JOURNAL OF COMPUTATIONAL PHYSICS **136,** 660–661 (1997)
ARTICLE NO. CP975811

Abstracts of Papers to Appear in Future Issues

AVERAGE-STATE JACOBIANS AND IMPLICIT METHODS FOR COMPRESSIBLE VISCOUS AND TURBULENT FLOWS. P. Batten,* M. A. Leschziner,* and U. C. Goldberg.† **Department of Mechanical Engineering, UMIST, Manchester United Kingdom; †Metacomp Technologies, Inc.* E-mail: Paul.Batten@umist.ac.uk.

Several new implicit schemes for the solution of the compressible Navier–Stokes equations are presented. These methods are derived from a hierarchy of average-state approximate solutions to the Riemann problem, ranging from the Lax–Friedrichs flux to the exact Riemann-solver flux. In contrast to linearised approximations, these methods will (with certain provisos on the signal velocities) enforce the entropy condition and preserve positivity without the need of additional corrections. The hierarchy also encompasses and explains the origin of many other upwind and centred methods, including the space-time scheme (due to Chang) and the more recent FORCE scheme (due to Toro). Based on an analysis of the above hierarchy, attention is focussed on the development of a new implicit scheme using a positivity-preserving version of Toro *et al.*'s HLLC scheme, which is the simplest average-state solver capable of exactly preserving isolated shock, contact, and shear waves. Solutions obtained with this method are essentially indistinguishable from those produced with an exact Riemann solver, whilst convergence to the steady state is the most rapid of all the implicit average-stage schemes considered and directly comparable to that of the unmodified Roe scheme. A new two-step implicit method is applied to various test cases, including turbulent flow with shock/boundary-layer interaction. The new time-stepping scheme is composed of two backward Euler steps, but has twice the convergence rate of the backward Euler scheme and alleviates the convergence problems that are often experienced when employing compressive limiter functions.

COMPUTING THE HYPERGEOMETRIC FUNCTION. Robert C. Forrey. *Harvard–Smithsonian Center for Astrophysics, 60 Garden Street, Cambridge, Massachusetts 02138.*

The hypergeometric function of a real variable is computed for arbitrary real parameters. The transformation theory of the hypergeometric function is used to obtain rapidly convergent power series. The divergences that occur in the individual terms of the transformation for integer parameters are removed using a finite difference technique.

NUMERICAL METHOD FOR INCOMPRESSIBLE VORTICAL FLOWS WITH TWO UNBOUNDED DIRECTIONS. Steven C. Rennich and Sanjiva K. Lele. *Department of Aeronautics and Astronautics, Stanford University, Stanford, California 94305-4035.* E-mail: lele@leland.stanford.edu.

A new, efficient, and accurate method has been developed for computing unsteady, incompressible, viscous flows in a domain where two dimensions are unbounded, the third dimension is periodic, and the vorticity is rapidly decaying in the unbounded directions. We use the term unbounded to mean doubly infinite (no boundaries of any kind). The method is an extension of the methods described for flows with two periodic and one unbounded direction, where the irrotational velocities outside the vortical domain are treated analytically. The new method is shown to be both accurate and efficient. Unlike the method which implements the analytical extension with spectral accuracy and negligible cost, the method presented here has finite, but arbitrarily high order, formal accuracy, and incurs substantial additional cost for a given mesh. However, when compared to other methods, this increased cost is more than offset by the reduction in the number of mesh points required for a given accuracy. The result is that for accurate computations, the present method can be orders of magnitude more efficient than others currently in use. This paper presents the method, discusses implementation issues, validates its accuracy, and presents sample calculations.

A SPECTRAL FILTERING PROCEDURE FOR EDDY-RESOLVING SIMULATIONS WITH A SPECTRAL ELEMENT OCEAN MODEL. Julia G. Levin, Mohamed Iskandarani, and Dale B. Haidvogel. *Institute of Marine and Coastal Sciences, Rutgers University, New Brunswick, New Jersey 08903-0231.* E-mail: julia@imcs.rutgers.edu.

The numerical simulation of turbulent oceanic flows is susceptible to the appearance of instabilities associated with the misrepresentation of nonlinear interactions among small-scale motions. Specialized filters and differencing schemes have been successfully used in the past to suppress the growth of these instabilities in finite-difference ocean models. Here, we introduce a new filtering procedure designed to control the growth of nonlinear instabilities in the spectral element solution of nonlinear oceanic flows. The new procedure involves two separate steps. First, a spectral filter is applied to the vorticity and divergence fields to damp oscillations in high-gradient regions and to restore spectral accuracy away from them. Second, the associated velocity field is computed from a set of Poisson equations, and its boundary conditions and interelement continuity are restored. This two-step strategy avoids the loss of C^0 continuity and the weakening of Dirichlet boundary conditions that can result when the filter is directly applied to the velocity field. The behavior of the filter is investigated numerically on the canonical problem of the double-gyre wind-driven circulation in a rectangular basin using a spectral element shallow water model. The parameters of the simulation are chosen to produce mesoscale eddies. The filter is able to stabilize the simulation even at coarse resolution and to recover the "correct" statistical behavior with as few as two grid points per Rossby deformation radius. Finally, a simulation of the wind-driven circulation in the North Atlantic Ocean is performed to illustrate the effectiveness of the filter in realistic settings.

AN INEXACT NEWTON METHOD FOR FULLY COUPLED SOLUTION OF THE NAVIER–STOKES EQUATIONS WITH HEAT AND MASS TRANSPORT. John N. Shadid,* Ray S. Tuminaro,* and Homer F. Walker.† **Sandia National Laboratories, MS 1111, P.O. Box 5800, Albuquerque, New Mexico 87185-1111; †Department of Mathematics and Statistics, Utah State University, Logan, Utah 84322-3900.* E-mail: jnshadi@cs.sandia.gov; tuminaro@cs.sandia.gov; walker@math.usu.edu.

The solution of the governing steady transport equations for momentum, heat, and mass transfer in flowing fluids can be very difficult. These difficulties arise from the nonlinear, coupled, nonsymmetric nature of

0021-9991/97 $25.00

the system of algebraic equations that results from spatial discretization of the PDEs. In this manuscript we focus on evaluating a proposed nonlinear solution method based on an inexact Newton method with backtracking. In this context we use a particular spatial discretization based on a pressure stabilized Petrov–Galerkin finite element formulation of the low Mach number Navier–Stokes equations with heat and mass transport. Our discussion considers computational efficiency, robustness, and some implementation issues related to the proposed nonlinear solution scheme. Computational results are presented for several challenging CFD benchmark problems as well as two large scale 3D flow simulations.