NUMERICAL SIMULATIONS OF PLASMAS
WITH SMOOTHING IN PHASE SPACE
AND FILTERING IN TIME

MASTER

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) Computer simulation of field-reversed ion ring stability.
- (iii) Computer simulations of nonlinear electrostatic wave phenomena.

RESEARCH ACCOMPLISHED SINCE LAST RENEWAL

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

The drift-kinetic equation in toroidal plasmas, Fourier transformed with respect to the poloidal and toroidal angles, was used to derive dispersion relations for dissipative trapped-electron modes (DTEM) in the local approximation. In this formulation the instability occurs as a result of coupling between satellite modes, caused by trapped electron motions. Computer simulations of the DTEM were carried out using the spectral formulation of the drift-kinetic equation, coupled with Poisson's equation and the ion drift motion. These simulations (to our knowledge, the first computer simulations of the DTEM) confirm the main features of theory, viz., dependence of the growth rates on the gradient ratio η , square root of the aspect ratio $\epsilon^{1/2}$ and energy dependence of the collision frequency. This research is described in the paper "Spectral Formulation of the Dissipative Trapped-Electron Instability," by J. Denavit and C. E. Rathmann, to be presented at the APS, Div. of Plasma Physics meeting in Atlanta (Nov. 1977) and now in final stages of preparation of submission to The Physics of Fluids. This work was done in cooperation with the Controlled Thermonuclear Division at Oak Ridge National Laboratory. (Drs. C. O. Beasley, Jr., J. D. Callen and H. K. Meier)

- (ii) Computer simulation of field-reversed ion ring stability.

(Part B. of Technical Scope)

The development of a three-dimensional linearized particle codes to examine the stability of ion rings was continued in cooperation with the Laboratory of Plasma Studies at Cornell University. Results from the initial code in which the ambient plasma contributes only to charge neutralization were presented in the paper "A Linearized Three-Dimensional Code for the

Study of Strong Ion Ring Stability" by A. Friedman, R. N. Sudan and J. Denavit (Annual Controlled Fusion Theory Conference, San Diego, 1977). A more advanced code including a zero-temperature MHD model for the ambient plasma was formulated last June, during a month-long visit of the principal investigator at Cornell. This more advanced hybrid code is now being tested and preliminary results will be presented in the paper "A Linearized 3-D Hybrid Code for Stability Studies of Field-Reversed Ion Rings in Mirror Confinement" by A. Friedman, R. N. Sudan and J. Denavit (APS, Div. of Plasma Physics meeting in Atlanta, Nov. 1977). The equilibrium of ion rings with a finite pressure confined plasma is also under consideration.

(iii) Computer simulations of nonlinear electrostatic wave phenomena.

Three separate studies are grouped under this heading.

(a) One-dimensional particle simulations of single-mode nonlinear saturation of the bump-in-tail instability with immobile ions have been done in cooperation with Professor Albert Simon of the University of Rochester [see A. Simon and M. N. Rosenbluth, Phys. Fluids 19, 1567 (1976)]. These simulations, were carried out to $3000 \omega_p^{-1}$, corresponding to ~ 50 trapping periods after saturation. The observed frequency linear growth rate γ and trapping frequency ω_T agree closely with theory. Saturation was observed for $\omega_T/\gamma \approx 2$ at a level much lower than predicted by the Simon-Rosenbluth theory, but these runs also disclose, for $t \geq 400 \omega_p^{-1}$, a slow growth at a rate $\sim 10^{-4}$ accompanied by beats near the trapping frequency.

(b) The collisional particle code was applied to a computer study of the two-beam instability in collisional plasmas. These computations confirm the theoretical result that the growth rate γ is not strongly affected by collisions, even for collision frequencies $\nu \sim 0.2 \omega_p$, in the case of beams

having a small thermal spread $\langle (v-v_b)^2 \rangle^{1/2} \leq v/k$. For longer thermal spreads, collisions have a strong stabilizing effect.

(c) The development of a long-time-scale algorithm for simulation of resonant particle effects in Langmuir waves was completed. This algorithm includes collisions and was tested in terms of the instability and trapping of a monoenergetic beam, large-amplitude oscillations and the bump-in-tail instability. This research is described in the paper "Long-Time-Scale Simulation of Resonant Particle Effects in Langmuir and Whistler Waves" by C. E. Rathmann, J. L. Vomvoridis and J. Denavit to appear in the May 1978 issue of the Journal of Computational Physics.

PERSONNEL

During the present period (1 February 1977 to 31 January 1978) research on the project is carried out by the following personnel:

1. Principal investigator:

Professor J. Denavit, 15% of time from 1 February 1977 to 15 June 1977
16 September 1977 to 31 January 1978
Full time from 16 June 1977 to 31 July 1977
1 September 1977 to 15 September 1977

2. Research Associates:

Carl E. Rathmann, full time from 16 June 1977 to 22 July 1977
John Vomvoridis, full time from 7 October 1977 to 31 January 1978
Thomas L. Crystal, full time from 21 November 1977 to 31 January 1978

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 ERDA Support</u> (under present contract)
"Long-Time-Scale Simulations of Resonant Particle Effects in Langmuir and Whistler Waves"	C. E. Rathmann J. Vomvoridis and J. Denavit	To appear in <u>Journal of Computational Physics</u>	50%
"Spectral Formulation of the Dissipative Trapped-Electron Instability"	J. Denavit C. E. Rathmann	To be submitted to <u>The Physics of Fluids</u>	100%

2) Publications submitted during previous years

"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%
"Collisional Effects on Electron Heating Due to Parametric Instability"	J. Denavit	Published in <u>The Physics of Fluids</u> <u>19</u> , 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%

<u>Title</u>	<u>Authors</u>	<u>Journal/Status</u>	<u>Percent ERDA Support</u> (under present contract)
"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%