their ability to remove continuity violations, without adding vorticity, in channels that have been fitted with nonorthogonal MAC grids. Each of these combinations achieves conservation of mass, but only one of them makes the pressure gradient effectively irrotational. The latter condition is achieved by using identical approximations for coordinate derivatives and pressure derivatives throughout the flow, and by using one-sided approximations next to the boundaries for ambiguous derivatives in the off-boundary direction.

AUTOMATED ANGULAR MOMENTUM RECOUPLING ALGEBRA. H. T. Williams, *Washington and Lee University, Lexington, Virginia 24450, USA*; Richard R. Silbar, *Los Alamos National Laboratory, University of California, Los Alamos, New Mexico 87545, USA.*

We present a set of heuristic rules for algebraic solution of angular momentum recoupling problems. The general problem reduces to that of finding an optimal path from one binary tree (representing the angular momentum coupling scheme for the reduced matrix element) to another (representing the sub-integrals and spin sums to be done). The method lends itself to implementation on a microcomputer, and we have developed such an implementation using a dialect of LISP. We describe both how our code, called RACAH, works and how it appears to the user. We illustrate the use of RACAH for several transition and scattering amplitudes matrix elements occurring in atomic, nuclear, and particle physics.

SIMULATION OF THE STEADY-STATE ENERGY TRANSFER IN RIGID BODIES, WITH CONVECTIVE/RADIATIVE BOUNDARY CONDITIONS, EMPLOYING A MINIMUM PRINCIPLE. Rogério Martins Saldanha da Gama, *Laboratório Nacional de Computação Cientifica, Rua Lauro Müller 455, 22290 Rio de Janeiro, Brazil.*

The subject of this paper is the energy transfer phenomenon in a rigid and opaque body that exchanges energy, with the environment, by convection and by diffuse thermal radiation. The considered phenomenon is described by a partial differential equation, subjected to (nonlinear) boundary conditions. It is presented with a minimum principle, suitable for a large class of energy transfer problems. Some particular cases are simulated.

A DOMAIN DECOMPOSITION METHOD FOR GENERATING ORTHOGONAL POLYNOMIALS FOR A GAUSSIAN WEIGHT ON A FINITE INTERVAL. Raymond C. Y. Chin, *Lawrence Livermore National Laboratory, Livermore, California 94550, USA.*

A domain decomposition method has been developed for generating orthogonal polynomials for a Gaussian weight on $(-1, 1)$. The method takes advantage of the underlying asymptotic structure of the orthogonal polynomials and, hence, it is *effective* in the sense that it makes maximal use of the analytic properties of the solution to increase accuracy and efficiency. These polynomials are necessary for constructing Gaussian quadrature formulas that are encountered in large quantum chemistry computational packages and in calculating the Compton scattering kernel and its associated angular moments.

A FRONT-TRACKING METHOD FOR VISCOUS, INCOMPRESSIBLE, MULTI-FLUID FLOWS. Salih Ozen Unverdi and Grétar Tryggvason, *The University of Michigan, Ann Arbor, Michigan 48109, USA.*

A method to simulate unsteady multi-fluid flows in which a sharp interface or a front separates incompressible fluids of different density and viscosity is described. The flow field is discretized by a conservative finite difference approximation on a stationary grid, and the interface is explicitly represented by a separate, unstructured grid that moves through the stationary grid. Since the interface deforms continuously, it is necessary to restructure its grid as the calculations proceed. In addition to keeping the density and viscosity stratification sharp, the tracked interface provides a natural way to include surface tension effects. Both two- and three-dimensional, full numerical simulations of bubble motion are presented.

EXPLICIT ADAPTIVE-GRID RADIATION MAGNETOHYDRODYNAMICS. Osman Yasar and Gregory A. Moses, *University of Wisconsin-Madison, Madison, Wisconsin 53706, USA.*

An explicit adaptive-grid finite differencing method for one-dimensional radiation magnetohydrodynamics computations is described. Based on the equidistribution principle, this explicit procedure moves the grid points to regions with high spatial gradients in physical quantities, such as temperature, mass density, pressure, and momentum. The governing magnetic field, radiative tansfer, and hydrodynamics equations are transformed to the moving adaptive reference frame. The time and spatially dependent radiation field is determined by solving the radiative transfer equation with the multigroup discrete ordinate S_N method with implicit time differencing. The magnetic field is solved through a diffusion equation resulted from Maxwell's equations and Ohm's law. The fluid equations are solved using a first-order upwind spatial differencing and explicit time differencing scheme. The coupling between the fluid and radiation field is treated explicitly by first solving for the radiation field and then the fluid equations. A conservative differencing scheme based on the control volume approach is chosen to retain the conservative nature of the governing equations.

A MICROINSTABILITY CODE FOR A UNIFORM MAGNETIZED PLASMA WITH AN ARBITRARY DISTRIBUTION FUNCTION. Y. Matsuda and Gary R. Smith, *Lawrence Livermore National Laboratory, Livermore, California 94550, USA.*

We have developed a very general computer code for studying micro-instabilities in a uniform magnetized plasma. Employing a new algorithm to perform two-dimensional numerical integrals in the conductivity tensor, the code can handle an arbitrary distribution function given by either an analytical function or numerical values on a momentum space grid and solve the full dispersion relation for an arbitrary propagation angle in either a non-relativistic or relativistic plasma except for a highly relative plasma (energy $\geqslant$ 1 MeV). The results for cyclotron–maser instability and whistler–wave instability are presented to illustrate the validity of the method.

A BOUNDARY ELEMENT SOLUTION FOR TWO-DIMENSIONAL VISCOUS SINTERING. G. A. L. van de Vorst, R. M. M. Mattheij, and H. K. Kuiken, *University of Technology, P.O. Box 513, 5600 MB Eindhoven, The Netherlands.*

By viscous sintering is meant the processes in which a granular compact is heated to a temperature at which the viscosity of the material under consideration becomes low enough for surface tension to cause the powder particles to deform and coalesce. For the sake of simplicity this process is modeled in a two-dimensional space. The governing (Stokes) equations describe the deformation of a two-dimensional viscous liquid region under the influence of the curvature of the outer boundary. However, some extra conditions are needed to ensure that these equations can be solved uniquely. A boundary element method is applied to solve the equations for

an arbitrarily initial-shaped fluid region. The numerical problems that can arise in computing the curvature, in particular when this is varying rapidly, are discussed. A number of numerical examples are shown for simply connected regions which transform themselves into circles as time increases.

IMPLICIT PARTICLE SIMULATION OF ELECTROMAGNETIC PLASMA PHENOMENA. T. Kamimura, *National Institute of Fusion Science, Nagoya, Japan*; E. Montalvo, *Center for Fusion Engineering, The University of Texas 78712, USA*; D. C. Barnes, *Los Alamos National Laboratory, Los Alamos, New Mexico 87545, USA*; J. N. Leboeuf, *Oak Ridge National Laboratory, Oak Ridge, Tennessee 37831, USA*; T. Tajima, *Institute for Fusion Studies, The University of Texas 78712, USA.*

A direct method for the implicit particle simulation of electromagnetic phenomena in magnetized, multi-dimensional plasmas is developed. The method is second-order accurate for $\omega \Delta t < 1$, with ω a characteristic frequency and time step Δt. Direct time integration of the implicit equations with simplified space differencing allows the consistent inclusion of finite particle size. Decentered time differencing of the Lorentz force permits the simulation of strongly magnetized plasmas in the limit of zero perpendicular temperature. A Fourier-space iterative technique for solving the implicit field corrector equation, based on the separation of plasma responses perpendicular and parallel to the magnetic field and longitudinal and transverse to the wavevector, is described. Wave propagation properties in a uniform plasma are in excellent agreement with theoretical expectations. Applications to collisionless tearing and coalescence instabilities further demonstrate the usefulness of the algorithm.

MOMENTUM ADVECTION ON A STAGGERED MESH. David J. Benson, *University of California, San Diego, La Jolla, California 92093, USA.*

Eulerian and ALE (Arbitrary Lagrangian–Eulerian) hydrodynamics programs usually split a timestep into two parts. The first part is a Lagrangian step, which calculates the incremental motion of the material. The second part is referred to as the Eulerian step, the advection step, or the remap step, and it accounts for the transport of material between cells. In most finite difference and finite element formulations, all the solution variables except the velocities are cell-centered while the velocities are edge- or vertex-centered. As a result, the advection algorithm for the momentum is, by necessity, different than the algorithm used for the other variables. This paper reviews three momentum advection methods and proposes a new one. One method, pioneered in YAQUI, creates a new staggered mesh, while the other two, used in SALE and SHALE, are cell-centered. The new method is cell-centered and its relationship to the other methods is discussed. Both pure advection and strong shock calculations are presented to substantiate the mathematical analysis. From the standpoint of numerical accuracy, both the staggered mesh and the cell-centered algorithms can give good results, while the computational costs are highly dependent on the overall architecture of a code.

PARTICLE-METHOD SOLUTION OF TWO-DIMENSIONAL CONVECTION–DIFFUSION EQUATIONS. Aaron L. Fogelson, *University of Utah, Salt Lake City, Utah 84112, USA.*

We present a new method for solving two-dimensional convection-dominated convection–diffusion equations containing spatially and temporally localized source terms. The method uses grid-free transport: particles which carry point values of the concentration gradient move by convection and undergo random-walk to simulate diffusion. No numerical diffusion is introduced. Equations for the evolution of the gradient values are solved. The concentration is recovered from the particle data by solving Poisson equations. The method is applied to problems in rotational and elongational flow fields. Numerical results demonstrating convergence of the method are presented.

THE RAPID EVALUATION OF VOLUME INTEGRALS OF POTENTIAL THEORY ON GENERAL REGIONS. Anita Mayo, *IBM Research Division, T. J. Watson Research Division, Yorktown Heights, New York 10598, USA.*

We present a new method for the rapid, high order accurate evaluation of certain volume integrals in potential theory on general irregular regions. The kernels of the integrals are either a fundamental solution, or a linear combination of the derivatives of a fundamental solution of a second-order linear elliptic differential equation. Instead of using a standard quadrature formula or the exact evaluation of any integral, the methods rely on rapid methods of solving the differential equation of which the kernel is the solution. Therefore, the number of operations needed to evaluate the volume integral is essentially equal to the number of operations needed to solve the differential equation on a rectangular region with a regular grid, and the method requires no evaluation of the kernel.

VARIATIONAL CURVE AND SURFACE GRID GENERATION. Stanley Steinberg, *University of New Mexico, Albuquerque, New Mexico 87131, USA*; Patrick Roache, *Ecodynamics Research Associates, Inc., P.O. Box 8172, Albuquerque, New Mexico 87198, USA.*

Variational algorithms that control the lengths of grid lines, cell areas, and the orthogonality of grid lines can be used for generating boundary-conforming grids on surfaces. Additional geometric control is provided by using a reference grid, while solution adaptivity is achieved by using weights. In a typical application, the reference grid can be used to produce an exponential compression of the grid at a boundary, while the solution adaptive weights are used to make the grid spacing inversely proportional to the gradient (when the gradient is large) of some solution being computed on the grid. The grid is adapted on both the interior and boundary of the surface. The algorithm performs these tasks with exceptional precision, as demonstrated in the examples presented here.

A HIGH-RESOLUTION EULER SOLVER BASED ON MULTIGRID, SEMI-COARSENING, AND DEFECT CORRECTION. Wim A. Mulder, *University of California, Los Angeles, California 90024-1555, USA.*

In an earlier paper, an $O(N)$ method for the computation of stationary solutions to the Euler equations of inviscid compressible gas dynamics has been described. The method is a variant of the multigrid technique and employs semi-coarsening in all co-ordinate directions simultaneously. It provides good convergence rates for first-order upwind discretisations even in the case of alignment, the flow being aligned with the grid. Here we discuss the application of this scheme to higher-order discretisations. Two-grid analysis for the linear constant-coefficient case shows that it is difficult to obtain uniformly good convergence rates for a higher-order scheme, because of waves perpendicular to stream lines. The defect correction technique suffers from the same problem. However, convergence to a point where the residual of the total error (the sum of the iteration error and the discretisation error) is of the order of the truncation error can be obtained in about seven defect correction cycles, according to estimates for the linear constant-coefficient equations. This result is explored for the nonlinear case by some illustrative numerical experiments.