Lawrence Livermore Laboratory

THE COMPUTATIONAL PHYSICS PROGRAM OF THE NATIONAL MFE COMPUTER CENTER

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I. INTRODUCTION

Since June 1974 the MFE Computer Center has been engaged in a substantial computational physics research effort. This effort has involved the development and application of advanced numerical techniques for modeling plasma behavior in fusion devices such as PLT, PDX, TFTR, Doublet III, MFTF, and TMX.

The computational physics group, led by J. Killeen, currently consists of five PhD computational physicists - A. A. Mirin, K. D. Marx, M. G. McCoy, D. E. Shumaker and A. I. Shestakov. In addition, several students in the Department of Applied Science at U.C. Davis/Livermore are doing fusion research under the guidance of senior group members.

One of the principal objectives of the computational physics group is to provide support for experimental and theoretical work within the MFE community. At present, this support falls into the following areas:

1) We are performing Fokker-Planck/Transport and guiding center simulation calculations for the TFTR, PLT and PDX experiments at Princeton in collaboration with R. C. Grimm, D. L. Jassby and D. E. Post, and with J. G. Cordey of Culham Laboratory on Fokker-Planck/Transport applications to DITE.

2) We are collaborating with M Division (Lawrence Livermore Laboratory) personnel - namely M. E. Rensink, T. A. Cutler, B. G. Logan, J. K. Boyd, L. S. Hall, A. H. Futch, R. W. Moir and T. K. Fowler - on the continuing development and application of Fokker-Planck codes to the TMX, MFTF, 2XII and direct converter.

A summary of our program follows.

Work performed under the auspices of the U.S. Energy Research and Development Administration, contract No. W-7405-48.
II. COMPUTATIONAL STUDIES

A. Fokker-Planck Calculations

Beginning in late 1974 our one-and two-dimensional multispecies Fokker-Planck codes were generalized to deal with both toroidal and open-ended configurations. Since then many physical effects have been incorporated into these codes, and a variety of physical problems have been studied. They include:

1. a model for the Tandem Mirror Experiment (TMX), in which Fokker-Planck equations are solved separately in the plug and the main trap.

2. fusion source and loss terms for a complete D-D burning cycle, in which deuterium, tritium, helium-3, protons and alpha particles are treated as separate species.

3. the behavior of distribution functions in mirror devices employing a direct convertor. Comparisons are made with a Monte Carlo code.

4. a complete five-dimensional calculation, taking into account the anisotropy of the ion species.

5. the addition of radial dependence to model finite Larmor radius effects.

6. applications to the Counterstreaming Ion Torus (CIT) and the Two Component Torus (TCT), including fast major radius compression and energy clamping.

7. Q calculations for the toroidally linked mirror (TLM).

8. a study of the reversed field mirror.
9. the effects of plasma rotation on the ion loss-cone boundary and resulting $\eta_t$, in collaboration with V. Volosov of the Institute of Nuclear Physics in Novosibirsk.

10. a self-consistent treatment of thermal and Frank-Condon neutrals in mirror systems.

11. the calculation of $\eta_t$, the axial density profile and maximum stable $\beta$ for FERF plasmas.

12. the study of runaway electrons and ions.

13. the effect of off-angle injection in mirror systems.

14. a study of the electrostatically plugged cusp with T. Dolan of the University of Missouri - Rolla.

15. applications to the fission/fusion hybrid reactor.

16. bounce averaging for mirror devices.

**Papers**


Reports


Abstracts


5. A. A. Mirin, J. Killeen, K. D. Marx and M. E. Rensink, "Energy Multiplication Studies for a Pulsed Two Component Torus", Annual Meeting on Theoretical Aspects of Controlled Thermonuclear Research, Rosslyn (1975), 68

6. K. D. Marx, J. Killeen, A. A. Mirin and M. E. Rensink, "Energy Multiplication Studies for a Steady State Two Component Torus", Annual Meeting on Theoretical Aspects of Controlled Thermonuclear Research, Rosslyn (1975), 64


B. Transport Studies

1. Radial Transport

A multispecies Tokamak radial transport code has been written in which the ion densities, the ion temperature, the electron temperature and the poloidal magnetic field are calculated. A combination of neoclassical models of Connor and of Rosenbluth, Hazeltine and Hinton is used to describe the plasma transport.

2. Noncircular Transport

A variational principle has been used to compute neoclassical transport coefficients for noncircular cross-sectional toroidal plasmas. The model is essentially one-dimensional, in that the transport coefficients are obtained through integrations over surfaces of constant magnetic stream function $\psi$. It is assumed that the ion and electron temperatures are equal. These transport coefficients are being incorporated into a Tokamak transport code which uses adiabatic invariants (mass, entropy and toroidal magnetic flux) as dependent variables, thereby eliminating the need to compute the toroidal electric field. A fast Poisson solver is used to compute new equilibria.

3. Two Dimensional Transport

A code has been written to solve a system of transport equations for a plasma in two dimensions. Since no theoretical model exists for two-dimensional neoclassical transport, the classical transport coefficients are being used. It is intended that this code be used to study the PDX.
Papers

Reports

Abstracts
C. Fokker-Planck/Transport Studies

These studies employ a Fokker-Planck/Transport code, in which there is a warm Maxwellian background plasma described by a set of macroscopic radial transport equations and several energetic species described by two-dimensional Fokker-Planck equations. The model is applicable to circular cross-section toroidal systems in which there is beam injection, and is currently being generalized to handle non-circular devices such as Doublet III. A Monte Carlo neutrals package developed at Princeton Plasma Physics Laboratory is used to self-consistently compute the neutral density profile. Energy multiplication studies for the CIT have been carried out in which the diffusion constants, source parameters, neutral densities and impurity content have been varied. Applications to PDX and DITE are in progress.

Papers


Abstracts


D. MHD Studies

A two-dimensional nonlinear MHD code written for general orthogonal Eulerian coordinates has been used to study the evolution and saturation of magnetic islands in both Cartesian (sheet pinch) and cylindrical (diffuse) geometries. Both the linear and non-linear behavior of the double tearing instability have been studied. Cases involving helical symmetry are currently being examined. Further studies utilizing previously written one-dimensional linear codes are underway.

A three-dimensional generalization of the above model containing the full MHD equations has been written. Investigations of the tearing mode, internal kink modes and stability studies for the flux conserving Tokamak (FCT) are being carried out.

Papers


Abstracts


E. Vlasov and Particle Simulations

1. Guiding Center Toroidal
A self-consistent guiding center particle model coupled with a fluid equilibrium code has been used to study ion beam motion in a toroidal geometry. The model includes Fokker-Planck slowing down, and a Monte Carlo procedure is being developed to treat collisional angular scattering. Physical applications include:

a) studies of equilibrium and neutral beam injection for the Toroidal Fusion Test Reactor.
b) studies of collisionless beam behavior for scenarios involving strong counterstreaming beams, both with and without a background plasma.
c) steady state modeling of the proposed CIT reactor, in which the steady state beam currents, safety factor and energy reinjection rates necessary to maintain a steady state are computed.

2. Mirror
A study of self-consistent magnetic fields in a high beta TCM reactor was completed in Fiscal Year 1975. The modified Superlayer code was used for this purpose. This work was in collaboration with M Division of LLL.

3. Vlasov
A one-dimensional \( z-v_z \) Vlasov finite difference code for ions and electrons was written to study the formation of a plasma sheath and to compute the steady state distribution functions along with a self-consistent plasma potential.
Papers


Abstracts


F. Equilibrium Studies

1. Tarmac

A code has been developed to solve non-linear elliptic equations on domains of very general shape. Its main application is to solve the equilibrium fluid equations proposed for the TORMAC device. Equilibria including the effects of a rotating plasma will be investigated.

Reports


Abstracts

G. Convergent Neutral Beam Studies

A study has been made involving the creation of a very dense plasma by injecting convergent neutral beams into spherical or cylindrical chambers. Calculations of particle distribution functions, densities, ionization rate parameters and ionization probabilities have been carried out for both geometries.

Papers


Abstracts


H. General Numerical Methods

A general study of the Incomplete Cholesky Conjugate Gradient Method (ICCG) of matrix "inversion" is being carried out. This new technique has been shown to be considerably faster than other traditional linear solvers such as ADI, SIP and SOR. An ICCG solver applicable to general nine point two-dimensional difference operators has been written, and modifications to existing codes are being considered where beneficial.
III. APPENDIX - MISCELLANEOUS REFERENCES

A. Review Publications

Papers


Abstracts


B. Other publications of group members

Papers


Reports


Abstracts


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