first stage is to obtain a first approximation using a first-order method, such as the Godunov scheme. Subsequent stages of the method involve solving internal-layer problems identified using techniques derived via asymptotics. Finally a residual correction increases the accuracy of the scheme. The method is derived and justified via singular perturbation techniques, and is an example of the effective use of asymptotics for incorporating more of the physics into numerical methods. The method was demonstrated on the 1-D isentropic gas dynamic equations, and we are currently extending the method to multiple dimensions.

Sharon O. Seddougui

The spatial inviscid instability problem for Görtler vortices in a compressible fluid is being investigated jointly with P. Hall. In addition to the fastest growing spatial mode for an incompressible fluid, we find an additional mode existing when the Mach number exceeds a critical value. For the fastest growing spatial mode, we are able to investigate the receptivity problem in the same way as for the incompressible case, and can show that O(1) coupling coefficients between a surface perturbation and the induced vortex field are possible.

The extension of the work by Cowley and Hall (ICASE Report No. 88–72) on the instability of hypersonic flow past a wedge to include the effects of nonlinearity is currently being tackled jointly with A. Bassom (University of Exeter). A weakly-nonlinear analysis is being used to determine whether the nonlinear effects are destabilizing or whether a stable nonzero equilibrium amplitude is possible.

The hypersonic limit has been obtained for the non-axisymmetric viscous lower branch modes in axisymmetric supersonic flows from the work of Duck and Hall (ICASE Report No. 88-42). This will be used to investigate the interaction between a shock layer and the boundary layer in the flow past a cylinder.

Chi-Wang Shu

We are investigating numerical solutions for mixed hyperbolic-elliptic type equations arising from applications such as fluid dynamics. A flux splitting is used to decompose the elliptic flux as a sum of two hyperbolic ones. A hyperbolic ENO technique is then used separately on each of them. Preliminary numerical tests indicate convergence with good resolution towards admissible weak solutions with phase jumps. We plan to address more details about the stability of such approaches. ENO computations for two and three dimensional Euler/Navier-Stokes equations are also continuing.

Ralph C. Smith

We are continuing work on the application of fully Sinc-Galerkin methods to parameter recovery problems which arise in the modeling of flexible structures. In particular, fourth-order time-dependent problems with fixed and cantilever boundary conditions and unknown stiffness and damping parameters are being considered.

The techniques being developed center around the Sinc-Galerkin method as applied to the forward problems which arise when an output error criterion is used to formulate the parameter recovery problems as corresponding minimization problems. The forward fully Sinc-Galerkin method has an exponential convergence rate and provides an approximate solution which is valid on the infinite time interval rather than only on a truncated time domain. Hence the method avoids the time-stepping which is characteristic of many of the forward schemes which are employed in parameter recovery algorithms. This can be important since many of the problems which arise in the modeling of flexible structures lead to systems of ordinary differential equations which are moderately stiff. When discretized via the fully Galerkin method, these problems often lead to poorly conditioned coefficient matrices and one facet of current research is aimed at developing efficient algorithms for solving the resulting linear systems.

Yiorgos S. Smyrlis and Demetrius T. Papageorgiou

We have conducted extensive numerical experiments of the spatially periodic initial value problem for the Kuramoto-Sivashinsky equation.

$$u_t + uu_x + u_{xx} + \nu u_{xxxx} = 0\,,\; u_0(x+2\pi) = u_0(x).$$

Our concern is with the description of the dynamics which govern the nonlinear evolution as the dissipation parameter decreases and spatio-temporal chaos sets in. To this end the initial condition is taken to be the same for all numerical experiments (a single sine wave is used) and the large time evolution of the system is followed numerically. Numerous computations were performed to establish the existence of windows, in parameter space, in which the solution has the following characteristics as the viscosity is decreased: A steady fully modal attractor to a steady bimodal attractor to another steady fully modal attractor to a steady trimodal attractor to a periodic (in time) attractor, to another steady fully modal attractor, to another time-periodic attractor, to a steady tetramodal attractor, to another time-periodic attractor having a full sequence of period-doublings (in the parameter space) to chaos. Numerous solutions are presented which provide conclusive evidence of the period-doubling cascades which precede chaos for this infinite-dimensional dynamical system. At least seven period-doublings have been observed so far allowing us to define eight subwindows. These results permit a computation of the lengths of subwindows which in turn provide a rough estimate for their successive ratios as the cascade develops. This ratio is found to be between 4 and 5 which provides preliminary evidence of a new appearance of the Feigenbaum number which in this case is for an infinite dimensional dynamical system. Some preliminary work shows several other windows following the first chaotic one including periodic, chaotic and steady octamodal window; however the windows shrink significantly in size to enable complete quantitative conclusions to be made.

Alex Solomonoff

Research is directed at trying to accurately reconstruct functions with discontinuities using their first few fourier modes. If one simply sums the first few terms of the fourier series, the accuracy of this approximation is very poor. An alternative method involves convolving the fourier sum function with a kernel whose support does not include the discontinuity. This method has several free parameters. Presently the parameter space is being explored in order to understand how the choice of parameters affects the performance.

The purpose of this research is to allow the efficient use of spectral methods in solving hyperbolic partial differential equations, such as the equations of gas dynamics. The solutions of such PDE's usually have discontinuities in them, which makes the performance of conventional spectral methods very poor.

Charles G. Speziale

Research on the development of improved second-order closure models of turbulence for high-speed compressible flows has continued. One of the difficulties encountered in the integration of such complex turbulence models to a solid boundary involves the stiffness that arises from the modeled dissipation rate transport equation. A new method for the integration of this equation to a solid boundary – based on a change of variables to the turbulent time scale – has been developed in collaboration with R. Abid (Vigyan Research Associates, Inc.) and E. C. Anderson (Fluid Mechanics Division, LaRC). This new approach, which allows for the implementation of a no-slip Dirichlet boundary condition, yields more accurate and computationally robust solutions. A more simple, improved two-equation turbulence model was also developed based on this approach. In so far as the dissipation rate is concerned, the role of vortex stretching – which is neglected in most of the commonly used turbulence models for this term – has been examined recently in collaboration with P. Bernard (University of Maryland). It was found that when vortex stretching is accounted for, a production-equals-dissipation equilibrium, with bounded turbulent kinetic energy, is predicted in homogeneous shear flow. The commonly used models that neglect vortex stretching yield solutions for the turbulent kinetic energy that grow unbounded with time. This new model could be more computationally robust in stagnation point flows where these kind of singularities cause a major problem.

A large-eddy simulation (LES) of compressible isotropic turbulence was recently completed in collaboration with G. Erlebacher, M. Y. Hussaini and T. A. Zang (Fluid Mechanics Division, LaRC). The results obtained are extremely encouraging. It was rather surprising how well the course grid LES was able to reproduce the dilatational statistics of the flow (approximately 25% of the turbulent kinetic energy was compressible in the case considered). Future applications to homogeneous shear flows are envisioned.

J. Trevor Stuart

Two problems, both connected with transition to turbulence in shear flows and boundary layers were pursued. Transitional and turbulent boundary layers usually contain longitudinal vortex structures, with a component of vorticity aligned in the direction of the basic flow. Highly sheared regions can develop locally in the transitional case, while eruptions can occur in the turbulent situation. These occurrences may be related to the development of singularities in flow fields. Effort has been directed at this idea for inviscid (Euler) fields, initially for the incompressible case. The work has been extended to the case of a compressible fluid, and we have found the effects of compressibility to be very significant. The Lagrangian approach to these problems has been shown to be very effective.

In a number of areas of science, aeronautics and engineering there is considerable interest in studies of instabilities, and of eventual transition to turbulence, in shear flows and boundary layers whose properties vary slowly in time and in one or more spatial coordinates. Based on a classical eigenvalue problem with its eigenrelation, the notion that the eigenrelation becomes a partial differential equation of the first order when the wave number and frequency are replaced by slow space and time derivatives of a plate function have been used. Earlier work was based on the Orr-Sommerfeld eigenrelation for plane Poiseuille flow, especially in relation to squeeze films in lubrication. Extensions have been made in two ways: (i) a use of triple-deck analysis does show the possibility of making further analytical and computational progress; (ii) a study has been made of unsteady flow near a stagnation point in a boundary layer, again with triple-deck analysis, and an interesting set of possibilities emerges for types of unsteadiness which are amenable to this type of analysis.

Shlomo Ta'asan

The development of efficient multigrid solvers for constraint optimization problems governed by partial differential equations has continued with research in two directions. The first, which is well developed by now, deals with problems in which the parameter space on which optimization is done is of finite dimension in the differential formulation of the problem. The methods use relaxation for the parameter space in a multilevel way. Parameters that have a non-smooth effect on the solution are relaxed on fine levels while those of smooth effect are solved for on coarse grids only. Proper transfers between the grids are used to ensure convergence of the parameters to their fine grid values. The methods use adjoint variables to define a descent direction for the minimization problem. The other direction focuses on problems in which the optimization is over an infinite dimensional parameter space (in the differential level). Also here the same type of ideas for the treatment of the different scales in the problems are being used. Experiments with some model problems involving elliptic partial differential equations as the constraint equations have been performed showing that the full optimization problem can be solved with a computational cost which is only a few times more than that of solving the PDE alone.

The above ideas are being considered in the context of aerodynamics design problems where airfoils are to be calculated so as to meet certain design requirements, for example, to give pressure distribution in some flow conditions which are closest to a given pressure distribution. The present model for the flow is the transonic small disturbance equation in which an airfoil is modelled by the small disturbance boundary condition. The shape of the airfoil in these calculations is being expressed in terms of a finite number of given shape functions with amplitudes to be found by the design process. Preliminary test with subsonic design problems shows that such problems can be solved in a computational cost which is just a few time (2-3) that of the flow solver. This work is jointly done with M. D. Salas (Fluid Dynamics Division) and G. Kuruvila (Vigyan, Inc.).

New multigrid solvers for inviscid flow problems are being developed in which the convergence rates are independent of the Mach number. These solvers employ relaxation methods of the Gauss-Seidel type with a proper modification to handle systems of partial differential equations. Preliminary experiments with a 2x2 system modeling inviscid isentropic and isenthalpic flow (equivalent to the full potential equation) have been considered first. Experiments with subsonic flows show, as predicted by the theory for the relaxation involved, that the problem can be solved as efficient as the Poisson equation on the same grid even for extremely small Mach numbers. The scheme involved used a staggered grid discretization. Research continues in extending the ideas to transonic flows where discretization schemes which are genuinely multidimensional are being used.

Another area of research is the development of new computational techniques in elastic-plastic problems. Here a set of non-linear equations which involve also weak dependence of the history of the loading are to be calculated. A new numerical scheme for the integration of the plastic forces has been constructed. Using this scheme an efficient multigrid solver has been developed. It uses appropriate fine to coarse grid transfer of the yield functions so as to enable the solution of the large scale behavior of the plastic forces to be done on the coarsest levels, yielding the accuracy of the fine grid solution. The method is under study with some real elastic-plastic problems related to the understanding of fatigue failure in metals.

Eitan Tadmor

We study various kinetic models of nonlinear conservation laws, with particular emphasize on gasdynamics equations. Together with Perthame (Université d'Orléans) [ICASE Report No. 90-11] we constructed a nonlinear kinetic model equation whose moments are well adapted to describe general scalar conservation laws in several space dimensions. Using recent results on 'averaging compactness' we quantify the notion of 'nonlinearity' for such equations and prove their Besov regularity. Currently we are working with Perthame on the extensions of these results to the isentropic gasdynamics equations. Together with Schochet (Tel-Aviv University) we are studying a regularized Chapman-Enskog expansion for scalar conservation laws. We show that this model retains the essential properties of the usual viscosity approximations and at the same time it sharpens the standard viscous shock layers.

Together with Gottlieb [ICASE Report No. 90-42], the stability of Runge-Kutta and multi-step methods for spectral approximations for scalar hyperbolic equations was studied and we proved that these fully-discrete spectral approximations are stable under the appropriate CFL condition which is widely used in practice.

We continue our work on the development of Spectral Viscosity approximations to nonlinear conservation laws [ICASE Report No. 87-54]. In the one-dimensional periodic case we prove the essentially non-oscillatory behavior of these approximations (TV estimates, one-sided Lipschitz continuity etc.). We extended the convergence results to the scalar multidimensional case. Numerical experiments reported in ICASE Report No. 89-67 show that one can recover the exact entropy solution within spectral accuracy by post-processing the Spectral Viscosity approximation. Together with Maday (Massachusetts Institute of Technology) we treat the non-periodic case. Numerical experiments with the Spectral Viscosity Legendre method applied to standard shock tube problems are found to be comparable with the standard high resolution finite-difference approximations.

Together with Nessyahu (Tel-Aviv University) we are studying the convergence rate of various approximate solutions to scalar conservation laws. Following the local error estimates presented in ICASE Report No. 89-80 we obtained sharp error estimate to E-schemes, Glimm's scheme, the regularized Chapman-Enskog expansion approximation and certain Spectral Viscosity approximations.

Hillel Tal-Ezer

A standard spectral method for solving boundary value problems is based on polynomial expansion of the solution. It is well known that for analytic functions the error goes to zero exponentially fast. Nevertheless, we claim that in general, polynomial approximation of an analytic function is an inefficient numerical tool. The "bizarre" distribution of the interpolating points related to Chebyshev polynomials is one way in which the inefficiency reveals itself. Thus, on top of the fact that one has to use π points per wavelength (instead of two as demanded by Nyquist criteria) we end up with a very stringent stability condition. In the present research we develop a spectral method based on expanding the solution in a space of non-polynomial functions. This approach results in a more efficient spatial approximation and eliminates the severe stability condition.

Saleh Tanveer

Over the last six months, progress has been made in the theoretical modeling of crystal growth in a cylindrical Bridgman apparatus where a binary melt solidifies as it is translated through a temperature gradient. All previous analytical models neglect convection altogether. However, because of the horizontal thermal gradient in a Bridgman apparatus, there is a forced convection for any Rayleigh number and therefore the purely diffusive models are unrealistic. There exists numerical work modeling the convection process; however given the large number of parameters (around 15), it is difficult to have a clear idea of the role of each control parameter. Our effort has been focussed on the analytical understanding of the convection effects on the segregation of solute concentration in the crystal as well as the shape of the free boundary.

To make the problem tractable analytically, we assumed that the heat transfer is mainly through the ends of the cylindrical ampule rather than the sides. This allows us to linearize the Navier Stokes equation. Further, along the sides of the cylinder, we replaced the no slip boundary condition by the less realistic no tangential stress condition. This should not make much difference when viscosity is small enough. But in our problem, this is not very realistic since viscosity effects are not small. Regardless, we hope that this change of boundary condition will only effect the flow near the walls and will not make a significant change away from the walls. Once again, this assumption was necessary in our analytic method. Then using the Boussinesq equations, we are able to reduce the crystal growth problem with convection and free boundary problem to a set of uncoupled eighth order linear ordinary differential equations with four boundary conditions on each end of a known domain.

Asymptotic solution of these solutions have been obtained in the limit when the diffusion length scale is much smaller than the dimension of the ampule and when the thermal and solutal Rayleigh numbers are of order unity as will be true in a microgravity environment. Calculations for large ranges of Rayleigh numbers is being investigated. An ICASE report is in preparation.

Siva Thangam

The analysis and simulation of separated flow past a rearward - facing step is considered both from the computational and the experimental stand point. This work is a collaborative effort involving C. G. Speziale, M. Y. Hussaini , S. O. Kjelgaard (Fluid Mechanics Division, LaRC), among others. Computations for the viscous incompressible flow past rearward - facing steps with 1:2 and 1:3 step to channel height ratios have been completed using both the standard and the nonlinear $k-\epsilon$ models for different representations of the wall boundary conditions. The flow parameters were selected to match those used in the experiments and the results indicate that the nonlinear $k-\epsilon$ model is capable of accurately predicting the primary flow features including the size of the separated flow region and the mean velocity profiles. During the next phase the computational code will be extended to include the full Reynolds stress closure. This would involve the simultaneous solution of the equations for the conservation of mass, the transport equations for momentum, turbulence dissipation, and all the components of the turbulence stresses. The results will be compared with the experimental data to be generated by the Experimental Methods Branch using their new and upgraded facility for a range of flow conditions. Future investigations would also include large-eddy simulation and the effect of compressibility.

Lu Ting

In close collaboration with Lucio Maestrello (Fluid Mechanics Division, LaRC), we study boundary layer control by local transcient surface heating. We study the experimental data on the effectiveness of local surface heating (placed in the concave portion of the surface) on the changes of Görtler vortices and on relaminarization. We then formulate theoretical models to simulate the experimental flow condition in order to gain insights to the effectiveness of surface heating.

We study the coupling of the acoustic incidence wave, the boundary layer instability and flexible panel oscillation. In particular, we are trying to derive an on surface condition, that is, to derive an equation for the oscillation of the panel taking into account the damping effect of the flow field and the incident wave.

Eli Turkel

Work was finished on the construction of a central difference TVD scheme. This scheme has the advantage of being very similar to the standard central difference scheme with just a change in the switches near shocks. The connection with upwind schemes and the theory of matrix dissipations was also developed. Numerous two dimensional examples were tried for both inviscid and viscous flow. An ICASE report was completed together with R. C. Swanson (Fluid Mechanics Division, LaRC).

Work continued on the use of a matrix viscosity for the three-dimensional viscous code. An AIAA paper was delivered, together with V. Vatsa (Fluid Mechanics Division, LaRC), at the Seattle Applied Aeronautics conference, and a revision is being prepared for an ICASE report.

Multigrid has been used to accelerate hyperbolic equations to a steady state. Together with Naomi Decker an analysis of some of the important features of multigrid was completed. The results of the analysis and several inviscid hypersonic test cases were presented at the Third International Conference on Hyperbolic Problems. An ICASE report on the results has been completed.

Work was begun on extensions of the central difference scheme and multigrid to hypersonic problems. The standard method does not converge due to the presence of strong shocks. By revising the switch near shocks and using residual smoothing on the way to finer meshes, solutions with good convergence rates were obtained for Mach 10 and Mach 20 turbulent flows about a NACA 0012 airfoil and for Mach 6 three dimensional turbulent flows about a bicone.

Bram van Leer

Preconditioning of 2-D Euler residuals by a local matrix in order to remove the stiffness due to the differences in the wave speeds implied in the Euler equations is being investigated. A matrix was recently derived that lowers the local condition number to one for supersonic and almost incompressible flow, and to $(1 - M^2)^{-\frac{1}{2}}$ when approaching the sonic limit from below. Preliminary numerical tests, carried out by C.-H. Tai, indicate that the matrix has the desired effect. Analysis of the matrix and its properties concentrated on the question of why this matrix is not a straightforward extension of the preconditioning matrix traditionally used for the 1-D Euler equations. It turns out there is a one-parameter family of 1-D preconditioning matrices, of which only one extends to the 2-D case with the condition number reduced as much as indicated above.

The multi-dimensional Riemann solver developed with C. Rumsey (Fluid Mechanics Division, LaRC) and P. L. Roe was analyzed with regard to monotonicity. The monotonicity constraint used for scalar linear equations is one of positivity of coefficients; this translates into positivity of eigenvalues of matrix blocks resulting from linearizing the multi-dimensional Euler difference equations. This constraint was used as a tool in developing a multi-dimensional wave model that would minimize the appearance of numerical oscillations. The analysis shows that there are cases in which any wave model including other than grid-aligned waves causes a loss of positivity of the scheme.

John Van Rosendale

Spectral methods require frequent global communication, raising a fundamental barrier to their use on parallel architectures. Global communication is needed in both the spectral derivative computation, and in the implicit solves. One can do the solves in several different ways, but one of the best alternatives is to use finite element preconditioning, as pioneered by Deville and Mund. The preconditioning finite element system can in turn be solved by a multigrid algorithm. A well tuned multigrid algorithm adequately solves the preconditioning finite element system in one V-cycle.

To explore the issue of communication in spectral methods, we implemented a three dimensional implicit spectral code for the variable coefficient Helmholtz equation on an Intel hypercube. This equation arises frequently in acoustics and in the Ozawa formulation of the incompressible Navier Stokes equation. Our Fourier Spectral code, based on a V-cycle point-relaxation multigrid algorithm achieves utilization of 50% on a 32 node i860 hypercube, for a $32 \times 32 \times 32$ grid; finer grids yield higher utilizations.

Chebyshev spectral grids are more problematic, since plane-relaxation based multigrid is required. Algorithms like the semicoarsening "ZOOM" algorithm of Decker and Van

Rosendale work very well in this case, but do not parallelize easily. One alternative is to combine a semicoarsening plane relaxation multigrid algorithm, like ZOOM, with the use of concurrent relaxation between planes. While this approach reduces interprocessor communication and yields perfect load balance, it may solve the preconditioning finite element more accurately than is needed in the implicit solves. Exploration of this approach is currently underway.

This research is being done in collaboration with A. Overman of the Analysis and Computations Division.

Jan-Jan Wu

We are developing techniques which allow distributed memory machines to be programmed by using globally defined data structures. We have implemented primitives to support various run-time operations required by programs that make use of an embedded shared variable space on a distributed machine. Directly incorporating the primitives into programs by the users allows flexibility in various optimizations but requires user's getting involved in the lower level operations. Therefore, we developed the ARF language as an interface between the application programs and the run-time support primitives.

An ARF user specifies a mapping into distributed memory for each globally defined array in the declaration phase and describes the iterative computations with global iteration subscripts. The ARF compiler transforms an ARF program to a target program which has incorporated the primitives needed to carry out the distributed computation efficiently. The output of the transformations are composed of two segments of code, one as inspector, the other executor. The inspector schedules the communication needed to prefetch all the non-local data and the communication needed to scatter non-local results to the owning processor before the computation starts. The executor carries out the communication scheduled by the inspector and performs computation of the iteration part. In addition to generating the inspector and executor, the compiler also performs optimization on reducing preprocessing cost and the communication cost in the iterative portion of the code.

REPORTS AND ABSTRACTS

Don, Wai-Sun and David Gottlieb: *Spectral simulation of unsteady compressible flow past a circular cylinder.* ICASE Report No. 90-29, April 9, 1990, 25 pages. To appear in the Proceedings of the ICOSAHOM 1989.

An unsteady compressible viscous wake flow past a circular cylinder has been successfully simulated using spectral methods. A new approach in using the Chebyshev collocation method for periodic problems is introduced. We have further proved that the eigenvalues associated with the differentiation matrix are purely imaginary, reflecting the periodicity of the problem. It had been shown that the solution of a model problem has exponential growth in time if "improper" boundary conditions are used. A characteristic boundary condition, which is based on the characteristics of the Euler equations of gas dynamics, has been derived for the spectral code. The primary vortex shedding frequency computed agrees well with the results in the literature for Mach $= 0.4$, $\Re = 80$. No secondary frequency is observed in the power spectrum analysis of the pressure data.

Mavriplis, Dimitri J.: *Algebraic turbulence modeling for unstructured and adaptive meshes.* ICASE Report No. 90-30, May 3, 1990, 30 pages. Submitted to AIAA Journal.

An algebraic turbulence model based on the Baldwin-Lomax model, has been implemented for use on unstructured grids. The implementation is based on the use of local background structured turbulence meshes. At each time-step, flow variables are interpolated from the unstructured mesh onto the background structured meshes, the turbulence model is executed on these meshes, and the resulting eddy viscosity values are interpolated back to the unstructured mesh. Modifications to the algebraic model were required to enable the treatment of more complicated flows, such as confluent boundary layers and wakes. The model is used in conjunction with an efficient unstructured multigrid finite-element Navier-Stokes solver in order to compute compressible turbulent flows on fully unstructured meshes. Solutions about single and multiple element airfoils are obtained and compared with experimental data.

Denier, James P., Philip Hall, and Sharon Seddougui: *On the receptivity problem for Görtler vortices: Vortex motions induced by wall roughness.* ICASE Report No. 90-31, May 8, 1990, 59 pages. Submitted to Proceedings Royal Society.

The receptivity problem for Görtler vortices induced by wall roughness is investigated. The roughness is modelled by small amplitude perturbations to the curved wall over which the flow takes place. The amplitude of these perturbations is taken to be sufficiently small for the induced Görtler vortices to be described by linear theory. The roughness is assumed to vary in the spanwise direction on the boundary layer lengthscale, whilst in the flow direction the corresponding variation is on the lengthscale over which the wall curvature varies. In fact the latter condition can be relaxed to allow for a faster streamwise roughness variation so long as the variation does not become as fast as that in the spanwise direction. The function which describes the roughness is assumed to be such that its spanwise and streamwise dependences can be separated; this enables us to make progress by taking Fourier or Laplace transforms where appropriate. The cases of isolated and distributed roughness elements are investigated and the coupling coefficient which relates the amplitude of the forcing and the induced vortex amplitude is found asymptotically in the small wavelength limit. It is shown that this coefficient is exponentially small in the latter limit so that it is unlikely that this mode can be stimulated directly by wall roughness. The situation at 0(1) wavelengths is quite different and this is investigated numerically for different forcing functions. It is found that an isolated roughness element induces a vortex field which grows within a wedge at a finite distance downstream of the element. However, immediately downstream of the obstacle the disturbed flow produced by the element decays in amplitude. The receptivity problem at larger Görtler numbers appropriate to relatively large wall curvature is discussed in detail. It is found that the fastest growing linear mode of the Görtler instability equations has wavenumber proportional to the one fifth power of the Görtler number. The mode can be related to both inviscid disturbances and the disturbances appropriate to the right hand branch of neutral curve for Görtler vortices. The coupling co-efficient between this, the fastest growing vortex, and the forcing function is found in closed form.

Bassom, Andrew P. and Philip Hall: *Concerning the interaction of non-stationary cross-flow vortices in a three-dimensional boundary layer.* ICASE Report No. 90-32, May 8, 1990, 36 pages. To appear in Quart. Appl. Math.

Recently there has been much work devoted to considering some of the many and varied interaction mechanisms which may be operative in three-dimensional boundary layer flows. Here we are concerned with resonant triads of crossflow vortices. In contrast to much of the previous work we examine the effects of interactions upon resonant triads where each member of the triad has the property of being linearly neutrally stable; then the importance of the interplay between modes can be relatively easily assessed. We concentrate on investigating modes within the boundary layer flow above a rotating disc; this choice is motivated by the similarity between this disc flow and many important practical flows and, secondly, our selected flow is an exact solution of the Navier-Stokes equations which makes its theoretical analysis especially attractive. Firstly we demonstrate that the desired triads of linearly neutrally stable modes can exist within the chosen boundary layer flow and then subsequently obtain evolution equations to describe the development of the amplitudes of these modes once the interaction mechanism is accounted for. It is found that the coefficients of the interaction terms within the evolution equations are, in general, given by quite intricate expressions although some elementary numerical work shows that the evaluation of these coefficients is practicable. The basis of our work lends itself to generalization to more complicated boundary layers and effects of detuning or non-parallelism could be provided for within the asymptotic framework.

Mirchandaney, Seema, Joel Saltz, Piyush Mehrotra, and Harry Berryman: *A scheme for supporting automatic data migration on multicomputers.* ICASE Report No. 90-33, May 8, 1990, 18 pages. To appear in Proceedings of the Fifth Distributed Memory Computing Conference, Charleston, South Carolina, April 1990.

We propose a data migration mechanism that allows an explicit and controlled mapping of data to memory. While read or write copies of each data element can be assigned to any processor's memory, longer term storage of each data element is assigned to a specific location in the memory of a particular processor. We present data that suggests that the scheme may be a practical method for efficiently supporting data migration.

Saltz, Joel H., Ravi Mirchandaney, and Kay Crowley: *Run-time parallelization and scheduling of loops.* ICASE Report No. 90-34, May 9, 1990, 24 pages. Revised version of 88-70, submitted to Transactions on Computers; Excerpts in Proc. of the Third Int. Conf. on Supercomputing, Crete, Greece, June 1989, and in Proc. of the First Int. Symposium on Parallel Algorithms and Architectures, Santa Fe, New Mexico.

In this paper, we study run-time methods to automatically parallelize and schedule iterations of a do loop in certain cases, where compile-time information is inadequate. The methods we present in this paper involve execution time preprocessing of the loop. At compile-time, these methods set up the framework for performing a loop dependency analysis. At run-time, wavefronts of concurrently executable loop iterations are identified. Using this wavefront information, loop iterations are reordered for increased parallelism.

We utilize symbolic transformation rules to produce: (1) *inspector* procedures that perform execution time preprocessing and (2) *executors* or transformed versions of source code loop structures. These transformed loop structures carry out the calculations planned in the *inspector* procedures. We present performance results from experiments conducted on the Encore Multimax. These results illustrate that run-time reordering of loop indices can have a significant impact on performance. Furthermore, the overheads associated with this type of reordering are amortized when the loop is executed several times with the same dependency structure.

Deville, Michel O. and Ernest H. Mund: *Fourier analysis of finite element preconditioned collocation schemes.* ICASE Report No. 90-35, May 9, 1990, 24 pages. Submitted to SIAM J. Sci. Statist. Comput.

This paper investigates the spectrum of the iteration operator of some finite element preconditioned Fourier collocation schemes. The first part of the paper analyses one-dimensional elliptic and hyperbolic model problems and the advection-diffusion equation. Analytical expressions of the eigenvalues are obtained with use of symbolic computation. The second part of the paper considers the set of one-dimensional differential equations resulting from Fourier analysis (in the transverse direction) of the 2-D Stokes problem. All results agree with previous conclusions on the numerical efficiency of finite element preconditioning schemes.

Banks, H. T. and D. A. Rebnord: *Analytic semigroups: Applications to inverse problems for flexible structures.* ICASE Report No. 90-36, May 15, 1990, 17 pages. To appear in Proc. Intl. Conf. on Differential Equations & Applications, Lecture Notes in Pure and Appl. Math., Marcel Dekker, Inc., 1990.

We present new convergence and stability results for least squares inverse problems involving systems described by analytic semigroups. The practical importance of these results is demonstrated by application to several examples from problems of estimation of material parameters in flexible structures using accelerometer data.

Berger, M. J. and R. J. LeVeque: *Stable boundary conditions for Cartesian grid calculations.* ICASE Report No. 90-37, May 18, 1990, 16 pages. To appear in Symposium on Computational Technology for Flight Vehicles, edited by Ahmed Noor, 1990.

We solve the inviscid Euler equations in complicated geometries using a Cartesian grid. This requires solid wall boundary conditions in the irregular grid cells near the boundary. Since these cells may be orders of magnitude smaller than the regular grid cells, stability is a primary concern. We present a new approach to this problem and illustrate its use.

Bokhari, Shahid H.: *A network flow model for load balancing in circuit-switched multicomputers.* ICASE Report No. 90-38, May 18, 1990, 31 pages. Submitted to IEEE Trans. Parallel Distributed Systems.

In multicomputers that utilize circuit switching or wormhole routing, communication overhead depends largely on link contention–the variation due to distance between nodes is negligible. This has a major impact on the load balancing problem. In this case there are some nodes with excess load (sources) and others with deficit load (sinks) and it is required to find a matching of sources to sinks that avoids contention. The problem is made complex by the hardwired routing on currently available machines: the user can control only which nodes communicate but not how the messages are routed.

Network flow models of message flow in the mesh and the hypercube have been developed to solve this problem. The crucial property of these models is the correspondence between minimum cost flows and correctly routed messages. To solve a given load balancing problem, a minimum cost flow algorithm is applied to the network. This permits us to determine efficiently a maximum contention free matching of sources to sinks which, in turn, tells us how much of the given imbalance can be eliminated without contention.

Papageorgiou, D. T.: *The stability of two-dimensional shear-layers at high Mach numbers.* ICASE Report No. 90-39, May 24, 1990, 26 pages. Submitted to Phys. Fluids A.

This study is concerned with the stability properties of laminar free shear-layer flows, and in particular symmetric two-dimensional wakes, for the subsonic through the hypersonic regime. Emphasis is given to the use of proper wake profiles that satisfy the equations of motion at high Reynolds numbers. In particular we study the inviscid stability of a developing two-dimensional wake as it accelerates at the trailing edge of a splitter plate. The non-parallelism of the flow is a leading order effect, and the undisturbed state is solved numerically. The neutral stability characteristics are computed numerically and the hypersonic stability is obtained by increasing the Mach number. It is found that the neutral stability characteristics are altered significantly as the wake develops. Multiple modes (second modes) are found in the near-wake (they are shown to be closely related to the corresponding Blasius ones), but as the wake develops mode multiplicity is delayed to higher and higher Mach numbers. At a distance of about one plate length from the trailing edge, there is only one mode in a Mach number range of zero to twenty. The dominant mode emerging at all wake stations and for high enough Mach numbers is the so-called vorticity mode, which is centered around the generalized inflection point layer. The structure of the dominant mode is also obtained analytically for all streamwise wake locations and it is shown how the far-wake limit is approached. Asymptotic results for the hypersonic mixing layer given by a tanh and a Lock distribution are also given.

Blackaby, Nicholas, Stephen Cowley, and Philip Hall: *On the instability of hypersonic flow past a flat plate*. ICASE Report No. 90-40, May 30, 1990, 52 pages. Submitted to J. Fluid Mech.

The instability of hypersonic boundary-layer flows over flat plates is considered. The viscosity of the fluid is taken to be governed by Sutherland's law, which gives a much more accurate representation of the temperature dependence of fluid viscosity at hypersonic speeds than Chapman's approximate linear law; although at lower speeds the temperature variation of the mean state is less pronounced so that the Chapman law can be used with some confidence. Attention is focussed on the so-called "vorticity" mode of instability of the viscous hypersonic boundary layer. This is thought to be the fastest growing *inviscid* disturbance at hypersonic speeds; it is also believed to have an asymptotically larger growth rate than any viscous or centrifugal instability. As a starting point we investigate the instability of the hypersonic boundary layer which exists far downstream from the leading edge of the plate. In this regime the shock that is attached to the leading edge of the plate plays no role, so that the basic boundary layer is non-interactive. It is shown that the vorticity mode of instability of this flow operates on a significantly different lengthscale than that obtained if a Chapman viscosity law is assumed (see Smith and Brown, 1989). In particular, we find that the growth rate predicted by a linear viscosity law overestimates the size of the growth rate by $O(M^2)$. Next, the development of the vorticity mode as the wavenumber decreases is described, and it is shown that acoustic modes emerge when the wavenumber has decreased from it's $O(1)$ initial value to $O(M^{-\frac{3}{2}})$. Finally, the inviscid instability of the boundary layer near the leading edge in the interaction zone is discussed and particular attention is focussed on the strong interaction region which occurs sufficiently close to the leading edge. We find that the vorticity mode in this regime is again unstable, and that it is concentrated in the transition layer at the edge of the boundary layer where the temperature adjusts from its large, $O(M^2)$, value in the viscous boundary layer, to its $O(1)$ free stream value. The existence of the shock indirectly, but significantly, influences the instability problem by modifying the basic flow structure in this layer.

Berryman, Harry, Joel Saltz, and Jeffrey Scroggs: *Execution time support for adaptive scientific algorithms on distributed memory machines.* ICASE Report No. 90-41, May 31, 1990, 20 pages. Submitted to Concurrency, Practice, and Experience.

We consider optimizations that are required for efficient execution of code segments that consists of loops over distributed data structures. The PARTI execution time primitives are designed to carry out these optimizations and can be used to implement a wide range of scientific algorithms on distributed memory machines.

These primitives allow the user to control array mappings in a way that gives an appearance of shared memory. Computations can be based on a global index set. Primitives are used to carry out gather and scatter operations on distributed arrays. Communications patterns are derived at runtime, and the appropriate send and receive messages are automatically generated.

Gottlieb, David and Eitan Tadmor: *The CFL condition for spectral approximations to hyperbolic initial-boundary value problems.* ICASE Report No. 90-42, June 1, 1990, 27 pages. To appear in Math. Comp.

We study the stability of spectral approximations to scalar hyperbolic initial-boundary value problems with variable coefficients. Time is discretized by explicit multi-level or Runge-Kutta methods of order ≤ 3 (forward Euler time differencing is included), and we study spatial discretizations by spectral and pseudospectral approximations associated with the general family of Jacobi polynomials. We prove that these fully explicit spectral approximations are stable provided their time-step, Δt, is restricted by the CFL-like condition, $\Delta t <$ Const.N^{-2}, where N equals the spatial number of degrees of freedom. We give two independent proofs of this result, depending on two different choices of appropriate L^2-weighted norms. In both approaches, the proofs hinge on a certain inverse inequality interesting for its own sake. Our result confirms the commonly held belief that the above CFL stability restriction, which is extensively used in practical implementations, guarantees the stability (and hence the convergence) of fully-explicit spectral approximations in the non-periodic case.

Burns, J. A., Z. Y. Liu, and R. E. Miller: *Approximation of thermoelastic and viscoelastic control systems.* ICASE Report No. 90-43, June 1, 1990, 68 pages. Submitted to J. Numer. Functional Anal. Optim.

This paper deals with the development and analysis of well-posed models and computational algorithms for control of a class of partial differential equations that describe the motions of thermo-viscoelastic structures. We first present an abstract "state space" framework and a general well-posedness result that can be applied to a large class of thermo-elastic and thermo-viscoelastic models. This state space framework is used in the development of a computational scheme to be used in the solution of an LQR control problem. A detailed convergence proof is provided for the viscoelastic model and several numerical results are presented to illustrate the theory and to analyze problems for which the theory is incomplete.

Swanson, R. C. and Eli Turkel: *On central-difference and upwind schemes.* ICASE Report No. 90-44, June 15, 1990, 42 pages. To be submitted to J. Comput. Phys.

A class of numerical dissipation models for central-difference schemes constructed with second- and fourth-difference terms is considered. The notion of matrix dissipation associated with upwind schemes is used to establish improved shock capturing capability for these models. In addition, conditions are given that guarantee that such dissipation models produce a TVD scheme. Appropriate switches for this type of model to ensure satisfaction of the TVD property are presented. Significant improvements in the accuracy of a central-difference scheme are demonstrated by computing both inviscid and viscous transonic airfoil flows.

Burns, John A. and Sungkwon Kang: *A control problem for Burgers' equation with bounded input/output.* ICASE Report No. 90-45, June 13, 1990, 37 pages. Submitted to J. Nonlinear Dynamics.

A stabilization problem for Burgers' equation is considered. Using linearization, various controllers produce the desired degree of stability for the closed-loop nonlinear system. A numerical scheme for computing the feedback gain functional is developed and several numerical experiments are performed to show the theoretical results.

Speziale, Charles G., Ridha Abid, and E. Clay Anderson: *A critical evaluation of two-equation models for near wall turbulence.* ICASE Report No. 90-46, June 26, 1990, 28 pages. Submitted to AIAA J.

A variety of two-equation turbulence models – including several versions of the $K - \varepsilon$ model as well as the $K - \omega$ model – are analyzed critically for near wall turbulent flows from a theoretical and computational standpoint. It is shown that the $K - \varepsilon$ model has two major problems associated with it: the lack of natural boundary conditions for the dissipation rate and the appearance of higher-order correlations in the balance of terms for the dissipation rate at the wall. In so far as the former problem is concerned, either physically inconsistent boundary conditions have been used or the boundary conditions for the dissipation rate have been tied to higher-order derivatives of the turbulent kinetic energy which leads to numerical stiffness. The $K - \omega$ model can alleviate these problems since the asymptotic behavior of ω is known in more detail and since its near wall balance involves only exact viscous terms. However, the modeled form of the ω equation that is used in the literature is incomplete – an exact viscous term is missing which causes the model to behave in an asymptotically inconsistent manner. By including this viscous term – and by introducing new wall damping functions with improved asymptotic behavior – a new $K - \tau$ model (where $\tau \equiv 1/\omega$ is turbulent time scale) is developed. It is demonstrated that this new model is computationally robust and yields improved predictions for turbulent boundary layers.

Cowley, Stephen J. and Leon L. Van Dommelen: *On the use of Lagrangian variables in descriptions of unsteady boundary-layer separation.* ICASE Report No. 90-47, July 10, 1990, 67 pages. Submitted to Philos. Trans.

The Lagrangian description of unsteady boundary-layer separation is reviewed from both analytical and numerical perspectives. We explain in simple terms how particle distortion gives rise to unsteady separation, and why a theory centred on Lagrangian coordinates provides the clearest description of this phenomenon. Included in the review are some of the more recent results for unsteady three-dimensional compressible separation. The different forms of separation that can arise from symmetries are emphasized. Current work includes a possible description of separation when the detaching vorticity layer exits the classical boundary-layer region, but still remains much closer to the surface than a typical body-lengthscale.

Jones, Mark T. and Merrell L. Patrick: *The use of Lanczo's method to solve the large generalized symmetric eigenvalue problem in parallel.* ICASE Report No. 90-48, July 12, 1990, 28 pages.

The generalized eigenvalue problem, $K\chi = \lambda M\chi$, is of significant practical importance, especially in structural engineering where it arises as the vibration and buckling problems. New software, **LANZ**, based on Lanczo's method has been developed for solving these problems and runs on SUN 3, SUN 4, Convex C-220, Cray 2, and Cray Y-MP systems.

Preliminary results of using the Force to obtain a multiprocessor implementation of **LANZ** on MIMD parallel/vector systems are reported here. A parallel execution time model of **LANZ** is defined and used to predict the performance of **LANZ** as well as examine hypothetical modifications to **LANZ**. The results of using dynamic shifting to improve parallelism are presented. Finally, the results of assigning a group of processors to separate shifts and finding all the desired eigenvalues using **LANZ** in parallel are reported.

Iqbal, M. Ashraf and Shahid H. Bokhari: *Efficient algorithms for a class of partitioning problems.* ICASE Report No. 90-49, July 27, 1990, 26 pages. Submitted to IEEE Trans. Parallel Distributed Systems.

We address the problem of optimally partitioning the modules of chain- or tree-like tasks over chain-structured or host-satellite multiple computer systems. This important class of problems includes many signal processing and industrial control applications. Prior research has resulted in a succession of faster exact and approximate algorithms for these problems.

We describe polynomial exact and approximate algorithms for this class that are better than any of the previously reported algorithms. Our approach is based on a preprocessing step that condenses the given chain or tree structured task into a *monotonic* chain or tree. The partitioning of this monotonic task can then be carried out using fast search techniques.

Platt, N., L. Sirovich, and N. Fitzmaurice: *An investigation of chaotic Kolmogorov flows.* ICASE Report No. 90-50, August 10, 1990, 77 pages. Submitted to Phys. Fluids.

A two-dimensional flow governed by the incompressible Navier-Stokes equations with a steady spatially periodic forcing (known as the Kolmogorov flow) is numerically simulated. The behavior of the flow and its transition states as the Reynolds number *Re* varies is investigated in detail, as well as a number of the flow features. A sequence of bifurcations is shown to take place in the flow as *Re* varied. Two main regimes of the flow have been observed: small and large scale structure regimes corresponding to different ranges of *Re*. Each of the regimes includes a number of quasiperiodic, chaotic and relaminarization windows. In addition, each range contains a chaotic window with non-ergodic chaotic attractors. Spatially disordered, but temporally steady states have been discovered in large scale structure regime. Features of the diverse cases are displayed in terms of the temporal power spectrum, Poincare sections and, where possible, Lyapunov exponents and Kaplan-Yorke dimension.

Saylor, Paul E. and Robert D. Skeel: *Linear iterative solvers for implicit ODE methods.* ICASE Report No. 90-51, August 2, 1990, 21 pages. Proc. of the Copper Mountain Meeting on Iterative Methods, April 1990. Submitted to the SIAM J. Sci. Stat. Comput.

In this paper we consider the numerical solution of stiff initial value problems, which lead to the problem of solving large systems of mildly nonlinear equations. For many problems derived from engineering and science, a solution is possible only with methods derived from iterative linear equation solvers. A common approach to solving the nonlinear equations is to employ an approximate solution obtained from an explicit method. In this paper we shall examine the error to determine how it is distributed among the stiff and non-stiff components, which bears on the choice of an iterative method. Our conclusion is that error is (roughly) uniformly distributed, a fact that suggests the Chebyshev method (and the accompanying Manteuffel adaptive parameter algorithm). We describe this method, also commenting on Richardson's method and its advantages for large problems. We then apply Richardson's method and the Chebyshev method with the Manteuffel algorithm to the solution of the nonlinear equations by Newton's method.

Scroggs, Jeffrey S.: *Shock-layer bounds for a singularly perturbed equation.* ICASE Report No. 90-52, August 14, 1990, 12 pages. Submitted to SIAM J. Appl. Math.

The size of the shock-layer governed by a conservation law is studied. The conservation law is a parabolic reaction-convection-diffusion equation with a small parameter multiplying the diffusion term and convex flux. Rigorous upper and lower bounding functions for the solution of the conservation law are established based on maximum-principle arguments. The bounding functions demonstrate that the size of the shock-layer is proportional to the parameter multiplying the diffusion term.

Decker, Naomi H., Vijay K. Naik, and Michel Nicoules: *Parallelization of implicit finite difference schemes in computational fluid dynamics.* ICASE Report No. 90-53, August 16, 1990, 25 pages. Submitted to Proceedings of Copper Mountain Conference on Iterative Methods, 1990.

Implicit finite difference schemes are often the preferred numerical schemes in computational fluid dynamics, requiring less stringent stability bounds than the explicit schemes. Each iteration in an implicit scheme, however, involves global data dependencies in the form of second and higher order recurrences. Efficient parallel implementations of such iterative methods, therefore, are considerably more difficult and are used for solving the Euler and the thin layer Navier-Stokes equations and that require inversions of large linear systems in the form of block tri-diagonal and/or block penta-diagonal matrices. We focus our attention on three-dimensional cases and present schemes for alleviating the effects of the global data dependencies. An analysis of the communication and the computation aspects of these methods is presented. The effect of the boundary conditions on the parallel schemes is also discussed. The ARC-3D code, developed at NASA Ames, is used as an example application. Performance of the proposed methods is verified on the Victor multiprocessor system which is a message passing architecture developed at the IBM, T. J. Watson Research Center.

Decker, Naomi and Eli Turkel: *Multigrid for hypersonic inviscid flows.* ICASE Report No. 90-54, August 16, 1990, 18 pages. To appear in Proceedings of 3rd International Conference on Hyperbolic Problems, 1990.

We consider the use of multigrid methods to solve the Euler equations for hypersonic flow. We consider the steady state equations with a Runge-Kutta smoother based on the time accurate equations together with local time stepping and residual smoothing. We examine the effect of the Runge-Kutta coefficients on the convergence rate for hypersonic flow. Also of importance are the switch between the second and fourth difference viscosity. Solutions are given for flow around a bump in a channel and flow around a biconic section.

Shu, Chi-Wang: *Numerical experiments on the accuracy of ENO and modified ENO schemes.* ICASE Report No. 90-55, August 16, 1990, 25 pages. Submitted to J. Sci. Comput.

In this paper we make further numerical experiments assessing an accuracy degeneracy phenomena reported by A. Rogerson and E. Meiburg [7]. We also propose a modified ENO scheme, which recovers the correct order of accuracy for all the test problems with smooth initial conditions and gives comparable results with the original ENO schemes for discontinuous problems.

Shu, Chi-Wang: *Numerical methods for systems of conservation laws of mixed type using flux splitting.* ICASE Report No. 90-56, August 16, 1990, 17 pages. Submitted to J. Comput. Phys.

The essentially non-oscillatory (ENO) finite difference scheme is applied to systems of conservation laws $\mathbf{u}_t + \mathbf{f}(\mathbf{u})_x = 0$ of mixed hyperbolic-elliptic type. A flux splitting $\mathbf{f}(\mathbf{u}) = \mathbf{f}^+(\mathbf{u}) + \mathbf{f}^-(\mathbf{u})$, with the corresponding Jacobi matrices $\frac{\partial \mathbf{f}^\pm(\mathbf{u})}{\partial \mathbf{u}}$ having real and positive/negative eigenvalues, is used. The hyperbolic ENO operator is applied separately on $\mathbf{f}^+(\mathbf{u})_x$ and on $\mathbf{f}^-(\mathbf{u})_x$. The scheme is numerically tested on the van der Waals equation in fluid dynamics. We observe convergence with good resolution to weak solutions for various Riemann problems, which are then numerically checked to be admissible as the viscosity-capillarity limits. We also observe the interesting phenomena of the shrinking of elliptic regions if they are present in the initial conditions.

Geer, James F. and Carl M. Andersen: *A hybrid perturbation-Galerkin technique for partial differential equations.* ICASE Report No. 90-57, August 16, 1990, 29 pages. To appear in the Proceedings of the Workshop on Asymptotic Analysis and Numerical Solution of PDEs.

A two-step hybrid perturbation-Galerkin technique for improving the usefulness of perturbation solutions to partial differential equations which contain a parameter is presented and discussed. In the first step of the method, the leading terms in the asymptotic expansion(s) of the solution about one or more values of the perturbation parameter are obtained using standard perturbation methods. In the second step, the perturbation functions obtained in the first step are used as trial functions in a Bubnov-Galerkin approximation. This semi-analytical, semi-numerical hybrid technique appears to overcome some of the drawbacks of the perturbation and Galerkin methods when they are applied by themselves, while combining some of the good features of each. The technique is illustrated first by a simple example. It is then applied to the problem of determining the flow of a slightly compressible fluid past a circular cylinder and to the problem of determining the shape of a free surface due to a sink above the surface. Solutions obtained by the hybrid method are compared with other approximate solutions, and its possible application to certain problems associated with domain decomposition is discussed.

Ng, Lian and G. Erlebacher: *Secondary instabilities in compressible boundary layers.* ICASE Report No. 90-58, September 6, 1990, 52 pages. Submitted to Phys. Fluids.

This paper examines (linear) secondary instabilities in compressible boundary layers at Mach numbers $M_\infty = 0, 0.8, 1.6$ and 4.5. We find that there is a broad-band of highly unstable 3-d secondary disturbances whose growth rates increase with increasing primary wave amplitude. At $M_\infty \leq 1.6$, fundamental resonance dominates at relatively high (2-d) primary disturbance amplitude, while subharmonic resonance is characterized by a low (2-d) primary amplitude. At $M_\infty = 4.5$, the subharmonic instability which arises from the second mode disturbance is the strongest type of secondary instability.

The influence of the inclination, θ, of the primary wave with respect to the mean flow direction on secondary instability is investigated at $M_\infty = 1.6$ for small to moderate values of θ. It is found that the strongest fundamental instability occurs when the primary wave is inclined at 10° to the mean flow direction, although a 2-d primary mode yields the most amplified subharmonic. The subharmonic instability at a high value of θ (namely, $\theta = 45^\circ$) is also discussed.

Finally, a subset of the secondary instability results are compared against direct numerical simulations.

Saltz, Joel, Harry Berryman, and Janet Wu: *Multiprocessors and runtime compilation.* ICASE Report No. 90-59, September 21, 1990, 23 pages. Submitted to Concurrency, Practice, and Experience.

Runtime time preprocessing plays a major role in many efficient algorithms in computer science, as well as playing an important role in exploiting multiprocessor architectures. We give examples that elucidate the importance of run time preprocessing and show how these optimizations can be integrated into compilers. To support our arguments, we describe transformations implemented in prototype multiprocessor compilers and present benchmarks from the iPSC2/860, the CM-2, and the Encore Multimax/320.

Nicol, David, Subhendu Das, and Dan Palumbo: *Parallelized reliability estimation of reconfigurable computer networks.* ICASE Report No. 90-60, September 10, 1990, 24 pages. Submitted to IEEE Trans. Software Engrg.

This paper describes a parallelized system, ASSURE, for computing the reliability of embedded avionics flight control systems which are able to reconfigure themselves in the event of failure. ASSURE accepts a grammar that describes a reliability semi-Markov state-space. From this it creates a parallel program that simultaneously generates and analyzes the state-space, placing upper and lower bounds on the probability of system failure. ASSURE is implemented on a 32-node Intel iPSC/860, and has achieved high processor efficiencies on real problems. Through a combination of improved algorithms, exploitation of parallelism, and use of an advanced microprocessor architecture, ASSURE has reduced the execution time on substantial problems by a factor of one thousands over previous workstation implementations. Furthermore, ASSURE's parallel execution rate on the iPSC/860 is an order of magnitude faster than its serial execution rate on a Cray-2 supercomputer. While dynamic load balancing is necessary for ASSURE's good performance, it is needed only infrequently; the particular method of load balancing used does not substantially affect performance.

Mavriplis, Dimitri J.: *Turbulent flow calculations using unstructured and adaptive meshes.* ICASE Report No. 90-61, September 10, 1990, 32 pages. Submitted to J. Numer. Methods Fluids.

A method of efficiently computing turbulent compressible flow over complex two-dimensional configurations is presented. The method makes use of fully unstructured meshes throughout the entire flow-field, thus enabling the treatment of arbitrarily complex geometries and the use of adaptive meshing techniques throughout both viscous and inviscid regions of the flow-field. Mesh generation is based on a locally mapped Delaunay technique in order to generate unstructured meshes with highly-stretched elements in the viscous regions. The flow equations are discretized using a finite-element Navier-Stokes solver, and rapid convergence to steady-state is achieved using an unstructured multigrid algorithm. Turbulence modeling is performed using an inexpensive algebraic model, implemented for use on unstructured and adaptive meshes. Compressible turbulent flow solutions about multiple-element airfoil geometries are computed and compared with experimental data.

Bodonyi, R. J. and I. W. Duck: *Boundary-layer receptivity due to a wall suction and control of Tollmien-Schlichting waves.* ICASE Report No. 90-62, September 19, 1990, 33 pages. Submitted to Phys. Fluids.

A numerical study of the generation of Tollmien-Schlichting waves due to the interaction between a small free-stream disturbance and a small localized suction slot on an otherwise flat surface has been carried out using finite-difference methods. The nonlinear steady flow is of the viscous-inviscid interactive type while the unsteady disturbed flow is assumed to be governed by the Navier-Stokes equations linearized about this flow. Numerical solutions illustrate the growth or decay of the T-S waves generated by the interaction between the freestream disturbance and the suction slot, depending on the value of the scaled Strouhal number. An important result of this receptivity problem is the numerical determination of the amplitude of the Tollmien-Schlichting waves and the demonstration of the possible active control of the growth of Tollmien-Schlichting waves.

Nicol, David M.: *Inflated speedups in parallel simulations via malloc().* ICASE Report No. 90-63, September 28, 1990, 17 pages. Submitted to Internat. J. Simulation.

Discrete-event simulation programs make heavy use of dynamic memory allocation in order to support simulation's very dynamic space requirements. When programming in C one is likely to use the malloc() routine. However, a parallel simulation which uses the standard Unix System V malloc() implementation may achieve an overly optimistic speedup, possibly superlinear. An alternate implementation provided on some (but not all) systems can avoid the speedup anomaly, but at the price of significantly reduced available free space. This is especially severe on most parallel architectures, which tend not to support virtual memory. This paper illustrates the problem, then shows how a simply implemented user-constructed interface to malloc() can both avoid artificially inflated speedups, and make efficient use of the dynamic memory space. The interface simply caches blocks on the basis of their size. We demonstrate the problem empirically, and show the effectiveness of our solution both empirically and analytically.

Nicol, David: *Conservative parallel simulation of priority class queueing networks.* ICASE Report No. 90-64, September 28, 1990, 23 pages. Submitted to IEEE Trans. Parallel Distributed Systems.

This paper describes a conservative synchronization protocol for the parallel simulation of queueing networks having C job priority classes, where a job's class is fixed. This problem has long vexed designers of conservative synchronization protocols because of its seemingly poor ability to compute *lookahead*: the time of the next departure. For, a job in service having low priority can be preempted at any time by an arrival having higher priority and an arbitrarily small service time. Our solution is to skew the event generation activity so that events for higher priority jobs are generated farther ahead in simulated time than lower priority jobs. Thus, when a lower priority job enters service for the first time, all the higher priority jobs that may preempt it are already known and the job's departure time can be exactly predicted. Finally, we analyze the protocol and demonstrate that good performance can be expected on the simulation of large queueing networks.

Morris, K. A. and J. N. Juang: *Dissipative controller designs for second-order dynamic systems.* ICASE Report No. 90-65, September 28, 1990, 16 pages.

The passivity theorem may be used to design robust controllers for structures with positive transfer functions. This paper extends this result to more general configurations using dissipative system theory. A stability theorem for robust, model-independent controllers of structures which lack collocated rate sensors and actuators is given. The theory is illustrated for non-square systems and systems with displacement sensors.

ICASE INTERIM REPORTS

Bokhari, Shahid: *Communication overhead on the Intel iPSC-860 hypercube.* Interim Report No. 10, May 29, 1990, 26 pages.

Experiments have been conducted on the Intel iPSC-860 hypercube in order to evaluate the overhead of interprocessor communication. It is demonstrated that (1) contrary to popular belief, the distance between two communicating processors has a significant impact on communication time, (2) edge contention can increase communication time by a factor of more than 7, and (3) node contention has no measurable impact.

Saltz, Joel H. and Ravi Mirchandaney: *The preprocessed doacross loop.* Interim Report No. 11, May 29, 1990, 15 pages.

Dependencies between loop iterations cannot always be characterized during program compilation. *Doacross* loops typically make use of a-priori knowledge of inter-iteration dependencies to carry out required synchronizations. We propose a type of *doacross* loop that allows us to schedule iterations of a loop among processors without advance knowledge of inter-iteration dependencies. The method proposed for loop iterations requires us to carry out parallelizable preprocessing and postprocessing steps during program execution.

Jones, Mark T. and Merrell L. Patrick: *LANZ: Software for solving the large sparse symmetric generalized Eigenproblem.* Interim Report No. 12, August 16, 1990, 11 pages.

A package, LANZ, for solving the large symmetric generalized eigenproblem is described. The package has been tested on four different architectures: Convex 200, CRAY Y-MP, Sun-3, and Sun-4. The package uses a version of Lanczos' method and is based on recent research into solving the generalized ei[illegible]problem.

Berryman, Harry and Joel Saltz: *A manual for PARTI runtime primitives.* Interim Report No. 13, September 12, 1990, 24 pages.

Primitives are presented that are designed to help users efficiently program irregular problems (e.g., unstructured mesh sweeps, sparse matrix codes, adaptive mesh partial differential equations solvers) on distributed memory machines. These primitives are also designed for use in compilers for distributed memory multiprocessors. Communications patterns are captured at runtime, and the appropriate send and receive messages are automatically generated.

Tadmor, Eitan: *Spectral methods for time dependent problems.* Interim Report No. 14, September 12, 1990, 66 pages.

This short review on spectral approximations for time-dependent problems consists of three parts. In part I we discuss some basic ingredients from the spectral Fourier and Chebyshev approximation theory. Part II contains a brief survey on hyperbolic and parabolic time-dependent problems which are dealt with both the energy method and the related Fourier analysis. In part III we combine the ideas presented in the first two parts, in our study of accuracy stability and convergence of the spectral Fourier approximation to time-dependent problems.

ICASE COLLOQUIA

April 1, 1990 through September 30, 1990

Name/Affiliation/Title	Date
Marc Willebeek-LeMair, Cornell University "Dynamic Load Balancing on Highly Parallel Mulitprocessor Systems"	April 3
Daya Atapattu, Indiana University "Performance Prediction of Supercomputer Programs"	April 5
Professor Philip S. Marcus, University of California at Berkeley "Quasi-Periodicity and Chaos in Taylor-Couette Flow"	April 11
Professor Lawrence Sirovich, Brown University "Empirical Eigenfunctions and Turbulent Flows: Some New Results"	April 25
Dr. Jeffrey Scroggs, ICASE "Asymptotic-Induced Numerical Methods for Increased Accuracy and Computational Efficiency"	April 27
Dr. Mark Furtney, Cray Research, Inc. "Autotasking: Performance of Compiler Generated Parallelism on Cray Multiprocessors"	May 1
Dr. David Katz, University of California, Davis "Measurement and Analysis of Microorganism Motion"	May 2
Dr. Thierry Priol, IRISA - INRIA, France "Strategies for Distributing Data and Computation in Order to Parallelize a Ray-Tracing Algorithm"	May 3
Dr. Pierre Leca, ONERA, France "Parallel Computing at ONERA/Chatillon"	May 4
Professor Daniel D. Joseph, University of Minnesota "Water Lubricated Pipelining - A Review of Theory and Experiments"	May 7
Kyle Squires, Stanford University "The Interaction of Particles with Homogeneous Turbulence"	May 11

Name/Affiliation/Title	Date
Vasanth Balasundaram, California Institute of Technology "A Framework for the Design of Interactive Parallelization Tools"	May 11
Robert Schnabel, University of Colorado "Parallel Methods for Two Nonlinear Optimization Problems: Block Bordered Systems of Nonlinear Equations and Global Optimization"	May 18
Professor Eckart Meiburg, Brown University "The Three-Dimensional Evolution of an Axisymmetric Jet With and Without Reaction: A Numerical Investigation"	May 21
Professor Hideki Hashimoto, Institute of Industrial Science, University of Tokyo "Application of Neural Networks to Servo Control Systems"	May 22
Professor Avi Lin, Temple University "Second Order Mathematical Closure of the Reynolds Stress Equations"	May 24
Professor K. R. Rajagopal, University of Pittsburgh "Thermodynamics and Stability of Fluids of the Differential Type"	May 30
Ralph Smith, Montana State University "A Sinc-Galerkin Method for the Identification of Material Parameters in Euler-Bernoulli Beams"	June 4
Dr. Sungkwon Kang, Virginia Polytechnic Institute and State University "A Control Problem for Burgers' Equation"	June 6
Professor John Kallinderis, University of Texas at Austin "Adaptation Methods for Viscous Flows"	June 14
Dr. Flavio Dobran, Argonne National Laboratory "Formulation of Multiphase Flow Field Equations and Related Turbulence Modeling"	June 15
Dr. Marc Garbey, ENS de Lyon, France and Argonne National Laboratory "Bifurcation Analysis of Combustion Problems with Maple"	July 3

Name/Affiliation/Title	Date
Professoı Stanley Osher, University of California, Los Angeles "Computing Interface Motion Using Level Sets"	July 19
Dr. Bram van Leer, The University of Michigan "Characteristic Time-Stepping"	July 20
Dr. Philip Roe, University of Michigan "Multi-Dimensional Thinking in CFD – Some First Fruits"	August 3
Professor Saad Ragab, Virginia Polytechnic Institute and State University "Instabilities of a Compressible Mixing Layer"	August 6
Dr. Eli Turkel, Tel-Aviv University and ICASE "Multigrid and Central Differences for Hypersonics"	August 23
Professor J. T. Stuart, Imperial College of Science and Technology, England "Instability of Flows Which Vary Slowly in Space and Time"	August 24
Chris Thompson, Bergen Scientific Centre, IBM, Norway "Fully-Adaptive, Parallel Multigrid Methods for the Incompressible Navier-Stokes Equations"	August 27
Professor Avram Sidi, Technion – Israel Institute of Technology and ICOMP, NASA Lewis Research Center "Recent Developments in Convergence Acceleration Methods for Vector Sequences and Applications to Computational Fluid Dynamics"	August 29
Dr. Norman Zabusky, Rutgers University "Vortex Scattering: Collapse and Reconnection of Orthogonally Offset Vortex Tubes"	August 30
Dr. John E. Lavery, Office of Naval Research, Arlington, VA "The Applied Analysis Program at the Office of Naval Research and Solution of Steady-State Conservation Laws by Mathematical Programming"	September 5

Name/Affiliation/Title	Date
Dr. Serge Petiton, E.T.C.A., Paris, France and Yale University "Massively Parallel Sparse Matrix Computations; The Example of Arnoldi's Method"	September 6
Dr. Nahid Emad, Center d'Automatique et d'Informatique, Ecole Nationale Superieure des Mines de Paris, France "The PADE-RAYLEIGH-RITZ Projective Method for Large Symmetric Eigenproblems"	September 7
Dr. Stephen Vavasis, Cornell University "Automatic Domain Partitioning in Three Dimensions"	September 10
Dr. Jackson Herring, National Center for Atmospheric Research, Boulder, CO "Coherent Structures and Statistical Theory of Turbulence"	September 17

ICASE SUMMER ACTIVITIES

The summer program for 1990 included the following visitors:

NAME/AFFILIATION	DATE OF VISIT	AREA OF INTEREST
Saul S. Abarbanel Tel-Aviv University, Israel	7/2 - 10/5	Computational Fluid Dynamics
H. Thomas Banks University of Southern California	5/30 - 6/15	Control Theory
Stanley A. Berger University of California, Berkeley	7/2 - 8/3	Analytical & Numerical Studies of Vortex Breakdown
Kelly Black Brown University	6/14 - 6/19	Numerical Methods for PDE's
Kurt Bryan University of Washington	8/1 - Staff Appt.	Computational Methods for Inverse Problems
John A. Burns VPI and State University	5/29 - 6/8	Control Theory
Stephen J. Cowley Imperial College, England	7/2 - 7/6 & 2 wks in Sept.	Computational Fluid Dynamics
John Crawford Brown University	6/15 - 6/29	Numerical Methods for PDE's
William O. Criminale University of Washington	9/3 - 9/14	Transition & Instability Studies in Boundary Layers and Mixing Layers
Wai-Sun Don Brown University	6/15 - 8/15	Numerical Methods for PDE's
Peter W. Duck University of Manchester, England	7/9 - 8/31	Numerical Solution of Unsteady Boundary Layers
John W. Elliott University of Hull, England	8/20 - 9/14	High Reynolds Number Flow Theory

NAME/AFFILIATION	DATE OF VISIT	AREA OF INTEREST
Ben G. Fitzpatrick University of Tennessee	6/3 - 6/8	Control Theory
Marc P. Garbey Ecole Normale Superieure De Lyon	6/18 - 7/7	Asymptotics in the Numerical Solution of PDE's
Michael Gaster University of Cambridge, England	9/3 - 9/15	Transition/Stability of Boundary Layers
David Gottlieb Brown University	6/25 - 8/17	Numerical Methods for PDE's
Chester E. Grosch Old Dominion University	5/14 - 6/22	Computational Fluid Dynamics
Philip Hall Exeter University	6/25 - 8/17 9/20 - 10/11	Computational Fluid Dynamics
Amiram Harten Tel-Aviv University	7/2 - 8/10 9/17 - 9/28	Numerical Methods for PDE's
Dan Henningson Massachusetts Institute of Technology	8/21 - 8/24	Laminar Turbulent Transition
Ashraf Iqbal University of Electrical Engineering, Lahore, Pakistan	8/17 - 8/24	Mapping Problems onto Parallel Processors
Kazufumi Ito University of California, LA	6/11 - 6/15	Control Theory
Thomas Jackson Old Dominion University	6/1 - 8/31	Numerical and Analytical Methods for Chemically Reacting Flows
Mark Jones Duke University	5/7 - 5/11 5/22 - 5/25	Algorithms for Parallel Array Computers
Ashwani Kapila Rensselaer Polytechnic Institute	8/13 - 8/24	Mathematical Aspects of Combustion Processes

NAME/AFFILIATION	DATE OF VISIT	AREA OF INTEREST
Charles Koelbel Duke University	3/18 - 5/24	Compilers for Parallel Machines
Heinz-Otto Kreiss University of California, LA	5/11 - 5/15	Numerical Solution of PDE's
Glenn Lasseigne Old Dominion University	4/1 - 9/30 1 day each week	Numerical and Analytical Methods for Chemically Reacting Flows
Moshe Matalon Northwestern University	8/6 - 9/14	Flame Structure, Stability, and Propagation
H. S. Mukunda Indian Institute of Science, Bangalore	6/11 - 7/20	High Speed Reacting Flows
Roddam Narasimha National Aeronautical Laboratory, India	9/4 - 9/17	Transition Modeling
David Nicol College of William and Mary	5/14 - 6/29	Techniques for Mapping Algorithms onto Parallel Systems
Tobias Orloff Geometry Supercomputer Project	6/3 - 6/16	Parallel Graphics Algorithms
Stanley J. Osher University of California, LA	9/1 - 9/7	Numerical Techniques for Problems in Fluid Dynamics
D. Papageorgiou City College of New York	5/3 - 5/24	Computational Fluid Dynamics
Merrell L. Patrick Duke University	5/1 - 8/24	Algorithms for Parallel Array Computers
Ugo Piomelli University of Maryland	5/28 - 6/8	Large Eddy Simulation
Terry Pratt University of Virginia	5/1 - 8/31 2 days a week	Characteristics of Languages for Parallel Computers

NAME/AFFILIATION	DATE OF VISIT	AREA OF INTEREST
Georg Propst Karl-Franzens-Universitat Graz, Austria	5/21 - 6/8	Control Theory
Adam Rifkin College of William and Mary	6/1 - 8/15	Mapping Algorithms for Parallel Systems
Asok Ray The Pennsylvania State University	5/28 - 6/22	Control Systems for Flexible Space Structures
Daniel Reed University of Illinois, Urbana	6/4 - 6/8	Performance Evaluation of Computer Systems
Philip L. Roe The University of Michigan	7/23 - 8/3	Computatational Fluid Dynamics
Chi-Wang Shu Brown University	6/25 - 7/27	Computational Fluid Dynamics
Yiorgos S. Smyrlis University of California, LA	6/18 - 8/17	Difference Schemes with Dispersion for Approximating Conservation Laws
Alex Solomonoff Brown University	7/30 - 8/10	Numerical Methods for PDE's
J. Trevor Stuart Imperial College	8/6 - 8/24	Transition Process in Fluid Dynamics
Shlomo Ta'asan The Weizmann Institute of Science	6/18 - 8/17	Multi-Grid Methods for PDE's
Chang Hsien Tai The University of Michigan	6/11 - 7/13	Multi-Grid Methods in Hyperbolic Equations
Hillel Tal-Ezer Tel-Aviv University, Israel	9/10 - 9/28	Spectral Methods for PDE's
Saleh Tanveer Ohio State University	8/27 - 8/31	Problems for Crystal Growth

NAME/AFFILIATION	DATE OF VISIT	AREA OF INTEREST
Siva Thangam Stevens Institute of Technology	8/20 - Staff Appt.	Computational Fluid Dynamics
Brian Totty University of Illinois, Urbana	6/4 - 6/8	Problem Partitioning in Programming for Parallel Systems
Hien T. Tran Brown University	6/11 - 6/15	Control Theory
Eli Turkel Tel-Aviv University, Israel	6/20 - 8/24	Computational Fluid Dynamics
Leon van Dommelen Florida State University	5/14 - 5/25	Direct Simulation via the Navier-Stokes Equations
Bram van Leer University of Michigan, Ann Arbor	7/2 - 7/20	Computational Fluid Dynamics
Jan-Jan Wu Yale University	5/14 - 8/17	Optimizing Compilers on Distributed Memory Architectures

OTHER ACTIVITIES

The Workshop on Languages, Compilers, and Run-Time Environments for Distributed Memory Machines was held May 14-16, 1990, at NASA Langley Research Center. Fifty-four people attended this workshop. The overall goal of the workshop was to evaluate the current state of the research as it relates to coping with large scientific codes and to identify the areas which are not being adequately addressed. Invited speakers and their topics are listed below.

Vasanth Balasundaram, California Institute of Technology
"Estimating Communication Costs from Data Layout Specifications in an Interactive Data Partitioning Tool"

Marina Chen, Yale University
"The Crystal Model and Data-Parallel Language Extensions"

Thomas Gross, Carnegie-Mellon University
"Architecture/Compiler Interaction for Communication in iWarp Systems"

Philip Hatcher, University of New Hampshire
"An Optimizing C^* Compiler for a Hypercube Multicomputer"

Jay Hoeflinger, CSRD
"Cedar Fortran and Its Compiler"

Kenneth Kennedy, Rice University
"The CRPC Distributed-Memory Compilation Project"

Rik Littlefield, University of Washington, Seattle
"Repeated Irregular Computations - A Step Beyond the Testjig"

Piyush Mehrotra, ICASE
"Language Support for Data Parallel Algorithms on Distributed Memory Systems"

Jean-Louis Pazat, IRISA, France
"Pandore: A System to Manage Data Distribution"

Anthony P. Reeves, Cornell University
"Paragon: A Programming Paradigm for Multi Computer Systems"

Anne Rogers, Cornell University
"Compiling for Locality of Reference"

P. Sadayappan, Ohio State University
"Towards Automatic Partitioning of Regular Nested Loop Computations for Local-Memory Architectures"

Joel Saltz, ICASE
"Run Time Loop Optimizations and Off-Processor Data Caching for Distributed Memory Machines"

Robert Schnabel, University of Colorado
"Programming Distributed Memory Multiprocessors for Scientific Computation: Algorithmic Paradigms and Parallel Programming Constructs"

Marc Snir, IBM Corporation, T. J. Watson Research Center
"Nicke"

Larry Snyder, University of Washington, Seattle
"New Abstractions for Distributed Memory Parallel Programming"

Boleslaw Szymanski, Rensselaer Polytechnic Institute
"Scheduling EPL Specifications for Parallel Processing"

Ping-Sheng Tsend, Bellcore
"A Systolic Array Parallelizing Compiler"

Joel Williamson, Pacific-Sierra Research Corporation
"MIMDizer: Functional and Data Decomposition; Creating Parallel Programs from Scratch, Transforming Existing Fortran Programs to Parallel"

Michael Wolfe, Oregon Graduate Institute
"Parallel and Systolic Loops"

Hans P. Zima, University of Vienna, Austria
"Superb: Research Assessment and Outlook"

A volume of the proceedings from this conference will be published by Elsevier in the near future.

On September 24-25, 1990, a meeting regarding the book on Domain Decomposition and Parallel Computing for Partial Differential Equations was held at ICASE. There were seven attendees. The main objective of this meeting was to discuss collaboration on a book on the subject of domain decomposition and parallel computing for partial differential equations. Invited speakers were the following:

Charbel Farhat, University of Colorado at Boulder

Paul Fischer, California Institute of Technology

William D. Gropp, Argonne National Laboratory

David Keyes, Yale University

W. T. Thompkins, Jr., Northrop Research and Technical Center

Mary Wheeler, Rice University

The Workshop on Heterogeneous Boundary Conditions was held on September 26-28, 1990. at ICASE. Thirteen people attended and the main focus was on the formation and rigorous analysis of boundary conditions that interface regions of heterogeneous behavior, as well as their implementation in numerical simulations. Invited speakers are listed below.

Donna Blake, Stennis Space Center, MS
"Interface Preconditionings for Domain Decomposition"

B. Engquist, University of California at Los Angeles
"Absorbing Boundary Conditions at Domain Interfaces"

R. Glowinski, University of Houston
"Fictitious Domain Methods"

B. Gropp, Argonne National Laboratory
"Visual Artifacts in Boundary Conditions"

G. Hedstrom, Lawrence Livermore National Laboratory
"Layer Tracking, Asymptotics and Domain Decomposition"

D. Keyes, Yale University and ICASE
"Interface Preconditioning for Domain Decomposition"

L. Perkins, Massachusetts Institute of Technology
"Nested Ocean Models"

J. Scroggs, ICASE
"Radical Grid Refinement Interface Conditions"

ICASE STAFF

I. ADMINISTRATIVE

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

Linda T. Johnson, Office and Financial Administrator

Etta M. Blair, Personnel/Bookkeeping Secretary

Barbara A. Cardasis, Administrative Secretary

Rosa H. Milby, Technical Publications/Summer Housing Secretary

Shelly D. Millen, Technical Publications Secretary

Emily N. Todd, Executive Secretary/Visitor Coordinator

II. SCIENCE COUNCIL for APPLIED MATHEMATICS and COMPUTER SCIENCE

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

John Hopcroft, Joseph C. Ford Professor of Computer Science, Cornell University.

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

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

Joseph Oliger, Professor, Computer Science Department, Stanford University.

Robert O'Malley, Jr., Chairman, Department of Mathematical Sciences, Rensselaer Polytechnic Institute.

Stanley J. Osher, Professor, Mathematics Department, University of California.

John Rice, Chairman, Department of Computer Science, Purdue University.

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, Center for Applied Mathematical Sciences, University of Southern California.

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. LEAD COMPUTER SCIENTIST

Joel H. Saltz - Ph.D., Computer Science, Duke University, 1985. Parallel Computing with Emphasis on Systems and Algorithmic Issues. (beginning July 1989)

V. SENIOR STAFF SCIENTIST

Gordon Erlebacher - Ph.D., Plasma Physics, Columbia University, 1983. Computational Fluid Dynamics. (November 1989 to November 1994)

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 1991)

John R. Van Rosendale - Ph.D., Computer Science, University of Illinois, 1980. Parallel Systems and Algorithms. (July 1989 to July 1992)

VI. SCIENTIFIC STAFF

Harry Scott Berryman - B.S., Computer Science, Yale University, 1988. Performance Analysis of Parallel Computing Systems. (July 1989 to September 1990)

Kurt M. Bryan - Ph.D., Mathematics, University of Washington, 1990. Theoretical and Computational Methods for Inverse Problems. (August 1990 to August 1992)

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

Leon M. Clancy - B.S., Mechanical Engineering, University of Washington, 1971. System Manager. (December 1989 to Present)

Thomas W. Crockett - B.S., Mathematics, College of William and Mary, 1977. Parallel Systems Research. (February 1987 to February 1992)

Naomi Decker - Ph.D., Mathematics, University of Wisconsin-Madison, 1987. Multigrid Method Applied to Hyperbolic Equations. (September 1987 to August 1990)

Thomas M. Eidson - Ph.D., Mechanical Engineering, University of Michigan, 1982. Parallel Techniques for Computational Fluid Dynamics. (August 1989 to August 1991)

Fumio Kojima - Ph.D., Control Theory, Kyoto University, Japan, 1985. Probabilistic and Stochastic Methods for Optimal Control Problems. (September 1986 to September 1990)

Dimitri Mavriplis - Ph.D., Mechanical and Aerospace Engineering, Princeton University, 1988. Grid Techniques for Computational Fluid Dynamics. (February 1987 to February 1992)

Kirsten Morris - Ph.D., Electrical Engineering, University of Waterloo, Canada, 1989. Control Theory. (September 1989 to August 1991)

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

Peter W. Protzel - Ph.D., Electrical Engineering, Technical University of Braunschweig, Germany, 1987. Reliability of Computing Systems. (March 1987 to September 1991)

Sutanu Sarkar - Ph.D., Mechanical and Aerospace Engineering, Cornell University, 1988. Fluid Dynamics, Turbulence Modeling, Compressible Turbulence. (September 1988 to September 1991)

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

Sharon O. Seddougui - Ph.D., Applied Mathematics, University of Exeter, England, 1988. Compressible Fluid Dynamics. (June 1988 to June 1991)

Ralph C. Smith - Ph.D., Numerical Analysis, Montana State University, 1990. Theoretical and Computational Issues Associated with Inverse Problems. (August 1990 to August 1992)

VII. VISITING SCIENTISTS

Shahid Bokhari - Ph.D., Electrical and Computer Engineering, University of Massachusetts, Amherst, 1978. Professor, Electrical Engineering, University of Engineering & Technology, Lahore, Pakistan. Parallel Computing Systems. (October 1989 to December 1990)

Stanley A. Berger - Ph.D., Applied Mathematics, Brown University, 1959. Professor of Engineering Science, Department of Mechanical Engineering, University of California at Berkeley. Analytical and Numerical Studies of Vortex Breakdown. (July to August 1990)

Stephen J. Cowley - Ph.D., Mathematics, University of Cambridge, England, 1981. Lecturer, Department of Mathematics, Imperial College, England. Computational Fluid Dynamics. (July 1990)

William O. Criminale - Ph.D., Aeronautics, Johns Hopkins University, 1960. Professor, Department of Applied Mathematics, University of Washington. Transition and Instability Studies in Boundary Layers and Mixing Layers. (September 1990)

Wai-Sun Don - Ph.D., Applied Mathematics, Brown University, 1989. Visiting Assistant Professor, Department of Applied Mathematics, Brown University. Numerical Methods for Partial Differential Equations. (June to August 1990)

Peter W. Duck - Ph.D., Fluid Mechanics, University of Southampton, United Kingdom, 1975. Lecturer in Mathematics, Department of Mathematics, University of Manchester, United Kingdom. Numerical Solution of Unsteady Boundary Layer Equations. (July to August 1990)

John W. Elliott - Ph.D., Applied Mathematics, University of Manchester, 1982. Lecturer, Department of Applied Mathematics, University of Hull, England. High Reynolds Number Flow. (August to September 1990)

Ben G. Fitzpatrick - Ph.D., Applied Mathematics, Brown University, 1988. Assistant Professor, Department of Mathematics, University of Tennessee. Control Theory. (June 1990)

Marc P. Garbey - Ph.D., Applied Mathematics, Ecole Centrale of Lyon, 1984. Professor, Laboratoire d Analyse Numerique, University of Lyon 1, France. Asymptotics in the Numerical Solution of Partial Differential Equations. (June to July 1990)

Michael Gaster - Ph.D., Aerodynamics, London University, 1963. Professor of Aeronautical Engineering, Department of Engineering, Cambridge University, England. Transition/Stability of Boundary Layers. (September 1990)

Dan Henningson - Ph.D., Mechanics, Royal Institute of Technology, Stockholm, 1988. Assistant Professor, Department of Mathematics, Massachusetts Institute of Technology. Laminar Turbulent Transition. (August 1990)

Richard S. Hirsh - Ph.D., Fluid Mechanics, Case Western Reserve University, 1971. Associate Director, Office of Science and Technology Centers Development, National Science Foundation. Numerical Methods for Partial Differential Equations. (September 1990)

David E. Keyes - Ph.D., Applied Mathematics, Harvard University, 1984. Associate Professor, Department of Mechanical Engineering, Yale University. Parallelization of Numerical Procedures for Combustion. (August to December 1990)

Peter A. Jacobs - Ph.D., Computational Fluid Dynamics, University of Queensland, Australia, 1987. Compressible Fluid Dynamics. (January 1990 to January 1991)

Jacques Liandrat - Ph.D., Fluid Mechanics-Numerical Simulations, University of Toulouse, France, 1986. Research Scientist, I.M.S.T., Marseille, France. Turbulence Simulation. (April to July 1990)

Moshe Matalon - Ph.D., Mechanical and Aerospace Engineering, Cornell University, 1978. Associate Professor, Department of Engineering Sciences and Applied Mathematics, Northwestern University. Flame Structure, Stability, and Propagation. (August 1990)

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 September 1991)

Hanasoge S. Mukunda - Ph.D., Aerospace Engineering, Indian Institute of Science, Bangalore, India, 1970. Professor, Department of Aerospace Engineering, Indian Institute of Science, Bangalore, India. High Speed Reacting Flows. (June to July 1990)

Roddam Narasimha - Ph.D., Aeronautics, California Institute of Technology, 1961. Director, National Aeronautical Laboratory, Bangalore, India. Transition Modeling. (September 1990)

Tobias B. Orloff - Ph.D., Mathematics, Princeton University, 1983. Staff, Geometry Super Computer Project, University of Minnesota. Parallel Graphics Algorithms. (June 1990)

Dimitrius Papageorgiou - Ph.D., Mathematics, University of London, 1985. Assistant Professor, Department of Mathematics, New Jersey Institute of Technology. Computational Fluid Dynamics. (May 1990)

Serge G. Petiton - Ph.D., Computer Science and Applied Mathematics, Pierre and Marie Curie University (Paris VI), 1988. Post Doctoral Fellow, Research Center for Scientific Computation, Yale University. Parallel Methods for Eigenvalue Problems for Non-Symmetric Linear Systems. (September 1990)

Georg Propst - Ph.D., Mathematics, Karl-Franzens Universitat Graz, Austria, 1985. Assistant Professor, Institut fur Mathematik, Karl-Franzens-Universitat, Graz, Austria. Control Theory. (May to June 1990)

Asok Ray - Ph.D., Mechanical Engineering, Northeastern University, 1976. Professor, Department of Mechanical Engineering, The Pennsylvania State University. Control Systems for Flexible Space Structures. (May to June 1990)

Philip L. Roe - Ph.D., Aeronautical Engineering, Cambridge University, England, 1962. Professor, Department of Aerospace Engineering, University of Michigan. Computational Fluid Dynamics. (July to August 1990)

Yiorgos S. Smyrlis - Ph.D., Mathematics, New York University, Courant Institute, 1989. Visiting Assistant Professor, Department of Mathematics, University of California at Los Angeles. Difference Schemes with Dispersion for Approximating Conservation Laws. (June to August 1990)

John Trevor Stuart - Ph.D., Applied Mathematics, Imperial College, London, 1951. Professor, Department of Mathematics, Imperial College, London. Transition Process in Fluid Dynamics. (August 1990)

Eitan Tadmor - Ph.D., Numerical Analysis, Tel-Aviv University, 1979. Professor, Department of Applied Mathematics, Tel-Aviv University. Numerical Methods for Partial Differential Equations. (July 1989 to October 1990)

Chang Hsien Tai - Ph.D., Aerospace Engineering, University of Michigan, 1990. Research Assistant, Department of Engineering, University of Michigan. Multi-Grid Methods for Partial Differential Equations. (June to July 1990)

Hillel Tal-Ezer - Ph.D., Mathematics, Tel-Aviv University, 1985. Lecturer, Tel-Aviv University, School of Mathematics, Israel. Spectral Methods for Partial Differential Equations. (September 1990)

Siva Thangam - Ph.D., Mechanical Engineering, Rutgers University, 1980. Professor, Department of Mechanical Engineering, Stevens Institute of Technology. Computational Fluid Mechanics. (August 1990 to August 1991)

Leonard L. van Dommelen - Ph.D., Aerospace Engineering, Cornell University, 1981. Associate Professor, Department of Mechanical Engineering, Florida State University. Direct Simulation via the Navier-Stokes Equations. (May 1990)

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.

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.

Percy Bobbitt - B.S., Aeronautics, Catholic University of America, 1949. NASA Langley Research Center - Retired. Fluid Mechanics.

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.

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.

Joel H. Ferziger - Ph.D., Nuclear Engineering, University of Michigan, 1962. Professor, Thermosciences Division, Department of Mechanical Engineering, Stanford University. Fluid Dynamics.

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.

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.

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

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, Department of Mathematics, University of Southern California. 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, Department of Mathematics, College of William and Mary. Numerical Linear Algebra.

Mark T. Jones - Ph.D., Computer Science, Duke University, 1990. Assistant Computer Scientist, MCS Division, Argonne National Labs. Parallel Algorithms for 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.

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