ANNUAL PROGRESS REPORT

Contract No.: EY-76-S-02-3497

Principal Investigator: Albert Simon, Prof. of Mechanical
and Aerospace Sciences and Prof.
of Physics

Co-Investigator : Peter J. Catto, Asst. Prof. of
Mechanical and Aerospace Sciences

Date of Report: August 5, 1977

Report Number: C00-3497-24

MASTER

NOTICE
This report was prepared as an account of work
sponsored by the United States Government. Neither the
United States nor the United States Department of
Energy, nor any of their employees, nor any of their
contractors, subcontractors, or their employees, makes
any warranty, express or implied, or assumes any legal
liability or responsibility for the accuracy, completeness
or usefulness of any information, apparatus, product or
process disclosed, or represents that its use would not
infringe privately owned rights.

ABSTRACT

Research has been performed on several topics on linear and nonlinear instabilities, primarily in geometries of interest to present and future magnetic fusion devices. The emphasis of the nonlinear studies has been on the dissipative trapped electron and drift cyclotron loss cone instabilities. The results of the former study are in good agreement with the experimental data in a linear mirror geometry. The latter studies are intended to provide predictions which can be checked by experiments on 2XIB. The two mode bump-on-tail problem has also been solved. The thrust of the linear program has been toward understanding radial eigenvalue problems appropriate to trapped electron and collisionless drift instabilities in tokamaks. Investigations of tearing effects due to drift instabilities are also underway. In addition, the gyro-kinetic formulation has been generalized from the linearized to the full Vlasov operator.

DISCLAIMER

This report was prepared as an account of work sponsored by an agency of the United States Government. Neither the United States Government nor any agency Thereof, nor any of their employees, makes any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness, or usefulness of any information, apparatus, product, or process disclosed, or represents that its use would not infringe privately owned rights. Reference herein to any specific commercial product, process, or service by trade name, trademark, manufacturer, or otherwise does not necessarily constitute or imply its endorsement, recommendation, or favoring by the United States Government or any agency thereof. The views and opinions of authors expressed herein do not necessarily state or reflect those of the United States Government or any agency thereof.

DISCLAIMER

Portions of this document may be illegible in electronic image products. Images are produced from the best available original document.

Introduction

During the past year, research carried out under this contract covered a number of topics in linear and nonlinear instability theory. Almost all applications were to instabilities and geometries of interest to current experimental studies in the magnetic fusion program.

The major part of the nonlinear studies were on two instabilities; the dissipative-trapped-electron and the drift cyclotron loss cone. The calculation of the trapped electron instability is carried out in linear mirror geometry with parameters characteristic of the Columbia University experiment. In the threshold regime, we find good agreement between the predicted amplitude of the saturated electrostatic oscillations and the observed ones. We have also studied the various saturation mechanisms. It appears that the nonlinear increase in density scale length has the strongest stabilizing effect (at least under conditions characteristic of the Columbia experiment) while a somewhat smaller effect from an increase in the electron temperature scale length is offset by the destabilizing action of increased electron temperature.

The-drift cyclotron loss cone analysis has been successfully carried through for a simple mirror distribution under rather ideal conditions. Threshold saturation was observed. We are now extending this analyses to more realistic perturbations and equilibria in order to make predictions about 2XIB behavior and to encourage experiments in the threshold region.

We have developed an analytic two dimensional treatment of the linear trapped electron instability in Tokamak geometry. This technique results in an accurate treatment of the effects of overlapping rational surfaces and the spatial localization caused by the sensitivity of the trapped electrons to the difference between the pitch of the magnetic field and the mode. It can also complement and under certain circumstances exceed results based on computer cal-

culations. In another development, an improved radial eigenmode treatment has been applied to the collisionless drift instability in Tokamaks, resulting in improved estimates of the growth rate especially away from marginal stability. Further, all radial modes can be considered.

In conjunction with the theoretical group at Oak Ridge, we are preparing a numerical study of tearing effects in Tokamaks caused by drift instabilities. We hope to gain some insight from a numerical solution of two coupled, second order differential equations.

In this report we also note completion of a study of the effect of two unstable modes in the bump on tail problem. It is remarkable that no time-asymptotic solution exists in which both modes have finite amplitude. One or the other must prevail, with the "loser" having zero amplitude at the end. Similar mode survival competition may obtain in multi-mode situations.

Among other items, we report the result of adiabatic modifications to plasma turbulence theories. An often stated prescription for including resonant orbit broadening effects is shown to be incorrect, and the correct prescription noted. We have also obtained an even more general gyro-kinetic procedure which enables one to treat the full Vlasov equation for arbitrary ratios of the gyration radius to the scale length. Finally, we note completion of work on collisional effects on trapped electron instabilities.

1. Nonlinear Saturation of the Dissipative Trapped-Electron Instability (Mirror Geometry)

Experimental studies at Columbia University have established the existence of the trapped electron instability in linear mirror geometry.¹ A stability threshold was observed and measurements were made of the saturated electrostatic field amplitude as a function of the electron collision frequency. We have now carried out an analytic calculation of this instability for parameters

representative of the Columbia experiment. We used methods developed earlier for threshold nonlinear time-asymptotic saturation. The ions were treated using a set of fluid equations including (perpendicular) viscosity, while the untrapped electrons are collisionless and obey the drift-kinetic equation. The trapped electrons are governed by the drift-kinetic equation with a Krook collision term added.

A linear analysis was carried out and a neutral stability curve and a threshold point established. Nonlinear theory then determined the time-asymptotic saturation amplitude and the frequency shift. Our results indicate good agreement with the experimental observations. If $\Delta = (\epsilon - \epsilon_c)/\epsilon_c$, where ϵ_c is the critical value of the electron collision rate and ϵ the actual value, we find $|\Gamma|^2 \approx 0.08\Delta$ while the experiments have $|\Gamma|^2 \approx 0.05\Delta$. Here the electrostatic potential is defined as $\phi = (KT_e/e)\Gamma \sin(\pi r/\ell) \exp[i(\theta + \omega t)]$ where ℓ is the radial dimension of the mirror experiment.

Our analytic results also enable us to verify that the solution is stable and should be of the "soft onset" variety, as observed. We have examined the contributions of various mechanisms to the saturation. The largest stabilizing term arises from the nonlinear increase in the density scale length. Somewhat surprisingly, the stabilizing effect due to increase of the electron temperature scale length is more than cancelled by a destabilizing term resulting from the nonlinear increase in the electron temperature itself.

The results, including some further numerical studies, will form part of Stefano Migliuolo's thesis and should be completed shortly. An article will be prepared, by Migliuolo and Simon, for submission to an appropriate journal.

2. The Trapped Electron Instability in Tokamaks

The trapped electron instability in a Tokamak geometry has a radial mode

structure that typically overlaps many rational surfaces. Numerical solutions of this two dimensional eigenvalue problem are currently being carried out at the University of Texas by Ross and Miner² and at the Princeton Plasma Physics Laboratory by Rewoldt, Tang, and Frieman.³ Previous analytic investigations have been one dimensional, retaining either the radial⁴ or the poloidal⁵ variation. However, retaining only the poloidal variation neglects both shear and, perhaps more importantly, spatial localization effects due to the difference between the pitch of the magnetic field and the mode. On the other hand, the one dimensional radial eigenvalue problem has only been solved in the limit in which the rational surface spacing is large compared to the spatial extent of the mode; a limit not satisfied by the most unstable poloidal mode numbers. Our solution technique removes the preceding analytic shortcomings and, unlike numerical methods, becomes more accurate as more rational surfaces are overlapped.

The results indicate that the spatial localization of the destabilizing trapped electron term is more important than the trapped electron induced coupling of rational surfaces. In fact, in the absence of the ion drifts, the rational surfaces do not couple but rather merely overlap.

Because of the spatial localization of the trapped electron term, Taylor's⁶ coupling mechanism for defeating shear stabilization does not occur. However, this mechanism is expected to enter if our technique can be generalized to include the additional term that represents the coupling of rational surfaces via the ion gradient and curvature drifts.

This work has been performed in collaboration with K. T. Tsang (Oak Ridge) and has been written up in a short version for Physical Review Letters and a longer version, ORNL/TM-5790 (1977), for The Physics of Fluids (Catto).

3. The Collisionless Drift Instability in Tokamaks

In the process of applying the techniques of Rosenbluth and Catto⁷ to the

trapped electron instability,⁸ we realized that their technique could be improved and extended. In the Rosenbluth and Catto paper an improved solution of the one dimensional radial eigenvalue problem for the collisionless drift instability was obtained by a method of matched asymptotic expansions. The resulting eigenvalue equation was found to be in good agreement with the less rigorous perturbation theory expression at marginal stability for the most unstable mode. We have extended the work of Rosenbluth and Catto so that arbitrary growth rates and all radial eigenmodes can be considered. The perturbation theory technique is shown to be valid only near marginal stability; away from marginal stability the more complete eigenvalue equation must be employed. Furthermore, we find that for $(m/M)^{1/2}(L_s/L_n)^{3/2} > 1$ the more complete result must be used near marginal stability as well. Here, m/M is the electron over the ion mass and L_s/L_n is the shear over the density scale length.

This work is also being performed with K. T. Tsang (Oak Ridge) and is nearly complete. The work will be assigned an ORNL/TM number shortly and will be submitted to either Nucl. Fusion or The Phys. of Fluids (Catto).

4. Drift Cyclotron Loss Cone Threshold Behavior in Mirror Machines

Experiments on the 2XIB mirror device have shown that a high density steady state plasma can be sustained by a neutral beam. It appears that a quasilinear model explains this,^{9,10} and that a steady spectrum of excited waves heats cold ions in the loss cone sufficiently to attain marginal stability. While this is a reasonable picture of events in the device when it is operated well beyond the linear instability onset point, it should be possible to operate the experiment at lower densities, close to the linear onset point, and study its saturation there. We are calculating the theory of the device near that point, in a situation when one or only a few modes are excited, in order to learn the precise

mechanism of saturation and in order to provide predictions which might be checked by experiments on 2XIB.

Initially, we have carried through the entire nonlinear saturation procedure for a single mode which has no variation in the field direction ($k_z=0$) and using the local approximation in the radial direction. The equilibrium itself has an empty loss cone and generally has the properties chosen by Post and Rosenbluth in their classic paper.¹¹ We find that there is no difficulty in obtaining an analytic expression for the saturation amplitude of the electrostatic field oscillations and for the nonlinear frequency shift. If we then assume a particularly simple form of the ion distribution function, we can evaluate the amplitude explicitly and have shown that stable saturation does occur ("soft onset" of the instability).

We are currently studying this result, evaluating the detailed saturation mechanism, and varying the ion distribution function and equilibrium to see if there is any special sensitivity of the result to the distribution chosen initially.

We plan a detailed program in which more realistic perturbations and equilibria will be used, including plasma streams in the loss cone, so as to more closely approach the situation actually existent in 2XIB. Details of this plan are in the Proposed Technical Program for continuation of this contract (Myer and Simon).

5. Tearing Effects in Tokamaks Caused by Drift Instabilities

Callen¹² has proposed that the fluctuating magnetic fields associated with drift instabilities may be the source of the anomalous electron heat transport in Tokamaks. These magnetic fields are generated by the microscopic currents associated with the trapped electron and collisionless drift instabilities and permit reconnection or tearing of the magnetic field in the vicinity of rational

surfaces. The resulting island structure then can result in a more rapid perpendicular electron heat transport.

This work is being performed jointly with the theory group at Oak Ridge. We are attempting to understand whether our previous studies¹³ of finite beta effects are adequate. It seems likely that important effects associated with shear Alfvén disturbances have not been properly treated in this or any other work to date. We hope to gain needed insight from a numerical solution of the two coupled, second order differential equations which describe the electric and magnetic fields. The numerical work is being carried out at Oak Ridge by John Whitson (Oak Ridge) and Julius Smith (University of Tennessee/Oak Ridge).

Further motivation for this work comes from this recent work of Rosenbluth and Rutherford¹⁴ and Sigmar and Chan¹⁵ which shows that for reactor size tokamaks the alpha particles can couple to shear Alfvén modes. The resulting instability can produce rapid spatial losses of the alpha population and energy, and prevent the alpha distribution function from obtaining a stable collisional equilibrium¹⁵ (Catto).

6. Nonlinear Saturation of Two Unstable Modes: Survival Competition

We have completed a study of the time-asymptotic solution of the bump-on-tail problem, when there are initially two closely spaced modes on the positive slope region of the bump. All other eigenmodes are assumed reasonably separated in phase velocity and located on negative (stable) slope regions. The time-asymptotic saturated nonlinear solutions are evaluated by a recently developed variation of the Bogoliubov method.¹⁶ In the "quasilinear" approximation (i.e.: zero-frequency mode coupling terms, alone, are retained) the only stable solution is one in which the initially fastest growing mode attains its "single-mode" amplitude and the second mode has zero amplitude. In the full nonlinear calcu-

lation, the result is the same unless the two modes are above a critical distance from the bottom of the slope. Above this critical value, there are two stable solutions. One as just described. The other in which the lower mode reaches its full "single-mode" amplitude and the first has zero amplitude. No stable solution exists for which both modes have finite amplitude. Similar mode survival competition may obtain in multi-mode situations.

A detailed report was issued in late November (PPG-9), and a condensed version by Simon and Migliuolo has been sent to the Physics of Fluids.

7. Adiabatic Modifications to Plasma Turbulence Theories

By treating the adiabatic or Maxwell-Boltzmann response of the electrons exactly the nonlinear dispersion relation for Langmuir waves in an unmagnetized plasma is obtained. The often stated prescription¹⁷ that the nonlinear dispersion relation can be obtained from the linear dispersion relation by replacing the wave frequency ω everywhere it appears by ω plus a nonlinear enhanced diffusion term is found to be incorrect. The proper prescription is found to be the same as for classical unlike Coulomb collisions. The nonlinear dispersion relation can be obtained from its linear counterpart by replacing ω by ω plus an enhanced diffusion term only in the resonant electron contribution to the dispersion relation.

This work is available as Dept. of Mech. and Aero. Sci. Report PPG-8 and has been submitted to The Physics of Fluids. Some work was also underway which attempted to combine Dupree's technique¹⁸ with gyro-kinetics in order to treat magnetized plasmas. However, the recent work of Dupree and Tetreault¹⁹ indicates that the previous work of Dupree for magnetized plasmas must be modified (Catto).

8. Gyro-Kinetics

In order to conveniently treat arbitrary values of the product of the poloidal wavevector times the ion gyroradius in complicated magnetic field geometries, a modification of the techniques of Rutherford and Frieman²⁰ and Taylor and Hastie²¹ has been developed for linearized descriptions.²² In addition, the technique has recently been generalized so that the full Vlasov operator can be treated. The resulting generalized gyro-kinetic equation is valid for arbitrary ratio of the gyration radius to the scale lengths for frequencies and inverse time scales less than the gyration frequency.

The linearized treatment has been written up as Dept. of Mech. and Aero. Sci. Report PPG-10 and submitted to The Physics of Fluids. The generalized treatment should be written up shortly. Some of this work was performed in collaboration with D. E. Baldwin (Livermore). (Catto).

9. Collisional Effects on the Trapped Electron Instability

In this work we considered the effects of ion-ion collisions, collisional broadening of the resonant electron response, and collisional modification of the electron velocity space boundary between the trapped and circulating electrons.

This work with K. T. Tsang and J. D. Callen of Oak Ridge was completed shortly after the previous report. The full report by K. T. Tsang, J. D. Callen, and P. J. Catto is available as ORNL/TM-5236 and has been accepted for publication by The Physics of Fluids. A summary of the preliminary results appears in Plasma Physics and Controlled Nuclear Fusion Research 1976 (International Atomic Energy Agency, Vienna, 1977), Vol. II, p. 489.

10. Personnel

FACULTY --

(a) Peter J. Catto (MAS Dept.) -- Dr. Catto has devoted 20% of his time to this project during the academic year, and full time for one and one half summer months. He supervised two graduate students: one, Tom Speziale, has nearly completed his Ph.D. requirements and is completing a problem related to laser fusion and which is also of interest for RF heating schemes. (Supported by the Laser Energetics Laboratory). The other is George Proulx.

(b) Albert Simon (MAS and Physics) -- Dr. Simon has devoted 20% of his time to this project during the academic year, and full time for two summer months. He supervised two graduate students, Stefano Migliuolo and Richard L. Myer.

GRADUATE RESEARCH ASSISTANTS --

(a) Stefano Migliuolo (Physics Dept.) -- Mr. Migliuolo has nearly completed his Ph.D. requirements. His dissertation concerns the threshold saturation of the dissipative trapped-electron instability. His supervisor is Prof. Simon.

(b) Richard Myer (MAS Dept.) -- Mr. Myer has completed his preliminary examinations and is working on the nonlinear saturation of the drift cyclotron loss cone under the supervision of Prof. Simon.

(c) George Proulx (MAS Dept.) -- Mr. Proulx began preliminary studies on trapped electron instabilities in Tokamak geometry under the supervision of Prof. Catto.

*(d) Chia-Hua Chen (Physics Dept.) -- Mr. Chen, who had just completed his first year of graduate work was considering beginning work on a theoretical thesis in plasma physics. We are sad to report that Mr. Chen died as the result of boating accident here in early July.

* Deceased.

Other Federal Support -- None of the personnel working on this contract have other federal support. The University recovers 4.7% of the academic salary of Prof. Simon and 10% of that of Prof. Catto from the Laboratory for Laser Energetics.

REFERENCES

1. S. C. Prager, T. C. Marshall, and A. K. Sen, *Plasma Physics* 17, 785 (1975).
2. D. W. Ross and W. H. Miner, *Bull. Am. Phys. Soc.* 21, 1152 (1976);
University of Texas Reports FRCR No. 128, January 1977 (unpublished)
and FRCR No. 133, March 1977.
3. G. Rewoldt, W. M. Tang, and E. A. Frieman, *Phys. Fluids* 20, 402 (1977).
4. C. S. Liu, M. N. Rosenbluth, and W. M. Tang, *Phys. Fluids* 19, 1040 (1976)
and P. J. Catto, K. T. Tsang, J. D. Callen, and W. M. Tang, *Phys. Fluids*
19, 1596 (1976).
5. P. T. Liewer, W. M. Manheimer, and W. M. Tang, *Phys. Fluids* 19, 276
(1976).
6. J. B. Taylor, in *Plasma Physics and Controlled Nuclear Fusion Research 1976*
(International Atomic Energy Agency, Vienna, 1977), Vol. II, p.323.
7. M. N. Rosenbluth and P. J. Catto, *Nucl. Fusion* 15, 573 (1975).
8. P. J. Catto and K. T. Tsang, "The Trapped Electron Instability in Tokamaks:
Analytic Solutions of the Two Dimensional Eigenvalue Problem", ORNL/TM-5970
and to be submitted to *The Phys. of Fluids*.
9. Baldwin, Berk, and Pearlstein, *Phys. Rev. Letters* 36, 1051 (1976).
10. Berk and Stewart, *Phys. Fluids* 20, 1080 (1977).
11. R. F. Post and M. N. Rosenbluth, *Phys. Fluids* 9, 730 (1966).
12. J. D. Callen, G. G. Kelly, K. T. Tsang, and B. V. Waddell, "Drift Wave
Turbulence Effects on Magnetic Structure and Plasma Transport in Tokamaks",
paper PC7, May 6, Annual Controlled Fusion Theory Conference, San Diego,
Calif., May 4-6, 1977.
13. P. J. Catto, A. M. El Nadi, C. S. Liu, and M. N. Rosenbluth, *Nucl. Fusion*
14, 405 (1974); and W. M. Tang, C. S. Liu, M. N. Rosenbluth, P. J. Catto,
and J. D. Callen, *Nucl. Fusion* 16, 191 (1976).
14. M. N. Rosenbluth and P. H. Rutherford, *Phys. Rev. Lett.* 34, 1428 (1975).
15. H. C. Chan and D. J. Sigmar, "Anomalous Transport of Alpha Particles in
Toroidal Fusion Plasma Due to Shear Alfvén Wave", paper PC9, May 6, Annual
Controlled Fusion Theory Conference, San Diego, Calif., May 4-6, 1977.
16. A. Simon and M. N. Rosenbluth, *Phys. Fluids* 19, 1567 (1976).
17. J. Weinstock, *Phys. Fluids* 13, 2308 (1970); J. Weinstock and R. H.
Williams, *Phys. Fluids* 14, 1472 (1971); J. Weinstock, *Phys. Fluids* 15,
454 (1972); and J. Weinstock, *Phys. Fluids* 19, 531 (1976).

18. T. H. Dupree, Phys. Fluids 10, 1049 (1967) and 11, 2680 (1968).
19. T. H. Dupree and D. J. Tetreault, "A Renormalized Dielectric Function for Collisionless Drift Wave Turbulence", paper J1, May 6, Annual Controlled Fusion Theory Conference. San Diego, Calif., May 4-6, 1977.
20. P. H. Rutherford and E. A. Frieman, Phys. Fluids 11, 569 (1968).
21. J. B. Taylor and R. J. Hastie, Plasma Phys. 10, 479 (1968).
22. P. J. Catto, "Linearized Gyro-Kinetics", MAS Dept. Report PPG-10, 1977.

PREVIOUS PUBLICATIONS UNDER THIS CONTRACT

1. A. Simon, "Nonlinear Transport in Weakly Ionized Plasma", Phys. Fluids 11, 1181 (1968).
2. A. Simon, "Convection of Weakly Ionized Plasma in a Non-uniform Magnetic Field", Phys. Fluids 11, 1186 (1968).
3. J. J. Kim and A. Simon, "Nonlinear Theory of the ExB Instability", Phys. Fluids 12, 895 (1969).
4. A. Simon and J. N. Shiao, "Quasilinear Theory of the Positive Column Spiral Instability", Phys. Fluids 12, 2630 (1969).
5. J. N. Shiao and A. Simon, "Nonlinear Theory of the Positive Column Spiral Instability", Phys. Fluids 13, 2569 (1970).
6. A. M. Sleeper and A. Simon, "Nonlinear Theory of the Drift-Dissipative Instability", Phys. Fluids 13, 2757 (1970).
7. Albert Simon and C. I. Weng, "Quasilinear Theory of the Mirror Flute Instability", Phys. Fluids 15, 2341 (1972).
8. V. G. Abhyankar and A. Simon, "Linear Threshold of the Buneman-Farley Instability", Phys. Fluids 17, 261 (1974).
9. Donald A. Monticello and Albert Simon, "Nonlinear Theory of the Collisional Drift-Wave Instability", Phys. Fluids 17, 791 (1974).
10. V. G. Abhyankar and A. Simon, "Stability Boundaries for Temperature and Density Gradient Flute Modes in Mirror Machines", Phys. Fluids 17, 2040 (1974).
11. A. Simon, L. Gross and P. J. Catto, "Shear Stability Boundaries for Collisionless Drift Modes in Finite Geometry", Phys. Fluids 18, 231 (1975).
12. M. N. Rosenbluth and P. J. Catto, "An Improved Calculation of Critical Magnetic Shear in an Inhomogeneous Plasma", Nucl. Fusion 15, 573 (1975).

PREVIOUS PUBLICATIONS UNDER THIS CONTRACT (Cont'd)

13. W. M. Tang, C. S. Liu, M. N. Rosenbluth, P. J. Catto, and J. D. Callen,
"Finite Beta and Resonant Electron Effects on Trapped Electron Instabilities", Nucl. Fusion 16, 191 (1976).

THESES COMPLETED UNDER THIS CONTRACT

1. John J. Kim, "The Second Order Shifts in Frequency and Amplitude in the Non-Linear Theory of ExB Instability", Physics Dept., 1969.
2. Jeng-Man Shiau, "Small Amplitude Nonlinear Theory of the Positive Column Spiral Instability", MAS Dept., 1969.
3. Arthur M. Sleeper, "The Drift Dissipative Instability", Physics Dept., 1970.
4. Cheng-I Weng, "Nonlinear Theory of the Mirror Flute Instability", MAS Dept., 1972.
5. Donald A. Monticello, "Nonlinear Theory of the Collisional Drift Wave Instability", Physics Dept., 1973.
6. Vishwas Govind Abhyankar, "Density and Temperature Gradient Flute-Mode Instabilities", MAS Dept., 1974.
7. Leonard Gross, "Nonlinear Theory of the Collisionless Drift Instability", Applied Physics Program, 1975.

LIST OF PUBLICATIONS (Sept. 1976 - Sept. 1977)

A. WORK COMPLETED PREVIOUSLY, BUT PUBLISHED THIS YEAR

<u>Title</u>	<u>Authors</u>	<u>Journal/Status</u>	<u>Percentage ERDA Support</u>
Single Mode Saturation of the Bump-on-Tail Instability: Immobile Ions	A. Simon & M. N. Rosenbluth	Phys. Fluids 19, 1567 (1976)	100%
Resonant Electron Effects on Trapped Electron Instabilities	P.J.Catto, K. T. Tsang, J.D. Callen, & W. M. Tang	Phys. Fluids 19, 1596 (1976)	100%
Single-Mode Saturation of the Bump-on-Tail Instability: II. Mobile Ions	A. Simon	Phys. Fluids 20, 79 (1977)	90%
Linearized Gyro-Kinetic Equation with Collisions	P.J.Catto & K.T. Tsang	Phys. Fluids 20, 396 (1977)	100%
Nonlinear Saturation of the Collisionless Drift Instability	A. Simon & L. S. Gross	Phys. Fluids 20, 946 (1977)	100%
Linear and Nonlinear Theory of Trapped-Particle Instabilities	W.M. Tang, Adam, Cohen, Frieman, Krommes, Rewoldt, Ross, Rosenbluth, Rutherford, Catto, Tsang, & Callen	Plasma Physics and Controlled Nuclear Fusion 1976 (IAEA, Vienna, 1977) Vol. II., p. 489	100%

B. WORK COMPLETED THIS YEAR, OR CONTINUING

<u>Title</u>	<u>Authors</u>	<u>Journal/Status</u>	<u>Percentage ERDA Support</u>
Collisional Effects on Trapped Electron Instabilities	K.T. Tsang, J.D. Callen, & P.J. Catto	Phys. Fluids (accepted)	100%
Non-linear Saturation of Two Unstable Modes: Survival Competition	A. Simon & S. Migliuolo	Phys. Fluids (submitted)	100%

LIST OF PUBLICATIONS (Sept. 1976 - Sept. 1977) (Cont.d)

<u>Title</u>	<u>Authors</u>	<u>Journal/Status</u>	<u>Percentage ERDA Support</u>
Linearized Gyro-Kinetics	P. J. Catto	Phys. Fluids (submitted)	100%
Adiabatic Modifications to Plasma Turbulence Theories	P. J. Catto	Phys. Fluids (submitted)	100%
Analytic Solutions of the Two-Dimensional Eigenvalue Problem for the Trapped Electron	K. T. Tsang & P. J. Catto	Phys. Rev. Lett. (submitted)	100%