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Annual Progress Report on DOE Grant for

LARGE EXPERIMENT DATA ANALYSIS COLLABORATION

Principal Investigator: J.D. Callen, University of Wisconsin-Madison

Grant Period: November 15, 2000 through November 14, 2001
(Plus no-cost extension period from 11/16/01 to 4/30/02)

This is the third and final annual progress report on the current 3-year "Large Experiment Data Analysis Collaboration" DOE grant DE-FG02-92ER54139. During this 12 month grant year (plus 5.5 month no-cost extension), the funding level was $155k. The participating personnel and their approximate degree of funded involvement in this research project this extended grant year has been as follows: J.D. Callen (PI, 9% during academic year, 1 summer month); C.C. Hegna (Associate Scientist promoted to Associate Professor 10/27/01, 20%); graduate students K. Comer (on average 50% RA) and X. Liu (50% RA beginning 9/01). In addition, this grant has provided a subcontract for about $80k for the period 11/00 through 12/01 for work by PI S.E. Kruger of SAIC San Diego on "Effect of Flow Shear On Tearing Modes."

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

Neoclassical Tearing Modes [1,2,4-8,19,20,21,24-27,29]

Because of the good agreement between theory and experiment (on a number of tokamak experiments) on the nonlinear development, saturation of neoclassical tearing modes (NTMs), the study of NTMs is becoming a mature subject. Thus, our contributions to studies of neoclassical (and regular classical) tearing modes over the past year have focused on a number of particular, more detailed issues: flow shear effects on linear tearing modes [4,5], exploring the possibility of NTMs in spherical tokamaks such as NSTX [5,19], assisting with classical tearing mode explorations in DIII-D [1,2,7,8,20], and fast ion effects on NTMs [24]. In addition, a collaboration with the Institute for Plasma Research group in India was initiated [19] due to their interest in using the NEAR code (developed in part under this grant) to explore neoclassical tearing modes. Finally, a number of talks have been given on basic [29], current frontier [25] and future extensions [26,27] of neoclassical tearing mode theory.

Disruption Precursors [1,3,9,11,12,14,16-18,22,23]

Our previous identification [J.D. Callen, C.C. Hegna, B.W. Rice, E.J. Strait and A.D. Turnbull, Phys. Plasmas **6**, 2963 (1999)] of the disruption precursor in DIII-D shot 87009 as being due to a global ideal MHD interchange-type instability being driven slowly though its threshold was featured prominently in the DIII-D MHD theory paper [1] at the 2000 IAEA Sorrento meeting. We have also stimulated the application [11] of the NIMROD code to this particular DIII-D disruption precursor and continued to support [16,18] this code exploration of it. To facilitate quicker evaluations of global-type

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

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ideal MHD growth rates and eigenmodes, we have continued our development of a new method for using perturbed equilibria to "maneuver in delta-W" space. Since this basic concept for efficiently finding trends in ideal MHD stability using perturbed equilibria has been proven using a screw-pinch geometry [9,14], we are now beginning to implement and test the procedure in the GATO code for specific DIII-D high beta equilibria [23]. In addition, to analytically explore the ultimate nonlinear evolution [12] of these types of modes, we have begun (primarily on our DOE "Nonlinear and Nonideal MHD" theory grant) exploring the growth rate and eigenmode structure of localized interchange instabilities [3,17,22]. A surprising aspect of that work is that robust, ideal MHD-like growth rates and radially spread eigenmodes are only obtained when the Suydam/Mercier criteria are exceeded by about a factor of two ($D_I > 0.45$) [3].

Other Topics [10,13,15,28]

A new issue we have begun exploring [13] is how "thin, isolated" magnetic islands and their effects can be incorporated into MHD equilibria and hence the EFIT code. In addition, we have given presentations on more general fusion [28], and MHD [10,15] topics, which have included some of the results developed under this research grant.

Summary

Progress in studies of neoclassical tearing modes has been made primarily on: flow shear effects [4,5], DIII-D tearing mode analysis [1,2,7,8,20], and application to NSTX spherical tokamak plasmas [5,19]. Regarding disruption precursors, we have mainly been developing models of linear eigenmodes and nonlinear evolution of interchange-type modes [3,12,17,22], and continued development of a perturbative approach to delta-W stability analysis [9,14,23]. In addition, over the past two years, this subcontract has facilitated the development of a stronger interaction between SAIC San Diego (particularly S.E. Kruger) and the DIII-D program. It has also introduced nonlinear initial value codes (NEAR and NIMROD) into the DIII-D program.

Grant-Related Publications

Journal Articles, Conference Proceedings Papers:

[1] A.D. Turnbull, D. Brennan, M.S. Chu, L.L. Lao, J.R. Ferron, A.M. Garofalo, P.B. Snyder, J. Bialek, I.N. Bogatu, J.D. Callen, M.S. Chance, K. Comer, D.H. Edgell, S.A. Galkin, D.A. Humphreys, J.S. Kim, R.J. La Haye, T.C. Luce, M. Okabayashi, B.W. Rice, E.J. Strait, T.S. Taylor, and H.R. Wilson, "Predictive Capability of MHD Stability Limits in High Performance DIII-D Discharges," Paper TH 3/6 at 18th IAEA Fusion Energy Conference, Sorrento, Italy, 4-10 October 2000 (IAEA, Vienna, 2001).

Reports (in the process of being revised, expanded and/or submitted for publication):

[2] D.Brennan, M.S. Chu, S. Kruger, R.J. LaHaye, T.C. Luce, E.J. Strait, T.S. Taylor, A.D. Turnbull "Tearing Mode Stability Studies on DIII-D," GA-A23717, July 2001

[3]+ Sangeeta Gupta, C.C. Hegna and J.D. Callen, "Violating Suydam criterion produces feeble instabilities," UW-CPTC 01-7, October 2001.

Meeting Presentations:

Annual DPP-APS Meeting, Quebec City, October 23-27, 2000:

[4] S.E. Kruger, C.C. Hegna, J.D. Callen, "Effect of Flow Shear on Tearing Modes," paper HP1 14, Bull. Am. Phys. Soc. **45**, No. 7, 168 (2000).

[5]+ C.C. Hegna, "The effect of sheared rotation on resistive layer calculations," paper HP1 15, Bull. Am. Phys. Soc. **45**, No.7, 168 (2000).

[6]+ A. Rosenberg, D. Gates, A. Pletzer, C. Hegna, S. Kruger, "Modeling of Neoclassical Tearing Mode Stability for NSTX," paper MP1 141, Bull. Am. Phys. Soc. **45**, No.7, 250 (2000).

[7] A.D. Turnbull, M.S. Chu, L.L. Lao, P.B. Snyder, J.R. Ferron, R.J. La Haye, E.J. Strait, J.D. Callen, K. Comer, M.S. Chance, A.M. Garafolo, S.A. Galkin, "Ideal and Non-Ideal MHD Stability in High-Performance DIII-D Discharges," paper NP1 82, Bull. Am. Phys. Soc. **45**, No.7, 276 (2000).

[8] D.P. Brennan, E.J. Strait, M.S. Chu, A.D. Turnbull, T.S. Taylor, S.E. Kruger, "Sensitivity Studies of Tearing Mode Stability Calculations," paper NP1 90, Bull. Am. Phys. Soc. **45**, No.7, 277 (2000).

[9] Kate Comer, Jim Callen, Chris Hegna, Steve Cowley, "Macroscopic Stability of Toroidal Plasma Equilibria," paper WP1 70, Bull. Am. Phys. Soc. **45**, No.7, 362 (2000).

[10]+ J.D. Callen, "MHD Theory and Computation," presentation to OFES/DOE Budget Planning Meeting, Gaithersburg, MD, March 13-15.

2001 International Fusion Theory Conference, Santa Fe, NM, April 2-4, 2001:

[11] D.D. Schnack, S.E. Kruger, A. Tarditi, M.S. Chu and The NIMROD Team, "Numerical Studies of High-Beta Disruption in DIII-D Shot 87009 Using the NIMROD Code," paper 1C24.

[12]+ S. Mahajan, J.D. Callen, C.C. Hegna, "Nonlinear Evolution of Driven Ideal MHD Instabilities," paper 1C30.

[13] J.D. Callen, C.C. Hegna, "Effects of Magnetic Islands in Axisymmetric Equilibria," paper 2D40.

[14] K.J. Comer, J.D. Callen, C.C. Hegna, S.C. Cowley, A.D. Turnbull, "Efficiently Finding Trends in Macroscopic MHD Stability Using Perturbed Equilibria: Review of Screw Pinch and Initial Application to Toroidal Geometry," paper 3B42.

[15]+ J.D. Callen, "ST Theory Development Panel: Preliminary Summary," NSTX PAC-11 Meeting at PPPL (via videoconference from Madison), October 4.

[16] S.E. Kruger, "Simulations of DIII-D Discharges with Vacuum," NIMROD Team meeting, Long Beach,, CA, October 27.

[17]+ Sangeeta Gupta, "Linear eigenmode analysis of localized ideal interchange modes," National MHD Working Group Meeting, Long Beach, CA, October 28.

DPP-APS Long Beach,CA, October 28 – November 2 Meeting:

[18] D.D. Schnack, S.E. Kruger, A.G. Tarditi, NIMROD Team, "Numerical Simulation of High-Beta Disruption in DIII-D Shot 87009 with the NIMROD Code," paper CP1 67, Bull. Am. Phys. Soc. **46**, No. 8, 76 (2001).

[19] D. Chandra, A. Sen, P. Kaw, M. Bora, S. Kruger, "Neoclassical Tearing Mode Simulations with NEAR," paper CP1 74, Bull. Am. Phys. Soc. **46**, No. 8, 78 (2001).

[20] D.P. Brennan, M.S. Chu, R.J. La Haye, T.C. Luce, E.J. Strait, T.S. Taylor, A.D. Turnbull, S. Kruger, "Tearing Mode Onset and Evolution Studies on DIII-D," paper FO1 7, Bull. Am. Phys. Soc. **46**, No. 8, 102 (2001).

[21] D.A. Gates, E. Fredrickson, J. Menard, A. Pletzer, A. Rosenberg, S.A. Sabbagh, S. Kruger, C.C. Hegna and the NSTX Team, "Investigation of Neoclassical Tearing Modes on NSTX," paper GO1 9, Bull. Am. Phys. Soc. **46**, No. 8, 138 (2001).

[22]+ Sangeeta Gupta, J.D. Callen, C.C. Hegna, "Linear and Nonlinear Evolution of Driven Ideal MHD Instability," paper GP1 121, Bull. Am. Phys. Soc. **46**, No. 8, 167 (2001).

[23] K.J. Comer, J.D. Callen, C.C. Hegna, A.D. Turnbull, S.C. Cowley, "Efficiently Finding Trends in Macroscopic MHD Stability Using Perturbed Equilibria," paper GP1 122, Bull. Am. Phys. Soc. **46**, No. 8, 167 (2001).

[24]+ C.C. Hegna, "The Effect of Energetic Ions on Magnetic Islands in Toroidal Plasmas," paper KP1 42, Bull. Am. Phys. Soc. **46**, No. 8, 190 (2001).

[25] C.C. Hegna, (invited talk), "Seed Magnetic Island Formation due to Coupling of MHD Perturbations," Workshop on Control of MHD Stability By Rotation, General Atomics, San Diego, CA, November 5-7.

[26] C.C. Hegna, "Future Plans for NTM Theory," and "Summary of Rotation Part of Meeting." Workshop on Control of MHD Stability By Rotation, General Atomics, San Diego, CA, November 7.

[27] C.C. Hegna, "Extended MHD and Applications to DIII-D," DIII-D PAC meeting, San Diego, CA, December 6.

Seminars:

[28]+ J.D. Callen, "Fusion Energy: Promise, Characteristics, Status and Future," Lawrence University, Appleton, WI, November 30, 2000.

[29]+ C.C. Hegna, "Neoclassical Tearing Modes," Engineering Physics Department Colloquium, UW-Madison, March 7, 2001.

+ These research contributions were supported primarily by our DOE theory grant (on "Nonideal and Nonlinear MHD," DE-FG02-ER53218) and are listed here because they are currently relevant to or were motivated by previous work on this Large Experiment Data Analysis Collaboration grant.

Magnetic Fusion Program Activities:

J.D. Callen:

Member, Fusion Theory Coordinating Committee (TCC) – meetings at Sherwood Santa Fe, NM April 2 and DPP-APS Long Beach, CA October 29.

Organizer and Host of Closures Workshop, July 30, 31 CEMM Workshop July 31 and NIMROD Meeting, August 1-3, all at Pyle Center, UW-Madison.

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

Participated in NSTX Results Review Meeting, PPPL, September 19,20.

Chair, ST Theory Development Panel – meetings at PPPL September 21 and at Long Beach, CA October 31; videoconference with NSTX PAC-11 October 4.

Member, Transport Task Force Steering Committee.

Sytems Administrator for UW NERSC Computing Allocations (uw repository, and mp200 repository until summer 2001 when Carl Sovinec took it over), and the CPTC cluster of X-terminals, workstations.

Participated in NIMROD Team meetings – Princeton, November 13-14, 2000, Santa Fe, NM, April 4-5, 2001, Madison, WI, August 1-2 and Long Beach, CA, October 27, 28.

Participated in CEMM meetings – Madison, WI, July 31 and Long Beach, CA, October 28.

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

Organizer of weekly Plasma Theory Seminars, UW-Madison, monthly informal UW Fusion Leaders meetings.

C.C. Hegna:

Participant in Burning Plasma Physics Issues Workshop, Austin, TX, December 2000.

Member FESAC MFE Theory Review Panel – mtgs. at UCLA January 31, February 1 and at PPPL March 29, 30.

Member, NCSX Program Advisory Committee – meetings at PPPL in April and November 12,13.

Organized RFP Theory Workshop, Madison, WI, April 18,19.

Participated in NIMROD Team meetings – Santa Fe, NM, April 4,5, Madison, WI, August 1-3 and Long Beach, CA, October 27, 28.

Participated in CEMM meetings – Madison, WI July 31 and Long Beach, CA October 28.

ITPA Participant, Co-organizer of NTM Physics Studies on JET as part of US/JET Collaboration.

Member, DIII-D Program Advisory Committee, San Diego, December 5-6.

Co-convener for MHD Subgroup of Burning Plasma Physics Group, member of Organizing Committee for 2002 Snowmass Meeting on Burning Plasma Physics.

Member, Organizing Committee for 3D Systems Workshop to be held at ORNL, January 7-9, 2002.