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Final Annual Progress on Current DoE Grant for

NONLINEAR AND NONIDEAL MHD

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Co-Principal Investigator: C.C. Hegna, University of Wisconsin-Madison

Grant Period: January 1, 2003 through December 31, 2003

This is the third and final annual progress report on the current 3-year "Nonlinear and Nonideal MHD" DoE grant DE-FG02-86ER53218 for the six months since the November 2002 progress report. During this grant year the funding level was $309k. The participating personnel and their approximate degree of funded involvement in this research project this grant year has been as follows: Professor J.D. Callen (PI, 1.8 months during academic year, 2.2 summer months); Professor C.C. Hegna (Co-PI: 2.3 months during academic year, 1.5 summer months); postdoc Dr. S. Gupta (100%); and graduate students A.L. Garcia-Perciante (50% RA) and X. Liu (50% RA).

Progress on the three areas in which research was proposed for the current three-year grant period has been as follows* in the third year of the grant:

Nonlinear MHD [1,3,4,7,8,9]

Recently, we have developed a sheared-slab model for the nonlinear evolution of magnetic-shear-localized, pressure-gradient-driven interchange instabilities (Suydam, Mercier instabilities). Currently, we are using it to explore [7] the growth and "saturation" of these modes in both their feeble ($0.25 < D_I < 0.45$) and robust ($0.45 < D_I$) growth regimes. Unlike the case with no magnetic shear where quasilinear pressure profile flattenening produces saturation, here changes in the magnetic structure plays the dominant role in "saturation." Specifically, the magnetic field is distorted as the mode grows until the pressure gradient free energy is no longer accessible, and eventually plasma resistivity relaxes the "sheet" current induced by the radial advection of the magnetic field caused by the growing instability.

In addition, we have continued to explore various effects on the nonlinear evolution of neoclassical tearing modes: toroidal geometry, especially for spherical tokamaks at low aspect ratio [1], interaction of energetic ions and magnetic islands in toroidal plasmas [9], and seed island formation via transient transport events [4,8]. In recognition of our leadership in NTM theory and nonlinear MHD issues, the Co-PI has been called upon to give various workshop summary-type talks [3] on contemporary issues in these areas.

Nonideal MHD [2,3,6,10]

First, we have continued our development of a model for the dynamic electrical conductivity in a bumpy cylinder magnetic field [6]. In this work we seek to develop a basic theoretical model for calculating and understanding in a fluid context the responses to time-varying flows and currents when trapped particles are present and lead to (dynamic) parallel viscous damping. Second, we have been highlighting and exploring [3,10] the importance of both nonresonant and resonant [2] magnetic perturbations to the axisymmetric tokamak geometry in increasing neoclassical transport processes, and in particular in causing the (sometimes dominant) toroidal flow damping of Resistive Wall Modes (RWMs). (The fundamental theory has been carried out mainly by K.C. Shaing and funded by his DoE grant. The adaptation of the radial transport results to toroidal damping was done on this grant.)

* References indicated by [] are given at the end of this report and represent publications, talks and seminars that resulted from this grant.

NIMROD Collaboration [5]

Both the PI and Co-PI have participated in most of the NIMROD Team and CEMM meetings over the past year. In addition, we have specifically begun to develop [5], in collaboration with C.R. Sovinec, two-fluid vector field equations that include diamagnetic flows, gyroviscosity and parallel viscous damping effects. The object of this work is to develop rigorous, complete two-fluid equations for NIMROD simulations in which the full vector-field equations of MHD are solved rather than the usual analytic-based reduced MHD descriptions.

Other Topics, Activities

A list of the numerous programmatic activities of the PI and Co-PI since the last progress report is given at the end of this brief report.

Summary

The primary research efforts this year have focused on exploring the nonlinear evolution of magnetic-shear-localized interchange instabilities [7], some extensions of neoclassical tearing mode theory [1,2,3,4,8,9,10], and developing a model for the dynamic electrical conductivity in a bumpy cylinder magnetic field [6]. In addition, we have vigorously participated in the computationally-focused NIMROD and CEMM projects.

Grant-Related Publications In Last Six Months

Journal Articles, Conference Proceedings Papers:

[1]+ A. L. Rosenberg, D. A. Gates, A. Pletzer, J. E. Menard, S. E. Kruger, C. C. Hegna, F. Paoletti, and S. Sabbagh, "Modeling of neoclassical tearing mode stability for generalized toroidal geometry," Phys. Plasmas **9**(11), 4567 (2002).

[2]+ K. C. Shaing, C. C. Hegna, J. D. Callen, and W. A. Houlberg, "Plasma Transport Processes in the Vicinity of a Magnetic Island in a Tokamak," Proceedings of the 19th IAEA Conference on Nuclear Fusion, Lyon, France, October 14-19, 2002, TH/2-6 (IAEA, Vienna, 2003).

Invited Talks:

[3]+ C.C. Hegna, "Issues in Neoclassical MHD Modeling," at Workshop on Active Control of MHD Stability, November 19, 2002, Columbia University, New York, NY.

[4] C.C. Hegna, "Seed Magnetic Island Formation Via Transient Transport Events," at the 8th Plasma Easter Meeting, April 23, 2003, Turin, Italy.

Meeting Presentations:

International Sherwood Fusion Theory Conference, Corpus Christi, TX April 28-30:

[5] J.D. Callen, C.C. Hegna, C.R. Sovinec, "Two-Fluid Vector Equations For MHD Numerical Simulations."

[6] A.L. Garcia-Perciante, J.D. Callen, K.C. Shaing and C.C. Hegna, "Dynamic Electrical Conductivity In A Bumpy Cylinder Magnetic Field."

[7] Sangeeta Gupta, J.D. Callen and C.C. Hegna, "Nonlinear Dynamics of Shear-Localized Interchange Instabilities."

[8] C.C. Hegna, "Seed island formation of neoclassical tearing modes via transient transport events."

[9] X. Liu, C.C. Hegna, "The Effects of Energetic Ions on Magnetic Islands in Toroidal Plasmas."

Seminars:

[10]+ J.D. Callen, "RWM Damping Due To Toroidal Viscosity," Integrated Modeling Meeting, General Atomics, March 19.

+ These research contributions were supported in part or primarily by our DOE collaboration grant (on "Large Scale Experiment Data Analysis Collaboration," DE-FG02-92ER54139) and/or K.C. Shaing's DoE grant (on "Neoclassical Transport Theory and Its Applications," DE-FG02-01ER54619). They are listed here because they are currently relevant to or were primarily motivated by current or previous work on this Nonlinear and Nonideal MHD grant.

Magnetic Fusion Program and Professional Activities for Past Six Months:

J.D. Callen

Program Committee, International Sherwood Fusion Theory Conference, Corpus Christi, TX, April 28-30
Rosenbluth Theory Award Committee, General Atomics
Participated in NIMROD Team meeting – Corpus Christi, TX April 27
Participated in CEMM meeting – Corpus Christi, TX April 27
Participated in MHD Working Group meeting – Corpus Christi, TX April 27
Member, Fusion Theory Coordinating Committee (TCC) – meeting at Corpus Christi, TX April 27
Director, Center for Plasma Theory and Computation, UW-Madison
Organizer of weekly Plasma Theory Seminars, UW-Madison
Arranged, hosted biannual UW Fusion Town meetings
Organizer, host of monthly informal UW Fusion Leaders meetings.

C.C. Hegna

US-JET Coordinating Committee on Collaborations, Deputy US coordinator on neoclassical tearing mode research
Member of the International Tokamak Physics Assessment (ITPA) Experts Group On MHD Issues.
Summarized MHD-related Snowmass Activities at the MHD Working Group Meeting, November 10, Orlando, FL.
National Compact Stellarator Experiment (NCSX) Program Advisory Committee Meeting, Princeton, NJ Dec. 9-10.
Responsible for UW-Madison Plasma Seminars for fall semester 2002
Participated in NIMROD Team meeting – Corpus Christi, TX April 27
Participated in CEMM meeting – Corpus Christi, TX April 27
Participated in MHD Working Group meeting – Corpus Christi, TX April 27
Marshall N. Rosenbluth Outstanding Doctoral Thesis Award Committee, American Physical Society
Trips to Culham/JET (February 1-14, March 9-21) and Kurchatov Institute, Moscow (tentatively May 11-16) in order to develop collaborations on theoretical topics of mutual interest.