November 2002

Annual Progress on 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, 2002 through December 31, 2002

This is the second annual progress report on the current 3-year "Nonlinear and Nonideal MHD" DoE grant DE-FG02-86ER53218. During this grant year the funding level was \$312k. 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, 15% during academic year, 2 summer months); Professor C.C. Hegna (Co-PI: 25% during academic year, 1 summer month); Professor C.R. Sovinec (1 summer month); postdoc Dr. S. Gupta (100%); and graduate student A.L. Garcia-Perciante (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 second year of the grant:

Nonlinear MHD [2,3,5,7,9,10,11,13,14,16,21]

A simple model for the linear stability of localized MHD interchange instabilities has been developed [2,21]. It shows that magnetic-shear-localized interchange instabilities have feeble growth rates, particularly when resistive and FLR effects are included – until the Suydam/Mercier criterion is exceeded by about a factor of two. Recently, we have developed a sheared-slab model [7] for the nonlinear evolution of these instabilities and are using it to explore [14,21] the growth and "saturation" of these modes in both their feeble and robust growth regimes.

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 [3], interaction of energetic ions and magnetic islands in toroidal plasmas [5], current sheets and magnetic island formation [13], and seed island formation via toroidally coupled magnetic perturbations [16]. 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 [9-11] on contemporary issues in these areas.

Nonideal MHD [4,6,12,15,17,19]

Two major new themes have emerged this past year. First, we have begun developing a model for the dynamic electrical conductivity in a bumpy cylinder magnetic field [12,17]. In this work we seek to develop a basic theoretical model for calculating and understanding the responses to time-varying flows and currents when trapped particles are present and lead to (dynamic) parallel viscous damping – as a paradigm for exploring the dynamics of seed island formation in NTMs and other transients in toroidal plasmas. Second, we have been highlighting [19] and exploring the role and importance of both nonresonant and resonant [4,6] magnetic perturbations to the axisymmetric tokamak geometry in increasing neoclassical transport processes, and in particular in causing (sometimes dominant) toroidal flow damping. (The theory has mainly been carried out by K.C. Shaing and funded by his DoE grant.) Finally, we continue to explore [15] possible hybrid ballooning-type instabilities in the presence of nonideal effects such as Landau damping and parallel electron heat conduction in low collisionality regimes.

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

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NIMROD Collaboration [1,20]

Both the PI and Co-PI have participated in most of the NIMROD Team and CEMM meetings over the past year. This past year a key paper was published [1] on the NIMROD simulation of neoclassical tearing modes (NTMs). It used numerical implementations of the heuristic closures developed by the Co-PI from our analytic work on NTMs over the years. Also, the PI gave a talk [20] at JET that highlighted NIMROD simulations of NTMs and the nonlinear evolution of a global ideal MHD instability as it is heated slowly through its instability threshold, which was stimulated by our analysis of shot #87009 in DII-D a few years ago.

Other Topics, Activities [8,9,10,11,18]

In addition to the preceding areas, we have been collaborating [18] with Wayne Houlberg of ORNL in exploring the possible "heat pinch" effects of neutral beam momentum input in NSTX, based on an extension and application of the ideas presented in the PI's paper on neutral beam effects in plasmas at the 1974 IAEA Tokyo meeting. Programmatically, we have been rather active this past year with the Co-PI having had a large role [8-11] in the 2002 Snowmass Fusion Summer Study through his co-chairing of the MHD Working Group there. A detailed list of the numerous programmatic activities of the PI and Co-PI this past year is given at the end of this brief report.

Summary

The primary efforts this year have focused on exploring the nonlinear evolution of localized interchange instabilities, some extensions of neoclassical tearing mode theory, and developing a model for the dynamic electrical conductivity in a bumpy cylinder magnetic field. In addition, we have vigorously participated in the computationally-focused NIMROD and CEMM projects.

Grant-Related Publications

Journal Articles, Conference Proceedings Papers:

- [1] T. A. Gianakon, S. E. Kruger and C. C. Hegna, "Heuristic Closure for Numerical Simulations of Neoclassical Tearing Modes," *Physics of Plasmas* **9**(2), 536-547 (2002).
- [2] S. Gupta, C. C. Hegna, and J. D. Callen "Violating Suydam criterion produces feeble instabilities," *Phys. Plasmas* **9**(8), 3395-3401 (2002).

Reports and Other Publications (in the process of being submitted for publication):

- [3] 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," to be published in *Phys. Plasmas*.
- [4] 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 (also UW-CPTC 02-2, October 2002).

Meeting Presentations:

International Sherwood Theory Conference, Rochester, NY April 22-24:

- [5] C.C. Hegna, "The Interaction of Energetic Ions and Magnetic Islands in Toroidal Plasmas," poster 1C44.
- [6] J.D. Callen, K.C. Shaing, C.C. Hegna, "Plasma and Momentum Transport in the Vicinity of a Magnetic Island in a Tokamak," poster 1D31.
- [7] Sangeeta Gupta, C.C. Hegna and J.D. Callen, "Nonlinear dynamics of a shear-localized ideal interchange instability," poster 2C29.
- [8] C.C. Hegna, "Activities of the MHD physics working group," special Snowmass Session.
- [9] C.C. Hegna, "Summary of the Discussion of Stability Issues for the U. S. Tokamak Program," presented with J. Menard, PPPL, U. S. Tokamak Planning Workshop on Alcator C-Mod and DIII-D Plans for 2003-2008, San Diego, CA June 10-12.
- [10] C.C. Hegna, "Neoclassical Tearing Mode Issues for ITER," "Neoclassical Tearing Mode Issues for FIRE," presentation on behalf of the MHD Working Group at the Snowmass 2002 Fusion Energy Sciences Summer Study, Snowmass, CO, July 10-11.
- [11] C.C. Hegna, "Stability of $m = 1$ Modes in Burning Plasma Experiments," presentation on behalf of the MHD Working Group at the Snowmass, 2002 Fusion Energy Sciences Summer Study, Snowmass, CO, July 16.
- [12] J.D. Callen, "Hybrid MHD Modeling of the Dynamic Electrical Conductivity Response in a Bumpy Cylinder Magnetic Field," Magnetofluid Modeling Workshop, GA, San Diego, August 19-20.

Annual DPP-APS Meeting Orlando, FL, November 11-15:

- [13] C.C. Hegna, "Current Sheets and Magnetic Island Formation in 3-D Magnetostatic Equilibria," oral FM1.002.
- [14] Sangeeta Gupta, J.D. Callen, C.C. Hegna, "Nonlinear evolution of shear-localized ideal interchange instability," poster FP1.089.
- [15] J.D. Callen, C.C. Hegna, "Hybrid MHD Ballooning Instabilities?" poster FP1.090.
- [16] C.C. Hegna, J.D. Callen, "Dynamics of toroidally coupled magnetic perturbations and seed magnetic island formation in tokamak plasmas," poster FP1.096.
- [17] A.L. Garcia-Perciante, J.D. Callen, C.C. Hegna, K.C. Shaing, "Dynamic Electrical Conductivity In A Bumpy Cylinder," poster GP1.078.
- [18] W.A. Houlberg, K.C. Shaing, J.D. Callen, "Neutral Beam Driven Neoclassical Transport in NSTX," poster GP1.104.

Seminars:

- [19] J.D. Callen, "Magnetic Island Effects On Equilibria; Flow Evolution With Field Errors," Integrated Modeling Group Meeting, General Atomics, San Diego, February 13.
- [20] J.D. Callen, "Studies of Nonlinear and Extended MHD Modes in Advanced Tokamaks," JET Seminar, Abingdon, UK, May 20.

[21] J.D. Callen, "Violating Suydam Criterion Produces Feeble Instabilities," Culham Theory Seminar, Culham, ENGLAND, May 21.

Magnetic Fusion Program Activities:

J.D. Callen

Participated in 3D Systems (Stellarator) Workshop, Oak Ridge, TN January 7-9

U.S. Selection Committee (Chair of Theory Part) for 2002 IAEA Conference, Germantown, MD, 25-26 February

Participated in NAE Regional Meeting, Madison, WI, March 18

Participated in NIMROD Team meetings – Rochester, NY April 20,21, GA, San Diego, August 21-22, and Orlando, FL November 10,11

Participated in CEMM meetings – Rochester, NY April 21, GA, San Diego, Aug. 21 and Orlando, FL November 11

Participated in MHD Working Group meetings – Rochester, NY April 21, Orlando, FL, November 11

Member, Fusion Theory Coordinating Committee (TCC) – meetings at Sherwood Rochester, NY April 22 and DPP-APS Orlando, FL November 11

Program Committee for 2002 IAEA Fusion Energy Conference, Lyon, FRANCE, October 14-19 – committee meeting (chair of theory part) in Vienna, AUSTRIA May 13-17

Member, Program Advisory Committee (PAC) for Fusion Science Discovery Through Advanced Computing (SCIDAC) – meeting at PPPL, June 3,4

Participated in PPPL 50 year celebration, Princeton, NJ June 5,6

Participated in Fusion Leaders meeting with Ray Orbach, Washington, DC June 28

Participated in 2002 Fusion Summer Study, Snowmass, CO, July 8-19, at which gave talk "Fusion Has A Unique Opportunity to Grow – By Adding An Energy Focus, BPX" on July 16

Member FESAC Burning Plasma Experiment Strategy Panel, Austin, TX, August 6-8

Member, Transport Task Force Steering Committee – meeting in Orlando, FL, November 10

Member, Program Committee for 2003 Sherwood Conference, Corpus Christi, TX, April 2003

Director, Center for Plasma Theory and Computation, UW-Madison

Organizer of weekly Plasma Theory Seminars, UW-Madison

Arranged, hosted UW Fusion Town meetings, May 1 and October 2

Organizer, host of monthly informal UW Fusion Leaders meetings

C.C. Hegna

Participated in 3D Systems (Stellarator) Workshop, Oak Ridge, TN January 7-9

DIII-D Program Advisory Committee – December 5,6, 2001

Participated in 3D Systems (Stellarator) Workshop, Oak Ridge, TN January 7-9

US-JET Coordinating Committee on Collaborations, Deputy US coordinator on neoclassical tearing mode research

Participated in NIMROD Team meetings – Rochester, NY April 20,21 and Orlando, FL November 10,11

Participated in CEMM meetings – Rochester, NY April 21, GA and Orlando, FL November 11

Participated in MHD Working Group meetings – Rochester, NY April 21, Orlando, FL, November 11

Organizer of the Snowmass MHD Working Group meeting, Rochester, NY, April, 2002.

Facilitator of the discussion of stability plans for the U. S. Tokamak Planning Workshop on Alcator C-Mod and DIII-D Plans for 2003-2008, June 10-12

MHD Sub-Group Convener for the 2002 Snowmass Summer Fusion Study, July 2002

Responsible for UW-Madison Plasma Seminars for fall semester 2002