MASTER

COMPUTER SIMULATION OF KINETIC PROPERTIES OF PLASMAS

Progress Report

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ABSTRACT

The research is directed toward the development and testing of new numerical methods for particle and hybrid simulation of plasmas, and their application to physical problems of current significance to Magnetic Fusion Energy. During the past year, research on the project has been concerned with the following specific problems:

- (i) Analysis and computer simulations of the dissipative trapped-electron instability in tokamaks.
- (ii) Long-time-scale algorithms for numerical solutions of the drift-kinetic equation
- (iii) Computer simulation of field-reversed ion ring stability.

RESEARCH ACCOMPLISHED SINCE LAST RENEWAL

- (i) Analysis and computer simulations of the dissipative trapped-electron instability in tokamaks. (Part A of Technical Scope)

Numerical solutions of the linearized electron drift-kinetic equation in toroidal geometry, to examine the behavior of dissipative trapped-electron modes, have been continued. The following problems have been considered.

(a) A Fokker-Planck collision model allowing pitch angle diffusion has been implemented in the code. This model gives a more accurate representation of collisions than the Krook model previously used. Solutions carried out with an energy-dependent velocity diffusion coefficient $\nu \approx \omega_*$ confirm the growth rates expected with corresponding effective collision frequencies $\nu_{ef} \approx \nu/\epsilon$ but show different mode structures associated with the Landau damping (ω_* is the drift frequency and ϵ is the aspect ratio). The accuracy and stability of the algorithm used in these solutions have been studied analytically and verified by computations in the paper "Numerical Solution of the Drift-kinetic Equation in Toroidal Geometry" by T. L. Crystal and J. Denavit presented at the 8-th Conference on Numerical Simulation of Plasmas in Monterey (June 1978).

(b) The case of odd modes ($\phi_{m+l} \approx -\phi_{m-l}$, where m denotes the rational mode) has been considered in two series of solutions with $\omega_* \ll \omega_b$ and $\omega_* \approx \omega_b$, where ω_b denotes the bounce frequency, to examine the resonance between the wave and trapped-electron motion.

(c) Gradient and curvature drift terms have been included in the code. Numerical solutions of the drift-kinetic equation for unperturbed electron motion agree closely with the analytically derived drift velocity and distribution function. Dissipative trapped electron modes have been examined to

consider the effect of drift resonances on the instability.

This research is described in the paper "Computer Simulations of Dissipative Trapped Electron Modes in Tokamaks" by T. L. Crystal, to be presented at the APS Division of Plasma Physics meeting in Colorado Springs, (Nov. 1978).

(ii) Long-time-scale algorithms for numerical solutions of the drift-kinetic equation.

Computer simulation of drift waves, which vary on a long time scale compared to the electron plasma frequency ω_p are limited by the time step Δt , which must usually satisfy the condition $\omega_p \Delta t \ll 1$. A time-averaging algorithm has been introduced, satisfying the conditions of (1) unconditional stability, (2) damping of high frequencies ($\omega \Delta t \gg 1$) and (3) damping approaching zero of low frequencies ($\omega \Delta t \ll 1$). This algorithm has been implemented in a code to solve the linearized drift-kinetic equation in toroidal geometry by polynomial expansion in velocity space, and simple tests of drift wave solutions have been carried out to demonstrate its validity. This research was presented in the paper "On Long-Time-Scale Solutions of Plasma Kinetic Equations" by C. E. Rathmann and J. Denavit, presented at the 8-th Conference on Numerical Simulation of Plasmas in Monterey (June 1978).

(iii) Computer simulation of field-reversed ion ring stability (part B of Technical Scope).

(a) The three-dimensional linearized hybrid code (RINGHYBRID) to study the azimuthal stability of field reversed ion rings has been tested with axial and radial Alfvén wave propagation, including finite resistivity effects and with infinitely long layers by comparison with the theories of Berk and Sudan,

Lovelace and Sudan and Rosenbluth. Testing based on "bicycle tire" rings is now being carried out. Several types of numerical instabilities inherent to this type of simulation techniques have been encountered. These instabilities have been analyzed in terms of self-consistent models which establish the numerically stable regions of parameter space. This work was presented in the paper "A Linearized 3-D Hybrid Code for Stability Studies of Axisymmetric Field Reversed Equilibria" by A. Friedman, R. N. Sudan and J. Denavit, Proceedings of the 8-th Conference on Numerical Simulation of Plasmas in Monterey (June 1978).

(b) Computer simulations of axially symmetric ion rings confining plasma in their field-reversed region have been done by including a Grad-Shafranov term for the plasma current in the field equations. Plasma equilibrium may be studied in this manner with $J_{\text{plasma}} \simeq J_{\text{beam}}$ and stability is studied by computations of $\int d\ell/B$ along the resulting field lines.

This research is carried out in cooperation with the Laboratory of Plasma Studies at Cornell University.

PERSONNEL

During the present period (1 February 1978 to 31 January 1979) research on the project is carried out by the following personnel:

1. Principal investigator:

Professor J. Denavit, 15% of time from 1 February 1978 to 15 June 1978
20% of time from 16 September 1978 to 31 January 1979
Full time from 1 September 1978 to 15 September 1978

2. Research Associates:

John L. Vomvoridis, full time from 1 April 1978 to 30 April 1978
1 November 1978 to 31 January 1978

Thomas L. Crystal, full time from 1 April 1978 to 31 May 1978
1 September 1978 to 30 September 1978
0.46 time from 1 October 1978 to 31 December 1978
full time from 1 January 1979 to 31 January 1979

LIST OF PUBLICATIONS

(Table I)

1) Publications submitted or in preparation during the past year

<u>Title</u>	<u>Authors</u>	<u>Journal/Status</u>	<u>Percent DOE Support</u> (under present contract)
"On Long-Time-Scale Solutions of Plasma Kinetic Equations	C. E. Rathmann J. Denavit	Proc. 8-th Conf. Num. Sim. of Plasmas (Monterey, June 1978)	70%
"Numerical Solution of the Drift-Kinetic Equation in Toroidal Geometry"	T. L. Crystal J. Denavit	Proc. 8-th Conf. Num. Sim. of Plasmas (Monterey, June 1978)	100%
"A Linearized Hybrid Code for Stability Studies of Field-Reversed Ion Rings"	A. Friedman R. N. Sudan J. Denavit	To be submitted to <u>Journal of Computational Physics</u>	20%
"Spectral Formulation of the Dissipative Trapped-Electron Instability"	J. Denavit C. E. Rathmann	Published in <u>The Physics of Fluids</u> <u>21</u> , 1533 (1978)	100%

2) Publications submitted during previous years

"Long-Time-Scale Simulations of Resonant Particle Effects in Langmuir and Whistler Waves"	C. E. Rathmann J. Vomvoridis and J. Denavit	Published in <u>Journal of Computational Physics</u> , <u>26</u> , 408 (1978).	50%
"Numerical Study of Two-Dimensional Generation and Collapse of Langmuir Solitons"	N. R. Pereira R. N. Sudan and J. Denavit	Published in <u>The Physics of Fluids</u> <u>20</u> , 936 (1977)	33%
"Numerical Simulation of One-Dimensional Langmuir Solitons"	N. R. Pereira R. N. Sudan and J. Denavit	Published in <u>The Physics of Fluids</u> <u>20</u> , 271 (1977)	33%

<u>Title</u>	<u>Authors</u>	<u>Journal/Status</u>	Percent DOE Support (under present contract)
"Collisional Effects on Electron Heating Due to Parametric Instability"	J. Denavit	Published in <u>The Physics of Fluids</u> 19, 972 (1976)	33%
"Numerical Simulation Methods for Collisional and Turbulent Heating in Plasmas"	C. E. Rathmann	Ph.D. Dissertation Northwestern Univ. (August 1975)	50%
"A Long-Time-Step Particle-Pushing Algorithm"	C. E. Rathmann and J. Denavit	Proc. 7-th Conf. Num. Sim. of Plasmas (Courant Inst. June 1975)	50%
"Whistler Sideband Instability"	J. Denavit and R. N. Sudan	Published in <u>The Physics of Fluids</u> 18, 575 (1975)	25%
"Effect of Phase-Correlated Electrons on Whistler Wavepacket Propagation"	J. Denavit and R. N. Sudan	Published in <u>The Physics of Fluids</u> 18, 1533 (1975)	25%
"Simulation of Collisional Effects in Plasmas"	C. E. Rathmann and J. Denavit	Published in <u>Journal of Computational Physics</u> 18, 165 (1975)	50%
"Two-Dimensional Stability of Langmuir Solitons"	J. Denavit, N. R. Pereira and R. N. Sudan	Published in <u>Physical Review Letters</u> 33, 1435 (1975)	33%
"Theory of Triggered VLF Emissions from the Magnetosphere"	R. N. Sudan and J. Denavit	Published in <u>Physics Today</u> , Vol. 12, Dec. 1973	25%
"Discrete Particle Effects in Whistler Simulation"	J. Denavit	Published in <u>Journal of Computational Physics</u> 15, 449 (1974)	50%