2003 International Sherwood Fusion Theory Meeting

April 28-30
Corpus Christi, Texas

Hosted by Members of the
Institute for Fusion Studies
The University of Texas at Austin

International Sherwood Fusion Theory Conference

April 28-30, 2003
Omni Corpus Christi Hotel
Bayfront Tower
Corpus Christi, Texas

Hosted by Members of the
Institute for Fusion Studies
The University of Texas at Austin

Executive Committee
Mark Carter (*Chair*), ORNL
Tom Rognlien (*Vice-Chair*), LLNL
Greg Hammett (*Secretary/Treasurer*), PPPL
John Cary, University of Colorado
Daniel D'Ippolito, Lodestar Research Corp
Stephen Eckstrand, U.S. Department of Energy
Richard Fitzpatrick, University of Texas
Alan Glasser, LANL
Parvez Guzdar, University of Maryland
Philip Snyder, General Atomics
Linda Sugiyama, MIT
Paul Terry, University of Wisconsin
Linda Vahala, Old Dominion University

Organizing Committee
Boris Breizman, University of Texas
John Cary, University of Colorado
Wendell Horton, University of Texas
Philip Morrison, University of Texas
Philip Snyder, General Atomics
Saralyn Stewart, University of Texas
Prashant Valanju, University of Texas

Program Committee
Diego del-Castillo-Negrete (Chair), ORNL
Boris Breizman, University of Texas
Jim Callen, University of Wisconsin
Cynthia Phillips, PPPL
Tom Rognlien, LLNL
Linda Sugiyama, MIT

Administrative Staff
Jill Morris, University of Rochester
Barbara Sarfaty, PPPL
Saralyn Stewart, University of Texas

Network Manager
Jim Dibble, University of Texas

Web Designer
Natalie Calvert, Stonehenge Networks
design@stonehenge-net.com

Cover photo: The south mall view of The University of Texas at Austin tower (built in 1936, standing 27 stories high) and the Littlefield War Memorial Fountain (made in Chicago, 1920). The fountain was donated to The University by George Washington Littlefield and the sculptor was Pompeo Coppini (born in Moglia Province of Mantova, Italy).

Registration Schedule

Sunday, April 27	18:00 to 21:00
Monday, April 28	7:30 to 11:30 and 13:00 to 17:00
Tuesday, April 29	7:30 to 11:30
Wednesday, April 30	7:30 to 10:00

Social Schedule

Sunday, April 27	19:00 to 21:00	*Howdy Reception*
Monday, April 28	9:00 to 10:30	*Companions Breakfast*
Tuesday, April 29	12:00 to 17:30	*Free afternoon*
Tuesday, April 29	17:30 to 19:00	*Fajita Feast*

Program Organization

The program consists of three invited review papers, 14 oral contributed papers selected out of 44 oral submissions, and poster presentations. The total number of presentations is 180. Satellite meetings are also scheduled during the conference.

Meeting Program

All technical sessions will be held in the Omni Hotel, Bayfront Tower, Third Level.

- The **review talks** will be held at 08:30 Monday through Wednesday (1A, 2A, 3A).
- The **oral sessions** will be held:
  - 1B at 09:30 Monday morning
  - 1D at 13:30 Monday afternoon
  - 2B at 09:30 Tuesday morning
  - 2D at 19:00 Tuesday evening
  - 3B at 09:30 Wednesday morning
  - 3C at 10:30 Wednesday morning
- The **poster sessions** will be held:
  - 1C at 10:00 Monday morning
  - 1E at 15:30 Monday afternoon
  - 2C at 10:00 Tuesday morning

Satellite Meetings

NIMROD Meeting

Saturday, April 26, 13:00 to 18:00
Aransas Room, Omni Bayfront Hotel, 3rd level
and
Sunday, April 27, 08:30 to 12:00
Aransas Room, Omni Bayfront Hotel, 3rd level

Center for Extended MHD Meeting

Sunday, April 27, 14:00 to 18:00
Aransas Room, Omni Bayfront Hotel, 3rd level

Theory Coordinating Committee Meeting

Monday, April 28, 20:00 to 22:00
Aransas Room, Omni Bayfront Hotel, 3rd level

Sherwood Executive Committee Meeting

Tuesday, April 29, 12:30 to 15:30
Aransas Room, Omni Bayfront Hotel, 3rd level

Poster Sessions

Poster Session 1C
Monday, April 28, 10:00 to 12:00, Corpus Christi Ballroom AB

1C01 J. D. Callen, C. C. Hegna, C. R. Sovinec
"Two-Fluid Vector Equations For MHD Numerical Simulations"

1C02 Emily Belli, Gregory W. Hammett, William Dorland
"Shaping and Toroidal Effects in a Local Linear Gyrokinetic Code"

1C03 Z. Lin, T. S. Hahm, and G. Rewoldt
"Progress in Global Gyrokinetic Simulations of Tokamak Microturbulences"

1C04 W. Park, J. A. Breslau, J. Chen, G. Y. Fu, S. C. Jardin, S. Klasky, A. Pletzer, H. R. Strauss, L. E. Sugiyama
"Nonlinear Plasma Simulation Studies Using M3D"

1C05 H. R. Strauss, W. Park, A. Pletzer, J. Breslau, S. Jardin, D. Monticello, G. Y. Fu, L. E. Sugiyama, R. Torasso, Roberto Paccagnella, Daniel Weil
"M3D Simulations of Stellarators, ITER Halo Currents, and Divertor Spheromaks"

1C06 L. E. Sugiyama, H. R. Strauss, W. Park, G. Y. Fu
"Two-Fluid Effects on Stability and Beta Limits in 3D Configurations"

1C07 G. Y. Fu, E. Fredrickson, W. Park, H. R. Strauss
"Simulations of Energetic Particle Mode in NSTX"

1C08 J. Breslau, S. Hudson, S. Jardin, W. Park
"Towards a Comprehensive Model of the m=1 Mode in Tokamaks"

1C09 Andrei M. Simakov, Peter J. Catto, X. Q. Xu
"Drift-Ordered Fluid Equations for Flute-Like Modes in Low-beta Collisional Plasma with Equilibrium Pressure Pedestals"

1C10 Peter J. Catto and Andrei N. Simakov
"Short Mean Free Path Transport for a Drift Ordering"

1C11 A. Y. Aydemir and A. B. Gott
"Driven Reconnection in a Quadrupole Cusp Field"

1C12 A. B. Gott and A. Y. Aydemir
"Equilibrium and Stability in Configurations with Large Flows"

1C13 M. K. Addae-Kagyah, J. W. James, E. D. Held
"Studies of Local and Nonlocal Models of Parallel Heat Flow"

1C14 A. Airoldi, G. Cenacci, B. Coppi
"Fusion Burning Physics Issues for the Ignitor Experiment"

Poster Sessions

1C15 A. Alexakis, F. Pétrélis, P. J. Morrison, C. R. Doering
"An Upper Bound on the Dissipation Rate of Hartmann's Flow"

1C16 Amit Apte and P. J. Morrison
"Renormalization and Destruction of Tori in Area Preserving Maps"

1C17 Rowena Ball
"A Smooth Path from Dissipative to Shear Regulation of Plasma Turbulence-Flow Dynamics"

1C18 Glenn Bateman, Jon Kinsey, Arnold H. Kritz, Alexie Pankin, Thawatchai Onjun, Jan Weiland, and Pär Strand
"Parameter Dependence of Drift Modes Associated with Turbulence in Tokamaks"

1C19 C. G. Bathke, J. M. Finn and R. A. Nebel
"Hysteresis in Single Helicity and Quasi-Single Helicity States in Reversed Field Pinches"

1C20 Roy Bickerton
"Burning Plasma Proposals"

1C21 G. Boffetta, D. del-Castillo-Negrete, C. Lopez, G. Pucacco and A. Vulpiani
"Self-Consistent Diffusion in Coupled Symplectic Maps"

1C22 F. Bombarda
"Diagnostic Issues for the Burning Plasma Experiment Ignitor"

1C23 P. T. Bonoli, M. Porkolab, J. C. Wright, R. W. Harvey
"A Comparison of Different Models for Lower Hybrid Current Drive"

1C24 D. Borgogno, F. Califano, D. Farino, D. Grasso, F. Pegoraro, F. Porcelli
"Multiple Helicity Modes in 3D Collisionless Magnetic Reconnection"

1C25 A. Bottino, S. Allfrey, P. Angelino, O. Sauter, L. Villard, and J. Vaclavik
"Electrostatic Microinstabilities in High Confinement and Internal Transport Barrier Discharges"

1C26 D. P. Brennan, R. J. La Haye, A. D. Turnbull, L. L. Lao, S. E. Kruger, D. D. Schnack
"Nonlinear Tearing Mode Evolution in Sawtoothing Discharges"

1C27 J. Candy and R. E. Waltz
"Semi-Implicit Electron Advection in GYRO"

1C28 Johan Carlsson
"Particle-in-Cell Simulations of ICRF Wave-Particle Interaction"

Poster Sessions

1C29 M. S. Chance, M. S. Chu, A. H. Glasser, M. Okabayashi and F. W. Perkins
"Modeling of the Feedback Stabilization of the Resistive Wall Mode in Tokamaks"

1C30 B. I. Cohen. A. M. Dimits, W. M. Nevins, Y. Chen, and S. E. Parker
"Limitations on a Kinetic Electron Closure for Extended Hybrid Electromagnetic Simulation of Drift Waves"

1C31 R. H. Cohen, B. I. Cohen, C. R. Sovinec, G. A. Cone
"Searching for a Better Spheromak with NIMROD"

1C32 A. Cole, R. Fitzpatrick
"Forced Magnetic Reconnection in the Taylor Problem"

1C33 K. J. Comer, J. D. Callen, C. C. Hegna, A. D. Turnbull, S. C. Cowley
"Exploring Macroscopic MHD Stability Trends Using Perturbed Equilibria: Successes and Limitations with Toroidal Geometry"

1C34 G. A. Cone and C. R. Sovinec
"Magnetic Topology Evolution and Thermal Energy Transport in Coaxial Plasma Gun Spheromak Simulations"

1C35 Bruno Coppi
"New Experimental Evidence in Support of the Accretion Theory for the Spontaneous Rotation Phenomenon and Relevant Developments"

1C36 P. S. Coppi and B. Coppi
"Importance of Non-Linear Effects on Tridimensional Singular Modes of Accretion Disks and Inadequacies of Axisymmetric Modes"

1C37 C. Crabtree, W. Horton, H. V. Wong, J. Van Dam, L. Chen
"Magnetic Drift Compressionl Modes in High beta Plasmas"

1C38 D. del-Castillo-Negrete, B. A. Carreras, and V. Lynch
"Fractional-Diffusion Models of Anomalous Diffusion"

1C39 J. Q. Dong, S. M. Mahajan, and W. Horton
"Double Tearing Mode in Plasmas with Anomalous Electron Viscosity"

1C40 J. F. Drake, M. Swisdak, M. A. Shay, C. Cattell, B. N. Rogers, A. Zeiler
"Development of Electron Holes and Anomalous Resistivity in 3-D Magnetic Reconnection"

1C41 D. Yu. Eremin and H. L. Berk
"Generation and Analysis of Multiple Phase Space Structures"

Poster Sessions

1C42 D. R. Ernst, P. T. Bonoli, P. Catto, W. Dorland, C. L. Fiore, M. Greenwald, A. Hubbard, J. Irby, E. Marmar, D. Mossessian, M. Redi, J. Rice, S. Wolfe, S. Wukitch, K. Zhurovich, and the Alcator C-Mod Group
"Role of Trapped Electron Mode Turbulence in Density Profile Control with ICRH in Alcator C-Mod"

1C43 E. G. Evstatiev, W. Horton, P. J. Morrison
"Multi-Wave Model for Plasma-Wave Interaction"

1C44 Willis Ferenbaugh, D. E. Newman, P. W. Terry
"Continuing Inquiries Into R/S-like Dynamic Scaling Measures"

1C45 N. M. Ferraro, B. N. Rogers
"Turbulence in Low-Beta Reconnection Events"

1C46 John M. Finn and Luis Chacon
"Control of Nonlinear Resistive Wall Modes"

1C47 M.-C. Firpo and B. Coppi
"Critical Importance of Nonlinear Processes for the Onset of Internal Modes"

1C48 Richard Fitzpatrick
"Scaling of Forced Magnetic Reconnection in the Hall-MHD Taylor Problem"

1C49 M. Fomyts'kyi, A. Arefiev, and B. Breizman
"Explosion of Laser-Irradiated Micro-Clusters"

1C50 R. Ganesh, P. Angelino, J. Vaclavik and L. Villard
"A Full Radius Gyro-Kinetic Stability Analysis for Large Aspect Ratio High-Beta Tokamaks: Role of B_||"

1C51 P. R. Garabedian
"Power Plant Study of Compact Stellarators"

1C52 A. L. Garcia-Perciante, J. D. Callen, K. C. Shaing and C. C. Hegna
"Dynamic Electrical Conductivity in a Bumpy Cylinder Magnetic Field"

1C53 A. M. Garofalo, T. H. Jensen, M. S. Chu, G. A. Navratil, M. Okabayashi, H. Reimerdes, and E. J. Strait
"Insight in the Stabilization of a Resistive Wall Mode by Plasma Rotation"

1C54 Preston Geren, Loren Steinhauer
"Effect of Conserved Angular Momentum on Minimum Energy States"

1C55 A. H. Glasser and X. Z. Tang
"Progress in the Development of the SEL Macroscopic Modeling Code"

Poster Sessions

Poster Session 1E
Monday, April 28, 15:30 to 17:30, Corpus Christi Ballroom AB

1E01 Brent Goode, John R. Cary, and L. A. Berry
"Combined Parallel Gradient and Collisional Decorrelation Effects in the Absorbtion of RF Waves"

1E02 N. N. Gorelenkov, E. Fredrickson, E. Belova, C. Z. Cheng
"Theory of Sub-Cyclotron Instabilities of Alfven Eigenmodes Due to Energetic Ions in Low Aspect Ratio Plasmas"

1E03 V. Grandgirard, M. Brunetti, P. Bertrand, P. Ghendrih, X. Garbet, G. Manfredi, M. Ottaviani, Y. Sarazin, O. Sauter, J. Vaclavik, L. Villard
"A Modified Semi-Lagrangian Scheme for Non-Linear Drift-Kinetic Simulations of SLAB-ITG"

1EO4 L. Guazzotto, R. Betti
"MHD Equilibria with Arbitrary Flow"

1E05 Sangeeta Gupta, J. D. Callen and C. C. Hegna
"Nonlinear Dynamics of Shear-Localized Interchange Instabilities"

1E06 P. N. Guzdar, R. G. Kleva, R. J. Groebner, P. Gohil, N. Chakrabarti
"Generation of Zonal Flows and Fields in Tokamak Edge Plasmas: Application to DIII-D and Effects of Ion Temperature"

1E07 Eliezer Hameiri
"Dynamically Accessible Perturbations and MHD Stability"

1E08 James D. Hanson, Steven P. Hirshman, Stephen F. Knowlton, Lang Lao and Edward A. Lazarus
"Equilibrium Reconstruction in Stellarators: V3FIT"

1E09 R. D. Hazeltine, S. M. Mahajan, H. Quevedo and P. M. Valanju
"Equilibrium of a Rotating Mirror Plasma - I"

1E10 C. C. Hegna
"Seed Island Formation of Neoclassical Tearing Modes via Transient Transport Events"

1E11 E. D. Held
"Neoclassical Tearing Mode Simulations with Integral Heat Flow Closures"

1E12 W. Horton
"Multi-Scale Temperature Gradient-Driven Turbulence in Tokamaks"

Poster Sessions

1E13 S. Hu and Liu Chen
"Hybrid Simulations of Alfvenic Instabilities Excited by Bounce-Precession Resonances in Tokamaks"

1E14 Yi-Min Huang and A. B. Hassam
"MHD Stability of Centrifugally Confined Plasmas"

1E15 S. R. Hudson, D. A. Monticello, A. H. Reiman, A. H. Boozer, D. J. Strickler, S. P. Hirshman, and M. C. Zarnstorff
"Eliminating Islands in High-Pressure Free-Boundary Stellarator Magnetohydrodynamic Equilibrium Solutions"

1E16 T. Islam and B. Coppi
"Analysis of Nonaxisymmetric Modes in Accretion Disks at Marginal Stability with Nonlinear Diffusion and Dissipation"

1E17 J. W. James, E. D. Held
"Electron Heat Confinement in Reversed Field Pinches"

1E18 B. D. Jemella, M. A. Shay and J. F. Drake
"Transition from Rutherford to Sweet Parker Magnetic Reconnection"

1E19 Christopher S. Jones, Philip J. Morrison
"Closures of the Vlasov-Poisson System"

1E20 Allan N. Kaufman, Eugene R. Tracy
"The Triple Helix in Two-Dimensional Linear Wave Conversion"

1E21 J. Kesner, L. Bromberg, D. T. Garnier, A. Hansen, M. Mauel
"Helium-Catalyzed D-D Fusion in a Levitated Dipole"

1E22 E. A. Keyes, B. Coppi
"Ballooning Modes in Thin Accretion Disks"

1E23 Charlson C. Kim and Scott E. Parker
"Hybrid Kinetic-MHD Simulations in General Geometry"

1E24 R. G. Kleva, P. N. Guzdar, W. Dorland, and J. F. Drake
"Edge Transport in Tokamaks with Noncircular Flux Surfaces"

1E25 James C. Kniep, Jean-Noel Leboeuf and Viktor K. Decyk
"Gyrokinetic Particle-in-Cell Calculations of Ion Temperature Gradient Driven Turbulence with Parallel Nonlinearity and Strong Flow Corrections"

1E26 D. A. Knoll and L. Chacon
"Physics-based Preconditioning and Newton-Krylov Methods for Extended MHD"

Poster Sessions

1E27 M. Kotschenreuther, L. Zheng
"Novel Divertor Designs and Their Motivation"

1E28 S. I. Krasheninnikov and P. J. Catto
"On Electron Heat Transport in Spherically Symmetric Geometry"

1E29 Todd Krause and P. J. Morrison
"A Darwin Fluid Model"

1E30 Arnold H. Kritz, Thawatchai Onjun, Vassili Parail, Glenn Bateman, Johnny Lönnroth, Guido Huysmans
"Simulations and Stability Analysis of ELMs in JET Discharges"

1E31 S. E. Kruger, D. D. Schnack
"NIMROD Simulations of a High Beta Disruption in the DIII-D Tokamak"

1E32 G. Lapenta, P. Ricci, and J. U. Brackbill
"Magnetic Reconnection: Effects of the 3rd Dimension"

1E33 J. N. Leboeuf, V. K. Decyk, A. Dimits, and D. Shumaker
"Tests of General Geometry Capabilities in the Summit Gyrokinetic Framework"

1E34 W. W. Lee, J. L. V. Lewandowski, H. Qin and T. Jenkins
"Shear and Compressional Alfven Waves in Gyrokinetic Plasmas"

1E35 H. Li. K. Nishimura, and X. Z. Tang
"Magnetic Dissipation in Force-Free Magnetic Fields -- 3D PIC Simulation of a Sheet-Pinch Configuration"

1E36 Y. R. Lin-Liu, F. L. Hinton, F. W. Perkins
"Neoclassical Bootstrap Current in High beta-p Tokamak Plasmas"

1E37 R. Lionello, D. D. Schnack
"MH4D: An MHD Algorithm on an Unstructured Tetrahedral Grid"

1E38 X. Liu, C. C. Hegna
"The Effects of Energetic Ions on Magnetic Islands in Toroidal Plasmas"

1E39 J. F. Lyon, L. A. Berry, M. J. Cole, S. P. Hirshman, B. E. Nelson, D. A. Spong, D. J. Strickler, A. S. Ware. D. E. Williamson, E. Barcikowski, P. J. Fogarty, G. Y. Fu, P. Goranson, D. Mikkelsen, P. K. Mioduszewski, D. A. Monticello, R. Sanchez, D. Westerly
"Overview of the QPS Experiment"

1E40 A. I. D. Macnab, G. Vahala, L. Vahala
"Nested Grids in Lattice Boltzmann Representation of Resistive MHD"

1E41 M. A. Malkov, P. H. Diamond, M. N. Rosenbluth, I. Gruzinov
"A Two-Field Model of the L-->H Bifurcation"

Poster Sessions

1E42 G. J. Marklin
"MHD Simulation of the HIT-SI Experiment"

1E43 J. P. Matte, F. Allais, C-G. Kim, F. Alouani-Bibi, D. Stotler, T. D. Rognlien
"Non-Local Electron Parallel Heat Transport in Divertor Plasmas and Atomic Physics Rates"

1E44 V. V. Mirnov, C. C. Hegna, S. C. Prager
"Effect of Dynamo on Electric Field and Current Density in Reversed Field Pinches"

1E45 M. J. Mithaiwala, W. Horton, Wei-Tai Lin
"Simulated Injection of Relativistic Electrons"

1E46 Robert Moestam, Dastgeer Sheikh and Jan Weiland
"Self Consistent Theory of Zonal Flows in Ion Temperature Gradient Turbulence"

1E47 D. Kh. Morozov and M. Pekker
"Self-Organization in Radiative Plasmas"

1E48 P. J. Morrison and B. A. Shadwick
"On the Fluctuation Spectrum of Plasma"

1E49 R. A. Nebel, J. Park, W. Rellergert, M. Sekora, S. Stange
"Experimental and Theoretical Studies of Electrostatic Confinement on the Intense Neutron Source (INS-e) Device"

1E50 C. Nieter, J. R. Cary, R. W. Harvey, R. Dominguez, A. P. Smirnov
"Simulation of Electron-Bernstein Wave Absorption Using VORPAL"

1E51 M. Ottaviani, F. Porcelli, D. Grasso
"Nonlinear Stability of Drift-Tearing Magnetic Islands"

1E52 Alexei Pankin, Glenn Bateman, Parvez Guzdar, Robert Kleva, Arnold Kritz and Thawatchai Onjun
"Evaluation of Models for L-H Transition in Tokamak Plasmas"

1E53 S. E. Parker, Y. Chen, W. M. Nevins and B. I. Cohen
"Characteristics and Features of Electromagnetic Microturbulence with Kinetic Electrons"

1E54 F. W. Perkins, R. Harvey, M. Chu, R. LaHaye, R. Prater
"Neoclassical Tearing Modes: Revisiting Theoretical Foundations"

1E55 F. Pétrélis, A. Alexandros, C. R. Doering, and P. J. Morrison
"Bounds on the Dissipation Rate in Sheared MHD Flows"

Poster Sessions

Poster Session 2C
Tuesday, April 29, 10:00 to 12:00, Corpus Christi Ballroom AB

2C01 A. Yu. Pigarov, G. Q. Yu, S. I. Krasheninnikov, D. A. D'Ippolito, J. R. Myra, D. R. McCarthy, T. D. Rognlien, J. A. Boedo, D. L. Rudakov, W. P. West, B. LaBombard, B. Lipschultz, R. Maingi, and V. Soukhanovsky
"On Non-Diffusive Plasma Transport at Tokamak Edge"

2C02 I. Predebon, L. Marrelli, R. B. White, and P. Martin
"Test Particle Approach for Transport Studies in the RFP"

2C03 J. Preinhaelter, V. Shevchenko, M. Valovic, P. Pavlo, L. Vahala, G. Vahala, and the MAST team
"Simulation of ECE from MAST"

2C04 T. Rafiq, M. H. Nasim, and M. Persson
"Influence of Geometry on Drift Waves in Tokamaks and Stellarators"

2C05 J. J. Ramos
"Dynamic Evolution of the Heat Fluxes in a Collisionless Magnetized Plasma"

2C06 H. L. Rappaport
"Driven Poloidal Spin-Up with Rotating Magnetic Field"

2C07 M. Redi, R. Bell, C. Bourdelle, W. Dorland, D. Gates, K. Hill, S. Kaye, B. LeBlanc, J. Menard, D. Mikkelsen, G. Rewoldt
"Linear Gyrokinetic Calculations of Microturbulence in H-Mode on NSTX"

2C08 Jim Reynolds and Carl Sovinec
"Computational Studies of Magnetohydrodynamic Phenomena in the Reversed Field Pinch During PPCD"

2C09 P. Ricci, G. Lapenta, and J.U. Brackbill
"Collisionless Reconnection in Presence of a Guide Field"

2C10 T. D. Rognlien, X. Q. Xu, M. V. Umansky, R. H. Cohen, and W. M. Nevins
"Coupled Turbulence and Transport Evolution for Magnetized Edge Plasmas"

2C11 V. Roytershteyn and B. Coppi
"Relevance of the ITG Localized Modes to the Accretion Theory of Angular Momentum "Generation" "

2C12 D. D. Ryutov, R. H. Cohen, L. D. Pearlstein
"Stability Analysis for a Finite Aspect Ratio Screw Pinch"

2C13 M. Salvetti and B. Coppi
"Rationale for the Columbus Experiment"

Poster Sessions

2C14 R. Samtaney, S. Jardin, P. Colella, D. Martin
"Simulations of Pellet Injection in Tokamaks Using AMR"

2C15 A. K. Sen, M. Nagashima, and R. W. Longman
"Optimal Control of Tokamak Resistive Wall Modes in Presence of Noise"

2C16 J. Seol and C. C. Hegna
"Role of Bumpy Fields on Single Particle Orbit of Near Quasi-Helically Symmetric Stellarators"

2C17 B. A. Shadwick, C. B. Schroeder, G. M. Tarkenton, and E. H. Esarey
"Comparing Envelope and Full-Fluid Models of Intense Laser-Plasma Interactions"

2C18 K. C. Shaing
"Island Rotation with Island Induced Viscosity in Tokamaks"

2C19 S. E. Sharapov and A. B. Mikhailovskii
"Effect of Hot Ions With Large Orbits on MHD Spectrum in Tokamaks"

2C20 WITHDRAWN

2C21 S. G. Shasharina, R. Eger, J. R. Cary, T. W. Fredian, D. Alexander
"Distributed Technologies for Nuclear Fusion Data"

2C22 C. Smith and S. Johnston
"Periodic Orbits in Muonic Hydrogen Atoms Exposed to Both Circularly-Polarized Laser Light and a Uniform Magnetic Field"

2C23 P. B. Snyder, H. R. Wilson and X. Q. Xu
"Developments in the Peeling-Ballooning Model of ELMs and Pedestal Constraints"

2C24 C. R. Sovinec and H. Tian
"Use of Nonsymmetric Algebraic Operators in a Semi-Implicit MHD Advance"

2C25 D. A. Spong, S. P. Hirshman, D. J. Strickler, J. F. Lyon. L. A. Berry, A. S. Ware, E. Barcikowski, G. Y. Fu, D. Mikkelsen, D. A. Monticello, R. Sanchez, D. Westerly
"Physics Issues of Compact Quasi-Poloidal Stellarators"

2C26 D. J. Strickler, S. P. Hirshman, D. A. Spong, L. A. Berry, M. J. Cole, J. F. Lyon, B. E. Nelson, A. S. Ware, D. E. Williamson
"Development of a Robust Class of Quasi-Poloidal Compact Stellarator Configurations"

2C27 D. J. Strozzi, A. K. Ram, and A. Bers
"Coherent Ion Energization by Electrostatic Waves"

Poster Sessions

2C28 V. A. Svidzinski, S. C. Prager
"Effects of Fast Particles on Internal Modes in Reversed Field Pinches"

2C29 A. Takayama, A. Yu. Pigarov, S. I. Krasheninnikov, Y. Tomita, and T. D. Rognlien
"Edge Plasma Simulations for Large Helical Device with UEDGE"

2C30 X. Z. Tang, Z. H. Wang, A. H. Boozer
"Plasma Potential of an Electrostatically Driven Plasma"

2C31 Alfonso G. Tarditi and Loren C. Steinhauer
"Plasma Flow Control in a Magnetic Nozzle for Electric Propulsion and Fusion Scrape-Off Layer Applications"

2C32 M. Tessarotto, A. Beklemishev
"Nonlinear Covariant Kinetic Theory of Magnetoplasmas"

2C33 Jean-Luc Thiffeault, P. J. Morrison
"Nonlinear MHD Stability and Dynamical Accessibility"

2C34 Y. Todo, H. L. Berk and B. N. Breizman
"Simulation of Intermittent Beam Ion Loss in a TFTR Experiment"

2C35 R. Torasso, E. Hameiri, H. R. Strauss, C. C. Hegna, S. R. Hudson
"Ideal MHD Ballooning Modes and Stability Boundaries of Near Helically Symmetric Stellarators"

2C36 Eugene R. Tracy, John M. Finn, Wei Yang, and Bill Cooke
"Random Attractors and ELMs"

2C37 Leaf Turner and Alan H. Glasser
"Nonlinear Resistive MHD Analysis of the Turbulent Dynamo and Pressure-Driven Transport in the Reversed-Field Pinch"

2C38 M. V. Umansky, R. H. Bulmer, D. N. Hill, W. M. Nevins, D. D. Ryutov, S. Woodruff
"Modeling of Effects of Magnetic Perturbation on the Quality of Flux Surfaces in SSPX Spheromak"

2C39 George Vahala, Linda Vahala, Jeffrey Yepez
"Quantum Lattice Gas Representation for Vector Solitons"

2C40 F. L. Waelbroeck
"Shielding of Resonant Magnetic Perturbations in the Long Mean-Free-Path Regime"

2C41 R. E. Waltz, J. Candy, and F. L. Hinton
"Progress on Full Radius Gyrokinetic Turbulence Simulations and Prospects for Treating Transport Time Scales With GYRO"

Poster Sessions

2C42 W. Wan, Y. Chen and S. E. Parker
"Delta-f Simulation of Collisionless Tearing Modes"

2C43 S. Wang, A. S. Ware, S. P. Hirshman, D. A. Spong
"Stellarator Optimization: A Comparison of Genetic, Differential Evolution, and Levenberg-Marquadt Optimization Algorithms"

2C44 W. X. Wang, W. M. Tang, F. L. Hinton, L. E. Zakharov, and R. B. White
"Neoclassical Transport Calculation for ST Plasma"

2C45 A. S. Ware, E. Barcikowski, L. A. Berry, G. Y. Fu, S. P. Hirshman, J. F. Lyon, R. Sanchez, D. A. Spong, D. J. Strickler
"Ideal MHD Stability of the Quasi-Poloidal Stellarator"

2C46 T.-H. Watanabe, H. Sugama, W. Horton, and V. H. Wong
"A Non-Dissipative Closure Model for Mirror Instability in a Collisionless Plasma"

2C47 P. G. Watson, I. J. D. Craig, J. Heerikhuisen
"Hall Current Effects in Dynamic Magnetic Reconnection Solutions"

2C48 D. Westerly, A. S. Ware, L. A. Berry, S. P. Hirshman, J. F. Lyon, R. Sanchez, D. A. Spong, D. J. Strickler
"Second Ballooning Stability Access in the Quasi-Poloidal Stellarator"

2C49 Roscoe White, Leonid Zakharov
"Bootstrap Current Simulation"

2C50 H. Vernon Wong
"MHD-Like Plasma Equations for Hybrid-Particle Simulations"

2C51 J. C. Wright, P. T. Bonoli, M. Brambilla and E. D'Azevedo
"Full Wave Simulations of ICRF Mode Conversion and Lower Propagation in Toroidal Geometry"

2C52 Alexander Wurm and P. J. Morrison
"Action Principle Derivation of Generalized Magnetofluid Models"

2C53 Bai-Yu Xu, W. Horton, H. V. Wong, C. Crabtree, J. Van Dam
"Nonlinear Dynamics of the Firehose Instability in Magnetic Dipoles"

2C54 L.-J. Zheng, M. Kotschenreuther
"Development of the Kinetic Adaptive MHD Codes: AEGIS"

Monday Morning, April 28

08:30 to 09:30

Corpus Christi Ballroom C

Review Talk 1A

1A01

New frontiers in controlling the motion of matter with light: from single atoms to neurons

Mark G. Raizen

Center for Nonlinear Dynamics and Department of Physics
The University of Texas at Austin
Austin, TX 78712

In this overview talk I will discuss recent experiments in my group on the interactions and control of matter with light. At the atomic level we have been studying the interface between quantum mechanics and nonlinear dynamics. I will describe some recent experiments on atomic motion in "optical billiards", a new system that we developed, and indicate some future directions for quantum dynamics and control in many-body systems. In the past two years we have also extended our work to the realm of biophysics in collaboration with the group of Josef Kas. We have shown experimentally that we can use weak light forces to precisely guide the direction of neuron growth, which opens many exciting directions for the future.

Monday Morning, April 28

09:30 to 10:00

Corpus Christi Ballroom C

Oral Session 1B

1B01

Blob Stability and Transport in the SOL Plasma*

D. A. D'Ippolito and J. R. Myra
Lodestar Research Corporation, Boulder, Colorado

S. I. Krasheninnikov, G. Q. Yu and S. A. Galkin
University of California, San Diego, California

A growing body of experimental data suggests that non-diffusive transport of particles can play a major role in the SOL. This transport may be associated with the propagation of high density plasma filaments or "blobs" that have been observed in experiments with both fast cameras and probes. Previous theoretical work [1, 2] showed that these structures would propagate to the wall due to the curvature-drift-induced polarization and the associated E×B radial drift. A remarkable feature of the blob convection theory is that experimentally observed properties, such as transport coefficients increasing toward the wall, emerge naturally as a result of the relation between the radial (x) convective velocity and poloidal (y) blob scale size, $v_x \propto 1/y_b^2$. The theory is also qualitatively consistent with the experimental observations of spatial and temporal intermittency and non-Gaussian statistics in SOL transport.

The simple blob theory predicts that the radial particle flux depends on the blob size distribution. Recent work has addressed the related question of blob stability. 2D simulations using a reduced MHD model appropriate to the SOL indicate that the dominant instability for small blobs is the Kelvin-Helmholtz mode, while for large blobs it is the sheath-interchange mode; the competition between these instabilities determines the blob size and shape distribution. Blobs that are highly elongated in either x or y are unstable, leading to smaller blobs with scale length L determined by stability considerations. The simulations reproduce the theoretical scaling of the convective transport $v_x(y_b)$ in the limit of a small background density; blobs are observed to merge or bifurcate to reach the optimal scale with corresponding changes in v_x. A background density reduces the radial velocity and modifies the blob structure: the leading edge steepens and the electrostatic potential forms a dipole structure. 1D stability analyses allow a more detailed study of parameter space and put the simulations in context. Implications of this work for SOL transport estimates and data analysis will be discussed.

*Work supported by the U.S. Dept. of Energy under DOE Grants No. DE-FG03-97ER54392 and DE-FG03-00ER54568.

1. S. I. Krasheninnikov, Phys. Lett. A **283**, 368 (2001).
2. D. A. D'Ippolito, J. R. Myra, and S. I. Krasheninnikov, Phys. Plasmas **9**, 222 (2002).

Monday Morning, April 28

10:00 to 12:00

Corpus Christi Ballroom AB

Poster Session 1C

Two-Fluid Vector Equations For MHD Numerical Simulations*

J.D. Callen, C.C. Hegna, C.R. Sovinec

University of Wisconsin, Madison, WI 53706-1609

The usual derivations of reduced equations for magnetohydrodynamic (MHD) and two-fluid descriptions of plasmas are based on reduced MHD descriptions [1] in which the plasma flow velocity **V** and the magnetic field **B** are represented by scalar and vector potentials. In these reduced MHD descriptions the compressional Alfvèn waves are eliminated analytically by the conditions that, to lowest order in $k_{\|}/k_{\perp}$, the perpendicular flow is incompressible and $\tilde{P} + \tilde{B}_{\|} B_0/\mu_0 = 0$.

However, the modern MHD simulation code NIMROD [2] advances the vector fields **V** and **B** directly — in order to avoid high-order spatial derivatives which are prone to numerical errors, to be able to consider free-boundary equilibria with embedded separatrices, and to more easily satisfy the boundary conditions at a bounding surface. In order to eliminate a time-step restriction due to compressional Alfvèn waves, the NIMROD code uses a semi-implicit algorithm [3] in which the operator describing the waves embodied in the linearized MHD force operator are put on the left of the flow velocity evolution equation [4]. This procedure allows a much larger time-step — many times longer than the compressional Alfvèn time scale and comparable to the shear-Alfven wave and hence instability time scale. It also facilitates simulations of the nonlinear evolution to saturation of regular and neoclassical tearing modes which occurs on time scales that are fractions of the magnetic skin diffusion time scale and of the order of the plasma energy confinement time scale.

In order to faclitate inclusion of two-fluid effects, and in particular the diamagnetic flow effects, in the NIMROD code, we have begun developing vector field forms of the two-fluid equations that include kinetic-based closure relations (for the heat flux **q** and parallel viscous stress $\pi_{\|}$) and the gyroviscosity effects [5], without eliminating the compressional Alfvèn waves and without using vector and scalar potential representations of **V** and **B**. This poster will report progress in this regard, and illustrate how electron and ion diamagnetic flow effects enter in both the reduced MHD and vector field forms of the equations, and lead to their respective effects on pressure-gradient-driven and tearing-type current-gradient-driven instabilities.

*Research supported by DoE grant DE-FG02-86ER53218.

[1] See S.E. Kruger, C.C. Hegna, and J.D. Callen, "Generalized reduced magnetohydrodynamic equations," Phys. Plasmas **5**, 4169 (1998) and references cited therein.
[2] C.R. Sovinec, D.C. Barnes, T.A. Gianakon, A.H. Glasser, R.A. Nebel, S.E. Kruger, D.D. Schnack, S.J. Plimpton, A. Tarditi, M.S. Chu and the NIMROD Team, "Nonlinear Magnetohydrodynamics Simulation using High-Order Finite Elements," UW-CPTC 02-05 (submitted to J. Comput. Phys.).
[3] D.S. Harned and D.D. Schnack, J. Comput. Phys. **65**, 57 (1986).
[4] K. Lerbinger and J.F. Luciani, J. Comput. Phys. **97** (1991)
[5] E.V. Belova, Phys. Plasmas **8**, 1267 (2001).

1C02

Shaping and Toroidal Effects in a Local Linear Gyrokinetic Code*

Emily Belli, Gregory W. Hammett
Princeton Plasma Physics Laboratory

William Dorland
Univ. of Maryland

A local linear gyrokinetic code has been developed for fast scoping studies. It includes models of effects of plasma shaping, magnetic shear, and toroidal geometry by using representative values of $k_{\|}$, $k_{\perp}^2$, ω_d, etc. averaged over a trial eigenfunction, using the same geometrical information available in the full GS2 gyrokinetic code. Thus it can use either a full numerical equilibrium or a local parameterized equilibrium such as developed by Miller et.al.†. This local code has recently been extended to include simple models for trapped particles and for the parallel free streaming of particles out of the bad-curvature region. The resulting reduced model is able to follow the scaling of the linear growth rate from the full GS2 code in many regimes studied so far, including trapped electron effects. We have also used this code to test a fast iterative implicit algorithm that can be useful for gyrokinetic codes. The full GS2 code and this local code have been used to examine the effects of local flux surface shape (in particularly elongation, triangularity, and their gradients, and also the second derivative of the Shafranov shift, as parameterized by the parameter $\alpha \approx -Rq^2\partial\beta/\partial r$) on gyrokinetic stability of tokamak plasmas. The most stabilizing influences are seen with 1) high elongation and elongation gradient with high triangularity at a fixed α, and 2) high triangularity at high α at a finite elongation. A high degree of shaping, in effect, opens up access to a type of second-microstability regime at high α, though it can have a destabilizing influence at low α. This behavior is qualitatively reminiscent of the effects of triangularity on MHD ballooning stability in previous studies†.

*Supported by DoE Contract No. DE-AC02-76CH03073

†R. Miller, M.S. Chu, J.M. Greene et al, Phys. Plasmas 5, 973 (1998).

#

1C03

Progress in global gyrokinetic simulations of tokamak microturbulences

Z. Lin[1], T. S. Hahm[2], and G. Rewoldt[2]

[1]University of Carlifornia, Irvine, CA 92697
[2]Princeton Plasma Physics Laboratory, Princeton, NJ 08540

Abstract

We report progress on nonlinear global gyrokinetic particle simulations of electrostatic microturbulences in tokamak, specifically, (i) comparisons between global and local simulations for ion temperature gradient (ITG) modes in the gyro-Bohm regime for large device sizes, and (ii) the effects of nonadiabatic electron response on the generation of zonal flows and the ion transport in the ITG-trapped electron mode regime.

1C04

Nonlinear Plasma Simulation Studies using M3D*

W. Park, J.A. Breslau, J. Chen, G.Y. Fu, S.C. Jardin, S. Klasky, A. Pletzer
Princeton University Plasma Physics Laboratory
H.R. Strauss, *New York University*
L.E. Sugiyama, *Massachusetts Institute of Technology*

The multilevel physics, parallel processing plasma simulation code, M3D [1,2] has been used to study various toroidal plasmas. M3D currently has physics levels of MHD, two-fluids [3], and hybrid gyrokinetic-particle/fluid models.[4] It uses unstructured meshes [5], and the parallel processing structure utilizes MPI and the PETSc framework[6], with good parallel scaling up to 1000s of processors.

M3D has been extensively used for nonlinear simulation studies of tokamaks, ST's, stellarators, etc. A particular result included in this poster is an extension of our previous studies[7,8] of the current hole [9,10] phenomenon in tokamaks. In our previous results with very low β, it was found that $n=0$ sawtoothing effectively prevented the current from becoming substantially negative in the current hole region. Finite β (with a peak β as low as a fractional percent) effects can change this picture and cause a saturation of the $n=0$ sawtoothing mode, thereby allowing a substantial negative current in the 'hole' region. This effect remains in both two-fluid and particle/fluid hybrid models. The physical reason for this phenomenon is analogous to the $n=1$ sawtooth saturation in tokamaks[11] and ST's[12] due to a pressure peak in the magnetic island (a 'snake'). Thus, it will be interesting to see whether such a correlation, i.e., more saturated cases with substantial negative current at higher plasma β, manifests in actual experiments.

* Work supported by US DoE Contracts DE-AC02-76-CH0-3073, DE-FG02-91ER54109, and DE-FG02-86ER53223.

1. W. Park, et al., Phys. Plasmas **6** 1796 (1999).
2. H. R. Strauss and W. Park, Phys. Plasmas **5** 2676 (1998).
3. L.E. Sugiyama and W. Park, Phys. Plasmas **7** 4644 (2000).
4. GY. Fu and W. Park, Phys. Rev. Lett. **74** 1594 (1995).
5. H.R. Strauss and D.W. Longcope, J. Comp. Physics, **2** 318 (1998).
6. The Portable, Extensible Toolkit for Scientific Computation, http://www-fp.mcs.anl.gov/petsc/index.html
7. B.C. Stratton, J.A. Breslau, et al, Plasma Phys. Controlled Fusion **44** 1127 (2002).
8. J.A. Breslau, S.C. Jardin, and W. Park (to appear in Phys. Plasmas, 2003).
9. N.C. Hawkes et al., Phys.Rev.Lett. **87** 115001 (2001).
10. T. Fujita, et al., Phys. Rev. Lett. 87, 245001 (2001).
11. W. Park, D.A. Monticello, and T.K. Chu, Phys.Fluids **30** 285 (1987).
12. W. Park, et al., The 19th IAEA Fusion Energy Conference (Lyon, France, 2002) Paper IAEA-CN-94/TH5-1 (submitted to Nucl.Fusion)

1C05

M3D Simulations of Stellarators, ITER Halo Currents, and Divertor Spheromaks

H.R. Strauss[1]
W. Park[2], A.Pletzer[2], J. Breslau[2], S. Jardin[2], D. Monticello[2], G.Y Fu[2]
L.E. Sugiyama[3], R. Torasso[1], Roberto Paccagnella[4], Daniel Weil[5]
[1] New York University, New York, NY
[2] Princeton Plasma Physics Laboratory, Princeton NJ
[3] Massachusetts Institute of Technology, Cambridge MA
[4] Istituto Gas Ionizzati del C.N.R., Padua, Italy
[5] Hebrew University, Jerusalem, Israel
e-mail: strauss@cims.nyu.edu

The M3D code [1] has been applied to several magnetic configurations, which contain magnetic separatrices and open field lines. (1) M3D is being interfaced with the PIES [2] code, so that equilibria can be directly compared. PIES free boundary equilibrium will be also used as initial condition for M3D free boundary kink mode studies. These modes limit the attainable β in the NCSX design. It has already been shown [3] using M3D that ideal and resistive ballooning modes in NCSX are stabilized by two fluid diamagnetic drifts. Computations of two fluid stabilization of resistive modes in W7AS are in progress. It is conjectured that a low temperature high β mode observed in W7AS may be a resistive pressure driven mode, which is stabilized at higher temperature by diamagnetic drifts. (2) Simulations have been done of halo currents in ITER. The vacuum or halo region between the plasma core and outer wall is modelled as a cold, resistive plasma. A resistive wall boundary condition was applied, with the exterior vacuum solution obtained from Green's functions. A self consistent Spitzer resistivity was calculated from $T^{-3/2}$, where T is the temperature. A temperature contrast of 100 between the core and halo region is possible. In 2D, VDEs can occur, with growth rate confirmed to scale linearly in wall resistivity. In 3D, disruptions can occur as well. Toroidal peaking factors of halo current are found to be about 2. (3) Simulations have been done of the Dag[4], a spheromak like configuration with an inboard divertor. Calculations of a special case with finite β, show stability for $\beta < 12\%$. Above this value, modes with toroidal mode number $n = 3, 4, ...$ are unstable, producing a turbulent steady state like an RFP.

1. PARK, W., et al., Phys. Plasmas **6** 1796 (1999).
2. RIEMAN, A.H., GREENSIDE, H.S., J. Comput. Phys. **87** (1990) 349.
3. H.R. Strauss, G.Y. Fu, L.E. Sugiyama, W. Park, J. Breslau, Nonlinear MHD and Energetic Particle Modes in Stellarators, Nineteenth IAEA Fusion Energy Conference, Lyon, France, IAEA-CN-94/TH/P2-12 (2002), submitted to Nuclear Fusion.
4. WEIL, D., Comments Plasma Phys. Controlled Fusion, **13**, p 45 - 56 (1989)

Supported by U.S. DOE grant DE-FG02-86ER53223 and contract DE-AC02-76-CHO-3073

1C06

Two-Fluid Effects on Stability and Beta Limits in 3D Configurations

L.E. Sugiyama[1], H.R. Strauss[2], W. Park[3], G.Y. Fu[3]

[1] Massachusetts Institute of Technology
Cambridge MA 02139

[2] Courant Institute of Mathematical Sciences, New York University
New York, NY 10012

[3] Princeton Plasma Physics Laboratory
Princeton NJ 08543

Abstract

Two-fluid plasmas, with independently evolving fluid electron and ion species connected through quasineutrality, can generate steady state flows in non-axisymmetric configurations, sustained by the equilibrium pressure gradients, but smaller than the diamagnetic drifts. These flows can have stabilizing effects on the pressure-driven instabilities that set one important limit on the maximum plasma beta. Starting from an ideal MHD equilibrium configuration (eg, calculated by the VMEC code) with zero plasma mass flow $\mathbf{v}_i = 0$, two-fluid flows develop rapidly on an MHD time scale, some few tens of shear Alfvén times, in the region of strong equilibrium pressure gradient. They persist over times long compared to the scales of MHD and the relaxation of the initial configuration Two fluid effects can favorably influence the stability of high and moderate mode number localized ballooning instabilities through shear flow stabilization. They can also affect the rate of magnetic reconnection occurring at mode rational surfaces, depending on the ratio of the electron and ion pressures and plasmas with higher ratios of the electron to ion pressure may have larger steady state islands (in the absence of neoclassical effects). Illustrations are given for stellarators, using the nonlinear two-fluid model in the massively parallel M3D code [1]. In the high beta, quasi-axisymmetric NCSX design, ballooning stability limits may be raised significantly above the nominal design value calculated from linear stability codes.

[1] L.E. Sugiyama and W. Park, *Phys. Plasmas* 7 4644 (2000).

1C07

Simulations of Energetic Particle Mode in NSTX

G.Y. Fu, E. Fredrickson, W. Park
Princeton Plasma Physics Laboratory, Princeton, NJ

H.R. Strauss
New York University, New York, NY

The energetic particle-driven MHD modes in the National Spherical Tokamak Experiments are studied using the global particle/MHD hybrid code M3D[1]. Neutral Beam Fast Ion-driven modes in the TAE frequency range were observed in the NSTX plasmas. Both steady state and bursting modes were seen depending on experimental conditions. The goal of this study is to understand the nonlinear dynamics of the fast ion-driven MHD modes in a spherical tokamak plasma. Our simulation results show unstable TAEs with mode number $n = 1 \quad 4$ and mode frequencies consistent with the experimental observation. Initial nonlinear simulation results indicate that the mode frequency chirps down as the modes move out radially. Details of the simulations will be presented.

References

[1] W. Park, E.V. Belova, G.Y. Fu, X.Z. Tang, H.R. Strauss, L.E. Sugiyama, Phys. Plasmas **6** 1796 (1999)

Supported by DOE DE-AC02-76-CHO-3073.

 Please place this paper with other M3D papers

1C08

Towards a comprehensive model of the *m*=1 mode in tokamaks

J. Breslau, S. Hudson, S. Jardin, W. Park

Princeton Plasma Physics Laboratory, Princeton, New Jersey 08543

We are developing the Extended MHD code, M3D [1], to provide a comprehensive model of global stability phenomena in tokamaks and other confinement devices. Toward that end, we have initially focused attention on the (1,1) mode, or sawtooth, as this is often the precursor to other MHD activity. The CDX-U tokamak is an attractive testbed for such simulation studies since the machine is relatively small and low-temperature, thus reducing resolution requirements. It is also very well diagnosed for a small device, with excellent spectroscopic data in particular. CDX-U exhibits a variety of m=1 activity, including classical Kadomtsev-like activity, a rotating 1/1 snake in the core coupled with a 2/1 island at the periphery, and the onset of disruption. In the M3D studies, we have focused on the nonlinear physics that couples the primary (1,1) mode to subsidiary modes. A large enough (monster) sawtooth can drive enough other modes unstable to cause a wide region of stochasticity, leading to a plasma disruption. We have employed new analysis tools to monitor the size of the sideband islands that are formed following the m=1 sawtooth reconnection. These tools allow quantification of the conditions that can lead to chaos. Other properties of the stochastic state that are calculated are the KAM surface, the Lyapunov exponent, and the fractal dimension.

[1]W. Park, *et al.*, Phys. Plasmas **6**, 1796 (1999).

1C09

Drift-Ordered Fluid Equations for Flute-Like Modes in Low-β Collisional Plasma with Equilibrium Pressure Pedestals*

Andrei N. Simakov[1], Peter J. Catto[1], X. Q. Xu[2]

[1]Plasma Science and Fusion Center, Massachusetts Institute of Technology
Cambridge, MA 02139

[2]Lawrence Livermore National Laboratory
Livermore, CA 94551

Abstract

Starting from modified Mikhailovskii-Tsypin fluid equations [1] (Braginskii-like equations [2] but with temperature gradient effects properly accounted for), equations are derived describing flute-like fluctuations ($k_\parallel/k_\perp \sim \varepsilon << 1$) in a low-β ($\beta \equiv 8\pi(p_e+p_i)/B^2 << 1$), magnetized ($\delta_j \equiv \rho_j/L_f \sim k_\perp\rho_j << 1$) collision-dominated ($\Delta_j \equiv \lambda_j/L_s \sim k_\parallel\lambda_j << 1$) plasma possessing two independent equilibrium length scales, L_s and L_f ($\varepsilon \equiv L_f/L_s << 1$). Here, p_e and p_i are electron and ion pressure, respectively, B is magnetic field, $\rho_j \equiv v_{Tj}/\Omega_j$ is gyro-radius and $\lambda_j \equiv v_{Tj}/\nu_j$ is mean-free path with v_{Tj} thermal speed, Ω_j gyro-frequency and ν_j collision frequency for species j ($j = e, i$). The slow length scale, $L_s \sim k_\parallel^{-1}$, is associated with gradients and curvature of the equilibrium magnetic field, whereas the fast length scale, $L_f \sim k_\perp^{-1}$, is associated with sharp radial pedestal gradients of plasma pressure, density and so on. Additional assumptions, $\Omega_j >> \nu_j >> \omega \sim \delta_i^2\Omega_i$ and $V_j/v_{Tj} \sim \delta_j << 1$, are also employed with ω frequency of the fluctuations and V_j the species flow velocity. The resulting equations for plasma density, vorticity (or, equivalently, electrostatic potential), and electron and ion parallel flow velocities and temperatures, supplemented with Ampere's law, modify and generalize the so-called BOUT equations [3] used to model plasma edge turbulence. They also allow recovering standard neoclassical Pfirsch-Schlüter results [4] (such as the equilibrium ion flow velocity, but not the equilibrium radial electric field) when used to describe axisymmetric toroidal plasma equilibria in the limit of $\delta_i << \Delta_i$, and generalize these results for $\delta_i \sim \Delta_i$.

[1] A.B. Mikhailovskii and V.S. Tsypin, Beitr. Plasmaphys. **24**, 335 (1984).
[2] S.I. Braginskii, in *Reviews of Plasma Physics*, edited by M.A. Leontovich (Consultants Bureau, New York, 1965), Vol. 1, p. 205.
[3] X.Q. Xu, R.H. Cohen, T.D. Rognlien, and J.R. Myra, Phys. Plasmas **7**, 1951 (2000).
[4] R.D. Hazeltine, Phys. Fluids **17**, 961 (1974).

*Work supported by U.S. D.o.E.

1C10

Short Mean Free Path Transport for a Drift Ordering

Peter J. Catto and Andrei N. Simakov

Plasma Science and Fusion Center, Massachusetts Institute of Technology
Cambridge, MA 02139

Abstract

The short mean free path description of magnetized plasma as originally formulated by Braginskii [1] assumes an ordering in which the ion mean flow is on the order of the ion thermal speed. Mikhailovskii and co-workers [2] realized that this ordering is not the one of most interest in many practical situations in which the flow is weaker and on the order of the ion heat flux divided by the pressure. In their ordering the ion flow velocity is allowed to be on the order of the diamagnetic drift velocity - the case of interest for most fusion devices in general, and the edge of many tokamaks in particular. Indeed, most short mean free path treatments of turbulence in magnetized plasmas must use some version of the Mikhailovskii results to properly treat the temperature gradient terms in the gyro-viscosity. However, the orderings employed by Mikhailovskii et al. are somewhat restrictive since they assume comparable parallel and perpendicular scale lengths as well as the collision frequency small compared to the cyclotron frequency. In many magnetized devices, including tokamaks, the perpendicular scale lengths can be much shorter than the parallel ones so that the ion gyro-radius over the perpendicular scale length can be comparable to the mean free path over the parallel scale length. In this case additional effects quadratic in the heat flux arise that can alter turbulent transport in tokamaks and allow stronger poloidal density and temperature variation than the normal Pfirsch-Schlüter ordering. In addition, the truncated polynomial expansion technique of Mikhailovskii gives only an approximate solution to the gyrophase dependent portion of the ion distribution function and is unable to completely and properly evaluate some of the terms in the perpendicular collisional viscosity.

[1] S. I. Braginskii, Soviet Phys. JETP **6**, 358 (1958) and in Reviews of Plasma Physics, edited by M. A. Leontovich (Consultants Bureau, NY 1965) Vol. 1, p. 205.
[2] A. B. Mikhailovskii and V. S. Tsypin, Beitr. Plasmaphys. **24**, 335 (1984) and references therein.

This work funded by the US Department of Energy.

1C11

Driven reconnection in a quadrupole cusp field*

A. Y. Aydemir and A. B. Gott

Institute for Fusion Studies
The University of Texas at Austin
Austin, TX 78712

Using acFm, a computational framework under development to facilitate easy and efficient solution of initial/boundary value problems, we are studying driven reconnection in a cusp field. The geometry is a linear version of the Versatile Toroidal Facility (VTF) experiment at MIT[1]. Reconnection is driven by an inductively applied external electric field in a quadrupole cusp field, augmented by a strong (toroidal) guide field. For these initial studies, reconnection physics is assumed to be described by a reduced two-fluid model extensively used elsewhere[2]. Our results differ significantly from both the experimental observations and the results of a previous study which assumed an infinite-sized system[3]. We see steady-state reconnection proceed essentially at a rate determined by the external electric field, but always accompanied by currents localized around the X-point, both in collisional and collisionless regimes. Remarkably, in the experiment these currents seem to asymptotically decay and disappear in time, which apparently cannot be reconciled with our simple model. Currently, we are cataloging the predictions of our model in different collisionality and parameter regimes. In a future collaborative effort with MIT, we will examine if the experimental results can be explained in terms of a more sophisticated extended-MHD model[4].

[1] J. Egedal, A. Fasoli, D. Tarkowski, and A. Scarabasio, Phys. Plasmas 8, 1935 (2001).

[2] See, for example, E.Cafaro, D. Grasso, F. Pegoraro, F. Porcelli, and A. Saluzzi, Phys. Rev. Lett. 80, 4430 (1998).

[3] J. J. Ramos, F. Porcelli, and R. Verastegui, Phys. Rev. Lett. 89, 055002 (2002).

[4] J. J. Ramos, MIT Report, December 2002.

*Work supported by U.S. Department of Energy Contract No. DE-FG03-96ER-54346.

1C12

Equilibrium and stability in configurations with large flows*

A. B. Gott and A. Y. Aydemir

Institute for Fusion Studies
The University of Texas at Austin
Austin, TX 78712

Plasma flows of significant magnitude seem to be a ubiquitous feature of confined plasmas. The flow by itself, or in combination with the shear in the flow profile, is now recognized to have a stabilizing influence on large scale instabilities such as the resistive wall and internal kink modes in tokamaks, and microturbulence. Long before the beneficial effects of these incidental flows were discovered, flows driven externally as in integral part of a confinement scheme were also examined[1]. Recently some of these ideas have been revived, as in the centrifugal confinement experiment MCT[2] of Maryland and the magneto-Bernoulli experiment of FRC[3]. Both use a mirror field in conjunction with a radial electric field to drive large cross-field flows. Recently we have started to examine these configurations numerically. Our initial goal is to reproduce and extend the shear-flow stabilization of interchange modes seen by the Maryland group[4] and look for self-organized states anticipated for the FRC device[5]. Preliminary results indicate that a radial electric field applied only at the ends, as in the FRC experiment, may not penetrate the plasma to drive a bulk rotation inside, but our numerical experiments are continuing.

[1] B. Lehnert, Nucl. Fusion **11**, 485 (1971).

[2] R. F. Ellis, A. B. Hassam, S. Messer, and R. B. Osborn, Phys. Plasmas **8**, 2057 (2001).

[3] H. Quevedo, P. M. Valanju, and Roger D. Bengtson, Bull. Am. Phys. Soc. **47**, 67 (2002).

[4] Yi-Min Huang and A. B. Hassam, Phys. Rev. Lett. **87**, 235002 (2001).

[5] S. M. Mahajan and Z. Yoshida, Phys. Rev. Lett. **81**, 4863 (1998).

*Work supported by U.S. Department of Energy Contract No. DE-FG03-96ER-54346.

1C13

Studies of Local and Nonlocal Models of Parallel Heat Flow *

M. K. Addae-Kagyah
, J. W. James
, E. D. Held
Physics Department, Utah State University
Logan, UT 84322-4415

Abstract

A general closure for the parallel heat flow [1] is presented in this work. This closure has an integral form and is more correct in capturing longer scale length contributions due to superimposed, secondary electron temperature perturbations. The efficacy of this closure in modelling phenomena associated with electron heat transport persists throughout all regimes of collisionality- from highly collisional to nearly-collisionless. In contrast with the diffusive form of parallel heat flow, which is proportional to the local gradient in electron temperature, the general closure involves the integrated effect of temperature perturbations over longer scale lengths. Evidently, both the diffusive and general closure give similar results for effects due to local, primary electron-temperature perturbations, in plasmas of high collisionality. In moderately collisional regimes, $\kappa_{\|}$ must be properly chosen for results to agree. However, effects due to secondary temperature perturbations are better captured only by the general closure.

To ascertain the validity and relevance of the general closure, as a new tool for extracting more accurate kinetic physics, model calculations of plasma temperature evolution in slab geometry[2] were developed and run using NIMROD. The linear slab geometry has a periodic length in the phi-direction of 2π, is periodic in the Z-direction with 5m length and has a width of 1m in the R-direction. The magnetic field at work here is built from three components- a sheared equilibrium magnetic field and a primary (n=0) perturbative field that together produce a magnetic island; and a secondary (n=1) perturbative field that leads to chaos or stochasticity near the island separatrix. The primary and secondary perturbative fields possess different scale lengths, characterized by $k_{\|n=0}/k_{\|n=1} \sim 10$.

NIMROD simulation runs comprised scans of various plasma parameters. Specifically the amplitude of n=1 perturbation and T_{e0} were independently varied, and the corresponding effect on parallel heat flow was measured. Temperature is evolved to steady state using either the diffusive or general closure, starting from a perpendicular heat flux boundary condition. Results show that the general closure results in more enhanced flattening of temperature along field lines when multiple scale lengths are present in the vicinity of a single-helicity magnetic island, characterized by finite stochasticity.

References

[1] E. D. Held, J. D. Callen, C. C. Hegna and C. R. Sovinec, Phys. Plasmas 8, 1171 (2001).
[2] T.A. Gianakon et al., (Work-in-Progress)

*Research supported by the U.S DOE under grants no. DE-FG03-01ER54618.

1C14

Fusion Burning Physics Issues for the Ignitor Experiment*

A. Airoldi+, G. Cenacchi++, and B. Coppi+++
+Istituto di Fisica del Plasma, EIRATOM-ENEA-CNR Association, Milan, Italy
++CRE ENEA, Bologna, Italy
+++Massachusetts Institute of Technology, Cambridge, MA 02139

The Ignitor experiment is designed to reach ignition preserving its stability against the onset of macroscopic modes driven by the plasma pressure gradient. Given the high values of the poloidal field which can be produced [1], these values are also sufficient to generate sufficient ohmic heating of the plasma to enter the α -particle heating regime and attain ignition. The time interval over which ignited plasmas, or slightly subignited ones, can be studied is limited by the ohmic heating of the cryogenic magnets of Ignitor [2]. Therefore it is important to reduce the time needed to reach ignition and it is noted that the most effective process is to apply a modest level of Ion Cyclotron Heating power ($\lesssim 3$ MW absorbed by the plasma) at the most critical phase of the approach to ignition. That corresponds roughly to the time when the ideal ignition condition is reached and the plasma peak temperatures is about 6 keV. In this phase the ohmic heating is weakened and the α –heating is beginning to be effective. A detailed numerical simulation of the relevant heating cycle has been carried out showing that ignition can be reached during the time over which the plasma current is ramped up to its final value of 11 MA. Thus the entire flattop of the current pulse (4 sec) is left to investigate methods to control the "thermonuclear instability" that follows ignition.

To keep the plasma temperature from "exploding" we consider the effects of small amplitude sawtooth oscillations that should take place when the magnetic parameter $q(\psi)$ drops below unity. The expectation that these amplitudes should be small is related to the fact that the parameter $\beta_p \quad 8\pi\langle p\rangle/B_p^2$ remains small at ignition and is supported by an extensive series of experiments carried out by the Alcator CMod machine. A provision that is investigated in order to attain slightly subignited conditions is that of controlling independently the concentration of deuterium and tritium departing from the 50/50 local mixture that corresponds to the maximum reactivity.

The relevance of the latest series of experiments carried out by the FTU machine in ohmically heated plasmas with repeated pellet injection to the predicted transport properties of Ignitor is demonstrated.

*Sponsored in part by the U.S. Department of Energy and ENEA of Italy

[1] B. Coppi, A. Airoldi, F. Bombarda, et al., *Nucl. Fusion* **41**, 1253 (2001)
[2] B. Coppi and the Ignitor Project Team, Massachusetts Institute of Technology, R.L.E., Report PTP-02/05 (December 2002)

1C15

An Upper Bound on the Dissipation Rate of Hartmann Flow

A. Alexakis[1], F. Pétrélis[2],
P.J. Morrison[3], C.R. Doering[4,5]

[1]Department of Physics, University of Chicago, Chicago, IL 60637, USA
[2]Laboratoire de Physique Statistique, ENS, 24 rue Lhomond, 75005 Paris, France
[3]Department of Physics and Institute for Fusion Studies,
The university of Texas Austin, Austin, TX 78712, USA
[4]Department of Mathematics, University of Michigan, Ann Arbor, MI 48109-1109, USA
and Michigan Center for Theoretical Physics, Ann Arbor, MI 48109-1120, USA

Abstract

The dissipation rate of Hartmann flow is studied using dissipative, incompressible MHD. The 'energy stability' method is used to derive explicit expressions for nonlinear stability regions in parameter space, which are compared with numerically derived results. An upper bound on the total energy dissipation rate, equivalently the drag coefficient, is obtained by using the 'background method' (Doering & Constantin, Phys. Rev. Lett. **69**, 1648–1651 (1992).) For small Reynolds numbers the bound is proportional to the laminar dissipation rate. For Reynolds numbers large enough for turbulence, the dissipation is shown to be bounded by a function of the magnetic Prandtl number. The function is linearly increasing if the Prandtl number is larger than one and constant if it is smaller than one in agreement with the bound derived using the same method for magnetic sheared MHD flows in (Pétrélis et al. Sherwood 2003).

1C16

Renormalization and destruction of tori in area preserving maps

Amit Apte and P.J. Morrison
Physics Department and Institute for Fusion Studies, University of Texas at Austin, Austin, TX 78712

Abstract

Magnetic field lines and particle orbits in toroidal plasma devices are described by low dimensional Hamiltonian systems. The simplest cases of two degrees of freedom correspond to area preserving maps of a cylinder. In such a description, the invariant tori represent transport barriers. When studying nonmonotonic q-profiles, the corresponding maps are nontwist i.e. they violate the twist condition. We study the breakup of the invariant tori with various different winding numbers for both twist and nontwist maps. At the critical values for destruction of invariant tori, the phase space exhibits invariance under rescaling. This leads to the renormalization group framework developed by MacKay[1] for the case of the golden mean winding number. We extend this to other winding numbers by constructing the appropriate renormalization group operators. The simple (integrable) and critical fixed points of these operators are presented. We relate the fixed points for different winding numbers by coordinate changes in the space of maps and the operators for different winding numbers are shown to be related by transformations induced by these coordinate changes.

[1] R.S. MacKay, Ph.D. thesis, Princeton (1982); R.S. MacKay, Physica D, 7, 283 (1983).

1C17

A smooth path from dissipative to shear regulation of plasma turbulence–flow dynamics

Rowena Ball
Department of Theoretical Physics
Australian National University, Canberra 0200 Australia

Abstract

The bulk dynamics of fusion plasmas around L–H transitions is regulated either by Reynolds stress decorrelation of turbulence, or by bifurcation of the radial electric field induced by a shear flow drive. In this study, these two mechanisms are smoothly reconciled. A low-dimensional model for plasma dynamics [1] is extended to include a nonlinear shear flow driving rate. As the rate coefficient is tuned quasistatically the system passes from a slow time-scale régime of hysteresis and associated limit cycles where the dynamics is essentially 3-dimensional, to an entirely different hysteretic domain in fast time which is dominated by the radial electric field. The smooth path between these two extremes passes through an intermediate domain where L–H transitions are oscillatory and non-hysteretic. These results provide unification of previous disparate models for L–H transitions, and also suggest appropriately tailored strategies that may be used to control access to high confinement modes or manipulate oscillatory behaviour.

[1] R. Ball, R. L. Dewar, and H. Sugama. Metamorphosis of plasma shear flow–turbulence dynamics through a transcritical bifurcation. *Phys. Rev. E*, 66:066408–1–066408–9, 2002.

1C18

Parameter Dependence of Drift Modes Associated with Turbulence in Tokamaks

Glenn Bateman, Jon Kinsey, Arnold H. Kritz, Alexie Pankin, Thawatchai Onjun

Lehigh University Physics Department
16 Memorial Drive East, Bethlehem, PA, 18015, USA

Jan Weiland, and Pär Strand

Chalmers University of Technology, G^ teborg, Sweden

Abstract

The spectra of drift modes are investigated as a function of plasma parameters in order to improve our understanding of the models for transport driven by drift-mode turbulence. There is substantial evidence that most of the transport in tokamaks is driven by drift modes such as the Ion Temperature Gradient (ITG) and Trapped Electron Mode (TEM). Quasi-linear models of transport driven by drift mode turbulence provide the central part of the Multi-Mode [1] and GLF23 [2] transport models that are used in integrated modeling codes to predict temperature and density profiles in tokamaks. Drift mode transport is "stiff" ó th e transport increases rapidly with increasing temperature gradient, once the temperature gradient rises above a threshold value. The dependence of the threshold temperature gradient and the degree of stiffness are investigated as a function of parameters such as the poloidal wave number, magnetic shear, T_i/T_e, impurity concentration, collisionality, and beta. Integrated modeling simulations are used to provide the expected ranges of these parameters in different parts of the plasma (*i.e.*, near the center or near the edge) in a variety of tokamak discharges. Particular emphasis is placed on the regions with low magnetic shear in the deep core of the plasma and on the regions with relatively high magnetic shear closer to the edge of the plasma. The dependence of the threshold on wave number and plasma parameters is particularly important in the low shear region near the center of the plasma, because drift modes are generally close to their marginal point in that region.

[1] G. Bateman, A.H. Kritz, J.E. Kinsey, A.J. Redd and J. Weiland, Phys. Plasmas, 5 (1998) 1793.
[2] R.E. Waltz, G.M. Staebler, W. Dorland, G.W. Hammett and M. Kotschenreuther, Phys. Plasmas, 4 (1997) 2482.
Work supported by US DOE contract DE-FG02-92-ER-5414.

Sherwood Fusion Theory Conference, Corpus Christi, Texas, 28-30 April 2003

1C19

Hysteresis in Single Helicity and Quasi-Single Helicity States in Reversed Field Pinches

C. G. Bathke, J. M. Finn and R. A. Nebel
Los Alamos National Laboratory
Los Alamos, New Mexico 87545

Abstract

We have performed 3D simulations of RFPs over a wide range of Hartman number H in search for single helicity and quasi-single helicity (QSH) states. Pure single helicity states are found only for small H, in agreement with results found by the Padua group. QSH states have a spectrum which consists of mostly one helicity with small amplitudes of other helicities. Multiple helicity (MH) states, on the other hand, have a wide spectrum. In contrast with Padua results, we find that there is a large region of hysteresis, i.e. a large range of H over which both QSH and MH states exist, and specifically, QSH states occur for much larger H than observed previously. We will show magnetic field surfaces of section for these RFP states obtained with a new field line integrator code. This code preserves the divergence free character of the magnetic field exactly by fitting the vector potential with cubic splines and differentiating the spline formula analytically. The field lines are then integrated by a volume preserving integrator which is time centered and second order accurate.

1C20

Burning Plasma Proposals

R. Bickerton, Oxford

Abstract

There is a desperate need for new Tokamak apparatus in which to investigate the physics of a plasma in which alpha-particle heating plays the dominant role in sustaining the plasma. Proposals have been on the table for years but nothing has yet been approved. In this note five such proposals plus JET are analysed using three different scaling laws for the energy confinement time. These are the Goldston [1984] law, the ITER-98 one used to design ITER-FEAT and finally one based on Gyro-Bohm physics. The results are remarkably similar. Only ITER, ITER-FEAT and ET4 ignite while Ignitor satisfies the burning plasma requirement, F>0.5 where F is the ratio between the alpha power and the total power loss from the plasma. FIRE, a Princeton proposal does not reach F=0.5 on any of the three scaling laws. Ignitor does. We conclude that Ignitor should be built without delay on the JET site taking advantage of the existing power supplies, and tritium-handling system. Ignitor is a mature design with prototypes of key components already made and tested in Italy. We could then have physics results on a burning plasma within five years. Decades have been lost due to indecision. This must stop.

1C21

Self-consistent diffusion in coupled symplectic maps

G. Boffetta (1), D. del-Castillo-Negrete (2), C. Lopez, G. Pucacco and A. Vulpiani (3)

(1) Dipartimento di Fisica Generale and INFM, Universita di Torino, Italy
(2) Oak Ridge National Laboratory, Oak Ridge TN, 37831-8071, USA
(3)Dipartimento di Fisica and INFM, Universit`a di Roma "La Sapienza", Italy

The study of diffusion in symplectic maps has been a problem of interest in plasma physics for a number of years. Since the introduction of the standard map as a simple model of magnetic field lines stochasticity, different maps have been proposed to model various aspects of plasmas transport. Maps are highly simplified models and there are many directions one can take to make them more physically meaningful. Here we explore the issue of self-consistency, which despite of its critical importance, is usually overlooked in the description of plasmas with maps and, in general, with low degrees of freedom models. We propose a class of self-consistent models consisting of an ensemble of standard maps globally coupled through a mean field [1]. The nontrivial effects of self-consistency on transport, including subcritical diffusion and suppression of diffusion, are studied analytically and numerically. [2]

[1] D. del-Castillo-Negrete, Chaos, 10, 75 (2000).
[2] G. Boffetta, D. del-Castillo-Negrete, C. Lopez, G. Pucacco, A. Vulpiani, Phys. Rev. E, 67, 026224 (2003).

1C22

Diagnostic Issues for the Burning Plasma Experiment Ignitor*

F. Bombarda

ENEA – UTS Fusione, Progetto Ignitor, Frascati (Italy)

The main goal of the Ignitor experiment[1] is to reach ignition in a toroidal magnetically confined plasma in order to investigate plasma heating, transport process and stability of fusion generated alpha-particles, and to identify methods for control, heating and fueling of high density burning plasmas, for a duration (~ 4 s) that exceeds all the relevant intrinsic physical time scales. The strategy is to use a compact, high field device (R_0 1.32 m, a 0.47 m, κ 1.8, B_T 13 T, I_p 11 MA) to reach ignition at high density (10^{21} m^{-3}) and low temperature (11 keV). The deployment, use and maintenance of the compact, radiation-hard diagnostic systems being selected for Ignitor will provide a very useful experience for future fusion reactors, and in this respect the contribution of the physics-oriented Ignitor experiment will be uniquely valuable.

The range of plasma parameters to be measured and the required spatial and time resolutions are shown to be within the range of present day diagnostics capabilities. However, the high radiation background fluxes[2] and the compact size of the machine do represent significant challenges for diagnostics. Fluences are not expected to be a problem for Ignitor, but the port geometry will require remote handling installation and maintenance of all the in-vessel components irrespective of the activation conditions.

The high value of the plasma density in general limits the applicability of certain types of diagnostics, for example those relying on neutral beams (either heating or diagnostic beams). However, the same parameters can be measured by alternative methods. The absence of a separate divertor chamber greatly simplifies the diagnostic requirements at the edge.

The basic diagnostics chosen for Ignitor are generally conventional and of proven reliability, but more advanced ones are also considered. In the case of the neutron diagnostics, which will be fundamental to document the physics mission of the experiment, Ignitor has motivated the proposal of new diagnostic concepts[3] that have been built and tested on existing experiments[4]. A similar effort will be needed to develop new diagnostic techniques to measure the characteristics of the charged fusion products directly.

*Work supported in part by ENEA of Italy and the US DOE.

[1] B. Coppi, A. Airoldi, F. Bombarda, et al., *Nucl. Fusion* **41**, 1253 (2001).
[2] S. Rollet, P. Batistoni, R. Forrest, *Fus, Eng. & Des.* **51-52**, 599 (2000).
[3] G. Gorini and J. Källne, *Il Nuovo Cimento* **14D**, 1115 (1992).
[4] J. Källne and H. Enge, *Nucl. Instrum. Methods* **A311**, 595 (1992).

1C23

A Comparison of Different Models for Lower Hybrid Current Drive

P.T. Bonoli, M.Porkolab, and J.C. Wright , PSFC, MIT, Cambridge, MA 02139

R.W. Harvey , CompX, Del Mar, CA 92014

Lower hybrid current drive (LHCD) is a promising technique for off-axis current profile control in both intermediate magnetic field (5 - 6T) and high field (8T) next step fusion devices. The attractiveness of this method lies primarily in its relatively high current drive effciency at the lower electron temperatures

characteristic of the outer half of fusion plasmas where local current profile modification is desired.

In view of the promise of this current profile control method, we have undertaken a comparison of two different approaches that are widely used for calculating lower hybrid current drive. In the first method[1] a direct 2-D (velocity) numerical solution of the Fokker Planck equation is obtained and used in a toroidal ray tracing package to compute wave polarizations and the quasilinear rf diffusion coeffciecnt. These physics modules are iterated to obtain a self-consistent electron distribution function $f_e(p_\perp , p_\parallel)$. In the second approach [2,3] an adjoint code is used to obtain the Spitzer – Harm function □. A combined 1-D parallel velocity Fokker Planck and ray tracing code is then used to compute the wave-induced rf flux which is combined with the Spitzer – Harm function to compute the driven rf current. Generally the predicted current from the exact 2-D approach is found to be larger than the prediction from the adjoint – ray tracing approach. The reasons for this difference will be analyzed and discussed.

Model predictions will be compared for a test case typical of the proposed ITER – FEAT device. We also compare model predictions for the planned lower hybrid current profile control experiment in the Alcator C-Mod tokamak.

Supported by U.S. DOE Contract No. DE-AC02-78ET51013

[1] R.W. Harvey and M.G. McCoy, in Proc. Of IAEA Tech. Comm. Meeting on Advances in Simulation and Modeling in Thermonuclear Plasmas (Montreal, 1992).

[2] C.F.F. Karney et al., Proceedings of the Eighth Topical Conference on Radio-frequency Heating in Plasmas, AIP Conf. Proc. 190 (AIP, NY, 1989) p. 430.

[3] R.S. Devoto et al., Nucl. Fusion **32**, 773 (1992).

1C24

Multiple helicity modes in 3D collisionless magnetic reconnection

D. Borgogno[1], F. Califano[2], D. Farina[3], D. Grasso[1], F. Pegoraro[2], F. Porcelli[1]

[1] Burning Plasma Research Group, INFM, Politecnico di Torino, Italy
[2] INFM, Sez. A and Dip. Fisica, Università di Pisa, Italy
[3] IFP, CNR, EURATOM-ENEA-CNR Assoc., Milano, Italy

Abstract

Nonlinear magnetic reconnection in collisionless regimes has been extensively analyzed in recent years in 2D configurations in the presence of a large magnetic guide field [1-4]. The removal of the 2D constraint is expected to show new phenomena. In particular, it leads to coupling between modes with different helicities and with different resonant surfaces and to magnetic field line stochasticity.

In our investigation we adopt a fluid Hamiltonian 3D model, derived in Ref. [5]. This model describes drift-Alfvén perturbations in a plasma immersed in a strong, uniform, externally imposed magnetic field, where spatial variations along the field lines are assumed to be small compared to variations normal to it. This system consists of two fluid equations, where small scale effects related to the electron temperature (ρ_s) and to electron inertia (d_e) are retained, but magnetic curvature effects are neglected.

First, we discuss the nonlinear structures of the current density and vorticity layers starting from an initial configuration where a single helicity mode is linearly unstable. This problem is equivalent to a 2D problem with non symmetric perturbations.

Second, we consider the case where two linearly unstable, resonant modes with different helicities interact nonlinearly. This interaction drives higher order harmonics which modify the nonlinear structure of the reconnection region significantly. In this case the magnetic flux function depends on all three spatial coordinates. Thus, the Hamiltonian function of the equivalent dynamical system that describes the spatial structure of the magnetic field lines is no longer integrable, as in the case of single helicity perturbations, and we observe the development of magnetic field line stochasticity.

The chaotic structure of magnetic field lines observed numerically is characterized in terms of Poincaré maps and Lyapunov exponents. These results suggest a modification of the adopted model, so as to account for the fact that the current density is expected to become uniformly distributed within the stochastic region.

[1] A. Aydemir *et al. Phys. Fluids B* **4**, 3469 (1992).
[2] M. Ottaviani and F. Porcelli, *Phys. Rev. Lett.* **71** (23), 3802 (1993).
[3] D. Grasso, F. Pegoraro, F. Porcelli, F. Califano, *Plasma Phys. Control. Fusion* **41**, 1500 (1999).
[4] D. Grasso *et al. Phys. Rev. Lett.* **86**, 5051 (2001).
[5] T.J. Schep, F. Pegoraro, B.N. Kuvshinov, *Phys. Plasmas* **1**, 2843 (1994).

1C25

Electrostatic microinstabilities in high confinement and internal transport barrier discharges

A.Bottino, S.Allfrey, P.Angelino, O.Sauter, L.Villard and J.Vaclavik

Centre de Recherches en Physique des Plasmas,
Association EURATOM - Confédération Suisse,
Ecole Polytechnique Fédérale de Lausanne,
1015 Lausanne, Switzerland

Recent experiments with Internal Transport Barriers (ITB) have shown that anomalous transport is considerably reduced by a sheared radial electric field in the plasma [1]. Several theoretical models predict a strong stabilizing effect on toroidal Ion Temperature Gradient (ITG) modes due to the fluctuation suppression caused by the shear in the electric field. Although the turbulence suppression is intrinsically a nonlinear effect, the presence of a radial electric field in the plasma also changes the linear behavior of electrostatic modes: the eddy deformation due to the equilibrium $\mathbf{E}\times\mathbf{B}$ shearing reduces the radial extend and the growth rate of modes. On the other hand, a sheared radial electric field is not the only possible source of stabilization in the plasma core: other mechanisms can reduce the growth rate of electrostatic microinstabilities, i.e. the local value of $\tau = T_e/T_i$ or reverse magnetic shear [2]. In this work we study the effect of the interplay of an applied radial electric field with other equilibrium parameters on the linear stability of ITG and Trapped Electron Modes (TEM) in experimental scenarios, using the gyrokinetic global electrostatic linear PIC code LORB5 [3]. This code includes the effect of an equilibrium $\mathbf{E}\times\mathbf{B}$ velocity; trapped electrons are modeled using drift-kinetic equations. In particular we will examine the role of the absolute value of ion and electron temperature on the instability of modes dominated by trapped electrons.

[1] K.H. Burrell, Phys. Plasmas **3**, 4658 (1996)
[2] A. Bottino, T.M. Tran, O. Sauter, J. Vaclavik and L. Villard, in Theory of Fusion Plasmas, Int. Workshop, (Editrice Compositori, Societá italiana di Fisica, Bologna, 2001), pag.327
[3] A. Bottino, S.J. Allfrey, A.G. Peeters, O. Sauter, L. Villard and ASDEX Upgrade Team, 29th EPS Conference on Controlled Fusion an Plasma Physics, Montreux, 2002, Europhysics Conference Abstract Vol.**26B P1.040**

1C26

Nonlinear tearing mode evolution in sawtoothing discharges*

D.P. Brennan,[1*] R.J. La Haye,[1] A.D. Turnbull,[1] L.L. Lao,[1] S.E. Kruger,[2] D.D. Schnack[2]

[1]General Atomics, P.O. Box 85608, San Diego, California 92186-5608.

[2]SAIC, San Diego, California

[*]Oak Ridge Institute for Science Education, Oak Ridge, Tennessee 37831.

The prevention of neoclassical tearing modes (NTMs) in tokamak plasmas is a major challenge for fusion. Ideal modes can seed NTMs through forced reconnection, yet in sawtoothing discharges in which NTMs are destabilized, this process is not well understood. A theoretical description is presented in which a particular sawtooth crash can seed an NTM, perhaps after several preceding sawteeth did not, due to any one of a number of reasons. Nonlinear mechanisms for tearing mode onset are studied based on ITER and DIII-D experimental equilibria using the NIMROD nonlinear 3-D resistive MHD code to evolve these equilibria in time and provide a comprehensive prediction of the island evolution during the early non-linear phase. The relative timescales of the change in linear instability drive versus the effects of finite island width and coupling drive will determine the evolution of the island, and the eventual nonlinear state. Time integration of the island evolution equation for an uncoupled mode is compared to these simulations and shows that both are consistent with the experimental observations in DIII-D. These results are then compared to the ITER case in light of scaling studies from the literature.

*Supported by U.S. Department of Energy Grant No. DE-FG03-95ER54309 and Contract Nos. DE-AC03-99ER54463 and DE-AC05-76OR00033.

1C27

Semi-implicit electron advection in GYRO*

J. Candy and R.E. Waltz

General Atomics, P.O. Box 85608
San Diego, California 92186-5608

Abstract

In this presentation we discuss continuing progress on GYRO – a physically comprehensive global Eulerian gyrokinetic code for simulating turbulent transport in tokamaks. Beyond the now standard ion-temperature-gradient (ITG) mode turbulence, the code includes trapped and passing electrons with pitch angle collisions, finite-β fluctuations, real flux-surface shape, linear and nonlinear $\mathbf{E}\times\mathbf{B}$ rotation, and parallel flow shear. It operates at finite $\rho_* = \rho_i/a$ using a WKB-like formulation to treat the small $1/n$ corrections due to radial variation of ω_*, η_i, s, etc, not present in the flux-tube approximation. A special technique[1] to remedy the troublesome Ampère cancellation problem[2] is critical to the finite-β mode of operation. A variant of this technique has recently been adopted for use in flux-tube gyrokinetic PIC codes,[3] apparently solving a longstanding problem for finite-β particle simulations. An important previous result is that we have shown systematically how to recover gyroBohm-scaled transport in the small-ρ_* limit with both quasi-periodic and non-periodic boundary conditions.[4] In this limit, we also reproduce the nonlinear, flux-tube Cyclone benchmarks[5] over the full range of R/L_T. First attempts to simulate actual DIII-D plasmas (shown at Sherwood 2002) gave transport levels within a factor of two of experimental levels. However, new and challenging obstacles (beyond the Ampère cancellation problem) arise with kinetic electrons at long wavelength; to wit, we found that these simulations were limited to radial box sizes of $80\rho_i$ or smaller (one-third the minor radius) and $\mu = \sqrt{m_i/m_e} = 20$ due to weak a $n = 0$ *box instability*. For this reason, we have implemented and are testing various implicit-explicit Runge-Kutta methods.[6] These treat the linear parallel electron advection implicitly, coupling the Poisson and Ampère equations, and subsequently regularizing them at long wavelength. The new schemes allow simulations with unrestricted radial domain sizes. Now, $240\rho_i$ DIII-D runs with $\mu = 60$ (deuterium) now execute in about the same real time as our original $80\rho_i$, $\mu = 20$ simulations. Very exciting but still preliminary results show electron *and* ion transport move closer to the DIII-D L-mode experimental levels in real-mass-ratio, large-domain simulations. We report on these new results, on new algorithms connected with the semi-implicit solver, and also discuss the reimplementation of GYRO as tool to rapidly scan *local* linear eigenfrequencies over global experimental profiles (for use with external transport modeling). We also discuss implementation and documentation issues of interest to the growing GYRO user base.

*Work supported by the U.S. Department of Energy under Grant Nos. DE-FG03-95ER54309 and the SciDAC Plasma Microturbulence Project.

---

[1] J. Candy and R.E. Waltz, General Atomics Report GA-A23876, November 2001.
[2] F. Jenko, private communication (2001).
[3] Y. Chen and S.E. Parker, Bull. Am. Phys. Soc. **47**, 200 (2002).
[4] R.E. Waltz, J. Candy and M.N. Rosenbluth, Phys. Plasmas **9**, 1938 (2002).
[5] A.M. Dimits, *et al.*, Phys. Plasmas **7**, 969 (2000).
[6] U. Ascher, S. Ruuth and J. Spiteri, Applied Numerical Mathematics, **25** 151 (1997)

1C28

Particle-in-Cell Simulations of ICRF Wave-Particle Interaction

Johan Carlsson

Tech-X Corporation, 5541 Central Avenue, Boulder, CO 80301

Abstract

When nonlinear effects come into play, traditional, linear RF theory becomes invalid. Examples of when this can occur is the coupling and absorption of IBWs. The Particle-in-Cell (PIC) algorithm [1] directly solves the coupled set of Maxwell's equations and the equations of motion for a distribution of macro particles (representing the real particles). Because few approximations are made the relevant nonlinear physics is retained and reproduced by PIC simulations. The directness of the PIC approach does however make it computationally demanding; small timesteps and many macroparticles are necessary for converging the solution.

IBWs are attractive for both heating and profile control [2]. Because of their large $k_\perp$ cyclotron absorption on bulk ions is strong even at high harmonics. At these high frequencies a waveguide can be used to launch the waves. This is crucial in a reactor where sensitive antenna structures are unlikely to withstand the harsh conditions at the plasma edge.

As IBWs are absorbed, poloidal ponderomotive forces can drive flows sufficiently large to suppress turbulent transport and create transport barriers [3]. IBWs can therefore be used for profile control, for example to shape the pressure profile and align the bootstrap current in advanced-tokamak scenarios. Nonlinear effects are believed to play a role both in the coupling [4] and absorption [5] of IBWs.

We are planning to perform PIC simulations to investigate the importance of these nonlinearities on the physics of IBWs. To make such simulations feasible it will be necessary to remove some of the fast timescales. The fastest timescale is the electron gyroperiod which is three orders of magnitude shorter than the timescale of interest: the ion gyroperiod. By replacing the electron equation of motion with its gyrocenter counterpart, the irrelevant electron gyration is removed while the electron Landau damping is kept.

At the plasma edge, the plasma-oscillation period is of the same order as the ion gyroperiod and the plasma oscillation can in fact be involved in the excitation of the IBW. However, in the plasma center the plasma oscillation is an order of magnitude faster than the ion gyration. It is therefore not relevant to the absorption and should preferably be removed. Keeping the plasma oscillation at the edge but removing it in the center could be achieved by using an implicit field solver such as the Darwin approximation [1] or the unconditionally stable algorithm recently introduced in Ref. [6]. For simulations on the quasilinear timescale it might also be necessary to use a symplectic integrator for the particles.

ICRF PIC simulations will allow us to go beyond linear RF theory and include the nonlinearities believed to be important for IBW coupling and absorption. To make such simulations feasible the standard PIC approach will need to be modified to remove fast timescales. We will present the necessary algorithms and discuss their pros and cons.

[1] C. K. Birdsall and A. B. Langdon, *Plasma Physics via Computer Simulation.*

[2] M. Ono, Phys. Fluids B **5** (1993) 241; and references therein.

[3] E. F. Jaeger, L. A. Berry and D. B. Batchelor, Phys. Plasmas **7** (2000) 3319.

[4] F. Skiff, M. Ono and K. L. Wong, Phys. Fluids **27** (1984) 1051.

[5] H. Abe, *et al.*, Phys. Rev. Lett. **53** (1984) 1153; M. Porkolab, Phys. Rev. Lett. **54** (1985) 434.

[6] H. De Raedt, *et al.*, in *Proceedings of ICAP 2002.*

1C29

Modeling of the Feedback Stabilization of the Resistive Wall Mode in Tokamaks*

M. S. Chance,[a] M. S. Chu,[b] A. H. Glasser,[c] M. Okabayashi[a] and F. W. Perkins.[a]

[a] *Princeton Plasma Physics Laboratory, Princeton, New Jersey.*
[b] *General Atomics, San Diego, California.*
[c] *Los Alamos National Laboratory, Los Alamos, New Mexico.*

Abstract

We have extended our model of the feedback stabilization of the RWM in tokamaks to incorporate feedback coils internal to the resistive vacuum vessel in accordance with the corresponding modification of the DIII-D device at General Atomics. These new coils add much more flexibility to the feedback capabilities, but at the same time add more complexity to the analysis. Whereas the external coil current path of the previous configuration was designed to primarily sustain the stabilizing eddy current in the shell, the field, $\vec{B}_{\text{coil}}$ of new internal coil configuration, can be tailored to more directly affect the plasma with the appropriate stabilizing $\vec{J}_{\text{plasma}} \times \vec{B}_{\text{coil}}$ forces. The previous analysis using a normal mode approach with the DCON-VACUUM [1, 2, 3] codes is extended for this study. It includes an assessment of various feedback and sensor coils configuration. Results of this study showing specifically the impact of the internal coils will be presented and compared with results from other models, e.g., the VALEN code [4]. Recent experimental results from DIII-D with the external feedback coil indicate that plasma rotation contributes significantly to maintaining the stability of the plasma during the course of feedback experiments. The rotation is however impeded by the presence of an external error field which interacts resonantly with the resistive wall mode [5, 6, 7]. Stability of a rotating plasma can only be studied using a formulation other than the normal mode approach, such as the MARS code [8]. We have thus embarked on enhancing the capabilities of the MARS code to study the response of the plasma to an externally imposed magnetic perturbation. This response will be compared with experimental measurements to investigate the loss of plasma rotation induced by the error fields.

References

[1] M. S. Chu, M. S. Chance, A. H. Glasser and M. Okabayashi, GA-A24048 (2002). Submitted to *Nuclear Fusion.*

[2] A. H. Glasser, and M. S. Chance, *Bull. Am. Phys. Soc.* **42**, 1848 (1997).

[3] M. S. Chance, *Phys. Plasma* **4**, 2161 (1997).

[4] J. Bialek, A.H. Boozer, M. E. Mauel, and G. A. Navratil, *Phys. Plasmas* **8**, 2170 (2001).

[5] A. H. Boozer, *Phys. Rev. Lett.* **86**, 5059 (2001).

[6] A. M. Garofalo, et al., *Phys. Plasmas* **9**, 1997 (2002).

[7] M. Okabayashi, et al., *Plasma Phys. and Control. Fusion* **44**, 339 (2002).

[8] Y. Q. Liu, and A. Bondeson, *Phys. Rev. Lett.* **84**, 907 (2000).

*Work supported by U. S. Department of Energy Contract No. DE-AC02-76-CH03073, and U. S. DoE grant No. DE-FG03-95ER54309 and DE-FG03-94ER54271.

1C30

Limitations on a Kinetic Electron Closure for Extended Hybrid Electromagnetic Simulation of Drift Waves

B. I. Cohen, A. M. Dimits, and W. M. Nevins
University of California Lawrence Livermore National Laboratory
Livermore, California 94550

Y. Chen and S. E. Parker
Center for Integrated Plasma Studies, Department of Physics
University of Colorado at Boulder, Boulder, CO 80309

Nonadiabatic electron effects significantly modify the stability and concomitant turbulent transport of drift-waves in tokamaks. Incorporating electron kinetic and electromagnetic effects into gyrokinetic particle-in-cell drift-wave turbulence simulations is challenging. Previously we extended the electromagnetic hybrid scheme of Chen and Parker (fluid electrons and gyrokinetic ions)[1] to include a kinetic electron closure valid for finite $\beta m_i/m_e > 1$, where $\beta = 4\pi n T_e/B^2$.[2] This scheme uses partially linearized (δf) drift-kinetic electrons whose number density moment is used to close the electron fluid momentum equation. The closure depends on a perturbation expansion of the electron response around the isothermal adiabatic fluid response.[3] The algorithm was successfully tested on kinetic shear-Alfvén waves, the ion-temperature-gradient instability, and the collisionless drift instability in an unsheared slab. This algorithm does *not* require that the mesh size perpendicular to B_0 be smaller than the skin depth c/ω_{pe} and gives good results for $\beta m_i/m_e > 1$. However, this implementation of a kinetic-electron extended hybrid algorithm yields spurious results for linear ITG modes in sheared slab and toroidal geometries. Frequencies and growth rates are systematically wrong, and the δf electron weights grow too large. The inherent difficulty is the failure of the perturbation expansion around an adiabatic electron fluid response in the resonance layers near mode rational surfaces where the electrons are far from adiabatic and kinetic effects are not necessarily perturbative. The recent work of Chen, *et. al*[4] demonstrates a direct kinetic electron δf PIC algorithm that works at finite β and can resolve non-adiabatic electron kinetic behavior correctly.

This work is supported by the U.S. Department of Energy, Office of Fusion Energy Sciences, under Contract No. W-7405-ENG-48 at the University of California Lawrence Livermore National Laboratory and is part of the SciDAC Plasma Microturbulence Project.

---

[1] Y. Chen and S. Parker, Phys. Plasmas 8, 441 (2001).
[2] B. I. Cohen, A. M. Dimits, W. M. Nevins, Y. Chen, and S. Parker, Phys. Plasmas 9, 252 and 1915 (2002).
[3] Z. Lin and L. Chen, Phys. Plasmas 8, 1447 (2001).
[4] Y. Chen, S. E. Parker, B. I. Cohen, A. M. Dimits, W. M. Nevins, D. Shumaker, V. K. Decyk, and J.-N. Leboeuf, IAEA 2002, submitted to Nucl. Fusion.

1C31

Searching for a better spheromak with NIMROD*

R.H. Cohen[1], B.I. Cohen[1] C.R. Sovinec[2], G.A. Cone[2]

[1] Lawrence Livermore National Laboratory
Livermore, CA 94550
[2] Department of Engineering Physics, University of Wisconsin
Madsion, WI 53706

Abstract

Resistive MHD simulations of steady driven spheromaks in simple cylindrical and gun-driven geometries consistently exhibit only chaotic field lines with relatively short connection length to a wall. We describe here a series of NIMROD simulations aimed at finding a more attractive spheromak. Specifically we follow two approaches: (1) pulsed operation, and (2) steady drive but with suppression of low-toroidal-mode-number global modes.

For approach (1), we simulate spheromak formation and decay with finite pressure and temperature evolution. With the driving electric field on, helicity is driven in from the edge of the plasma; and magnetic energy increases (for times less than the L/R time). A spheromak forms due to the action of the n=1 instability, and closed flux surfaces can appear transiently. Pulsing the driving electric field off allows the n=1 mode and its harmonics to decay in time faster than does the n=0 spheromak structure, and with enough poloidal field built up, closed flux surfaces emerge over significant volumes and then decay away. Repeated pulsing of the drive field on and off can increase the magnetic energy and the volume of closed flux surfaces during decay. The simulations address the influence of plasma flows in the temperature evolution equation.

For approach (2), we explore the possible conseequences through a driven simulation which suppress all odd toroidal harmonics, and hence in particular the global $n = 1$ mode. We find a configuration with an appreciable volume of closed flux surfaces which lives for a time long compared to the resistive decay time (but ultimately collapses.) The configuration is characterized by spontaneous oscillations in the poloidal flux, in the extent of the closed-flux-surface region, and in the parallel current.

We also explore a possible route to achieving a configuration with reduced $n = 1$ activity, via introduction of a rigid passive conducting structure which fills part of the central column. This work complements a parallel effort analyzing central-column stability via a variational principle.[3]

*Work performed under the auspices of the U.S. DOE by U.C. LLNL under contract W7405-ENG-48 and U. Wisc. under grant FG02-01ER54661.

[3]D.D. Ryutov, R.H. Cohen and L.D. Pearlstein, paper at this meeting.

1C32

Forced Magnetic Reconnection in the Taylor Problem

A. Cole, R. Fitzpatrick
Institute for Fusion Studies, University of Texas at Austin
Austin, TX 78712

Abstract

A Bromwich contour integral for the reconnected magnetic flux is derived, and numerically inverted, in order to study a well-known model of forced reconnection. This model, known as the Taylor problem, considers the response of a tearing-stable slab plasma equilibrium to a sudden, small amplitude boundary perturbation. The applied perturbation is such as to force magnetic reconnection and subsequent magnetic island formation within the plasma. The early dynamical phases of the reconnection process are studied and found to be in good agreement with the analysis of Hahm and Kulsrud [1]. Recent criticisms of this analysis by Ishizawa & Tokuda[2] are found to be unwarranted.

[1] T.S. Hahm, R.M. Kulsrud, Phys. Fluids, **28**, (1985), 2412.

[2] A. Ishizawa, S. Tokuda, Phys. Plasmas, 8, (2001), 376.

This work was supported by the U.S. Department of Energy Contract No. DE-FC02-01ER-54652.

1C33

Exploring Macroscopic MHD Stability Trends Using Perturbed Equilibria: Successes and Limitations of Application to Toroidal Geometry[1]

K.J. Comer[2], J.D. Callen, C.C. Hegna (U. of Wisconsin, Madison),
A.D. Turnbull (General Atomics), S.C. Cowley (Imperial College)

The effects of equilibrium parameters on long wavelength ideal MHD instabilities in toroidal plasmas are traditionally studied using numerical parameter scans. Previously, we introduced a new perturbative technique to explore these dependencies: changes in the potential energy δW due to small equilibrium variations are found using a perturbation of the energy principle, rather than with an eigenvalue-solver instability code.

With this perturbed equilibrium approach, stability dependencies can be quickly determined without numerically generating complete MHD stability results for every set of parameters (which can be time-intensive for accurate representations of several configurations). Compared to a routine parameter scan, this approach may also provide the researcher a more intuitive feel for the effects of various parameters.

Previous attempts to validate this approach in toroidal geometry using GATO (an ideal MHD stability code) and experimental equilibria gave correct stability trends in some cases, but not all. Analysis focused on DIII-D shot 87009, which exhibits global internal m=2 and m=3 kink modes. This technique should work well with global modes; however, changes more than only $\sim 0.1\%$ to q_o predicted δW several orders of magnitude too large.

We first briefly review the perturbed stability analysis for a cylindrical circular equilibrium, which works well with this approach, and also the previously presented results from DIII-D shot 87009, which are discouraging. Between the circular equilibrium and the shaped toroidal equilibrium of 87009 lie several other equilibria, which should produce intermediate results. We construct several of these intermediate equilibria, starting with a circular cross-section and making progressive changes to shape and profiles until ending at 87009. To gain some understanding about why q_o in 87009 is so sensitive, we perturb q_o in each of these intermediate equilibria.

[1]Research supported by US DOE Contract DE-FG02-92ER54139.
[2]comer@cae.wisc.edu, Engineering Research Building, 1500 Engineering Dr., Madison, WI 53705

Magnetic Topology Evolution and Thermal Energy Transport in Coaxial Plasma Gun Spheromak Simulations*

G. A. Cone and C. R. Sovinec

Department of Engineering Physics, University of Wisconsin-Madison
1500 Engineering Drive, Madison WI 53706

Abstract

Earlier nonlinear resistive MHD simulations of spheromak decay from a sustained state with open magnetic field and electrostatic helicity injection have shown the transient formation of closed magnetic flux surfaces.[1] The computations were performed in the limit of zero plasma-β and do not provide direct information on energy transport; however, the magnetic topology change suggests that the decay phase has relatively good confinement properties, consistent with the temperature profile peaking observed in many spheromak experiments.[2] To provide a more definitive assessment of the MHD evolution, subsequent simulation efforts[3,4] include finite plasma-β, Ohmic heating, and internal energy transport—modeled using an anisotropic thermal conductivity tensor. Here, we have found direct evidence of temperature profile peaking during spheromak decay that is sensitive to the specified $\chi_{\|}/\chi_{\perp}$ ratio, though the results obtained with a simplified coaxial gun geometry[3] lack sufficient numerical refinement.

Recent updates to the preprocessor for the NIMROD code[5] improve the realism and accuracy of finite plasma-β simulations in the coaxial gun configuration. The new finite element mesh avoids sudden changes in element dimensions across the mesh and conforms closely to the curved cross sections of the flux conserver and the central electrode in the SSPX experiment.[6] In addition, time-dependent boundary conditions at the entrance of the plasma gun region model the circuit current waveform of the SSPX power supply. A comparison is made between simulations using an applied tangential electric field and simulations where the total current across the electrodes is specified through the toroidal magnetic field at the surface that represents the insulating gap. The purpose of this comparison is to investigate how any differences in the current drive may affect the evolution of closed magnetic flux tubes and energy confinement.

[1]C. R. Sovinec, J. M. Finn, and D. del-Castillo-Negrete, Phys. Plasmas **8**, 475 (2001).
[2]T. R. Jarboe, Plasma Phys. Controlled Fusion **36**, 945 (1994).
[3]G. A. Cone, C. R. Sovinec, H. Tian, and B. I. Cohen, Bull. Am. Phys. Soc. **47**, No. 9, p. 43, presentation BP1 70 (2002).
[4]R. H. Cohen, B. I. Cohen, C. R. Sovinec, and G. A. Cone, "Searching for a Better Spheromak with NIMROD," 2003 Intl. Sherwood Fusion Theory Conf.
[5]A. H. Glasser, C. R. Sovinec, R. A. Nebel, et al., Plasma Phys. Control. Fusion **41**, A747 (1999).
[6]E. B. Hooper, L. D. Pearlstein, R. H. Bulmer, Nucl. Fusion **39**, 863 (1999).

*This work is supported by the U.S. Dept. of Energy.

1C35

New Experimental Evidence in Support of the Accretion Theory for the Spontaneous Rotation Phenomenon and Relevant Developments*

B. Coppi
Massachusetts Institute of Technology, Cambridge, MA 02139

The "accretion" theory was proposed since the early experimental indications of this phenomenon and was inspired by the theory of millisecond pulsars. Accordingly, the explanation given was and is that angular momentum is transferred to the material wall surrounding the plasma by the effects of collective modes excited at the edge of the plasma column and that opposite angular momentum is carried toward the center of the plasma column by a different set of modes [1]. Then a series of predictions could be made that would prove the validity of the theory. (1)The toroidal velocity would have to invert its direction as the plasma column is taken from a regime with a high degree of confinement of the plasma thermal energy (so called H-regime) to a regime of low confinement (so called L-regime). In fact, the modes that, according to the theory, had to be excited at the edge of the plasma column would have opposite phase velocities in the two regimes. (2) Since the inward transport of angular momentum is considered to be at the edge of the plasma column, when the rotation starts it should be observed as localized in the outer part of the plasma column propagating toward the center. (3) Since the inward transport of angular momentum is attributed to plasma modes that are responsible for the outward transport of the nuclei thermal energy, according to the theory, the transport characteristic times for the angular momentum and for the nuclei thermal energy should be about equal. (4) The phase velocities of the plasma modes excited at the edge of the plasma column should be in a given characteristic direction (the so called electron diamagnetic velocity) in the H-confinement regime and in the opposite direction in the L-confinement regime. Conversely, the plasma column should rotate contrary to these directions. (5) The modes that can carry the angular momentum toward the center of the plasma column can be suppressed when a strong gradient of the particle density is produced. Therefore the rotation in the central part of the plasma column should disappear when a strong particle density gradient is produced.

A cycle of experiments carried out during the past year has confirmed all these points [2]. In particular, experiments were performed at MIT by the Alcator CMod machine where the transition from the L-regime to the H-regime was programmed so that a state of zero velocity could be reached as the velocity inverted its direction as predicted by the theory. Then as the plasma entered the H-regime, the rotation was seen to start from the outside. The time scales for the inward propagation of the angular momentum and the outward transport of thermal energy were found to be comparable. Moreover, when a strong density gradient was produced on a "shell" within the plasma column, the rotation was observed to disappear within the shell as predicted by the theory. The observation that the modes excited at the edge of the plasma column invert their phase velocities in the transition from the L-regime to the H-regime has been confirmed by further experiments carried out by the JET facility in England.

*Sponsored in part by the U.S. Department of Energy

[1] B. Coppi, *Nucl. Fus.*, **41**, 12, 1 (2002)
[2] B. Coppi, in Proceedings of the 2002 International Conference on Fusion Energy, paper TH/P1-02 (Publ. I.A.E.A., Vienna, 2002) to be published in *Nucl. Fusion*

1C36

Importance of Non-Linear Effects on Tridimensional Singular Modes of Accretion Disks and Inadequacies of Axisymmetric Modes*

P.S. Coppi+ and B. Coppi++

+Yale University, New Haven, CT 06511
++Massachusetts Institute of Technology, Cambridge, MA 02139

Tridimensional modes [1], which are singular when described by the linearized ideal MHD approximation, are shown to be capable of producing outward transport of angular momentum at a significant rate in thin accretion disks. These modes are localized radially with two sets of singularities where the Doppler shifted frequency equals the shear Alfén mode frequency the latter set of singularities being the most difficult to resolve. The contribution of non-linearities is demonstrated to be important even for very small values of the mode amplitude at these singularities and model equations, which can describe the transition across the singularities, are identified and solved [2]. The rate of the transport of angular momentum is evaluated from the relevant quasilinear theory.

While tridimensional modes can exist in the case where the magnetic energy density is significant relative to the thermal energy density, two dimensional modes can be found only when the magnetic energy is much smaller than the thermal energy. They are vertically localized ballooning modes with relatively small growth rates and are oscillatory but not localized radially [2]. Both the growth rates and the radial mode number have discrete spectra. This feature makes it difficult to construct mode packets in order to resolve the problem of the radial localization of the modes. When all factors are taken into account, the axisymmetric modes that can fit into a thin magnetized disk do not appear to be suitable to produce transport of angular momentum at the rate necessary for realistic accretion disk models. These modes are, in fact, topologically quite different from the original Velikhov instability [3] of a magnetized rotating cylinder.

*Sponsored in part by the U.S. Department of Energy

[1] B. Coppi and P.S. Coppi, *Phys. Rev. Lett.*, **87**, 5, 051101-1 (2001)
[2] B. Coppi and P.S. Coppi, Massachusetts Institute of Technology, R.L.E. Report PTP-01/04 (Cambridge, MA, 2001) Submitted to Phys. Rev. Lett.
[3] E.P. Velikhov, *Soviet Phys.*, JETP, **36**, 995 (1959)

1C37

Magnetic Drift Compressional Modes in High β Plasmas*

C. Crabtree[1], W. Horton[1], H.V. Wong[1], J. Van Dam[1], L. Chen[2]

[1] Institute for Fusion Studies, University of Texas at Austin,
Austin, Texas 78712
[2] University of California at Irvine,
Irvine, CA 92697

Abstract

Magnetic dipoles are ubiquitous in nature and have desirable properties for magnetic fusion [1]. The stability and non-linear consequences of low-frequency drift compressional waves in high β plasmas with dipole like magnetic configurations is investigated. It is found tht there are two different regions of parameter space where drift-compressional waves can be unstable: (1) when pressure gradients become sufficiently steep to reverse the magnetic-guiding center drift and (2) when the temperature gradient is in the opposite direction to the density gradient. Nonlocal bounce-averaged eigenmode equations are solved for different equilibrium configurations and the resulting growth rates, frequencies and eigenmode structures are reported. A model PDE is found and solved that describes the non-linear evolution of this mode. The coupling of drift compressionl waves to electrostatic drift waves is also discussed. The results of this work make it clear that scientific experiments and large-scale particle simulations to investigate the nature of drift-compressionl modes are necessary.

[1] A. Hasegawa, L. Chen, M.E. Mauel, "A D-^{3}He fusion reactor based on a dipole magnetic field", Nuclear Fusion, **30**, (1990), 2405.

*This work was supported by the U.S. Dept. of Energy Contract No. DE-FG03-96ER-54346 and the National Science Foundation Grant ATM-9907637

1C38

Fractional-diffusion models of anomalous diffusion

D. del-Castillo-Negrete, B. A. Carreras, and V. Lynch
Oak Ridge National Laboratory,
Oak Ridge TN, 37831-8071, USA

Abstract

Reduced models of the turbulence shear-flow interaction have shown evidence of spatio-temporal propagating fronts during the L-H transition. In their simplest form, these models consists of reaction-diffusion equations in which the reaction kinetics models the dynamic coupling of the fields and standard diffusion operators (i.e. based on Ficks's law) model turbulent transport [1]. A general limitation of standard diffusion operators is their inability to describe non-Gaussian transport. That is, anomalous diffusion processes in which the mean-square displacement grows faster than linear (e.g. [2]). To explore the role of anomalous diffusion in the dynamics of fronts, we consider the Fractional-Fisher-Kolmogorov (FFK) model which is a reaction-diffusion equation with a fractional diffusion operator. In the absence of reaction kinetics, the FFK equation reduces to Feller's fractional diffusion equation whose solutions include Levy distributions. Numerical and analytical results are presented describing asymmetric ballistics-like transport, and accelerating fronts with algebraic decaying tails.

[1] D. del-Castillo-Negrete and B. A. Carreras, Phys. Plasmas, 9, 118 (2002), Physica D, (2002).
[2] D. del-Castillo-Negrete, Phys. Fluids, 10, 576 (1998).

1C39

Double tearing mode in plasmas with anomalous electron viscosity

J. Q. Dong
Southwestern Institute of Physics
P.O. Box 432, Chengdu, China
S. M. Mahajan and W. Horton
Institute for Fusion Studies
University of Texas at Austin
Austin, USA

Abstract

The linear behavior of double tearing mode in plasmas with anomalous electron viscosity is investigated within the framework of MHD theory. A two-space-scale analysis is performed and an approximate dispersion relation for the mode is obtained. For large Reynolds number $R = \tau_v/\tau_h$ with τ_v and τ_h being the viscosity penetration time of magnetic field and Alvén time for a plasma sheet of width a, respectively, it is shown that the growth rate scales as $R^{-1/5}$ if the two resonant surfaces, at $x = \pm x_s$, of the mode are close enough such that $x_s/a \ll (k_y a)^{-11/15} R^{-1/15}$. The growth rate scaling transits to $R^{-1/3}$ scaling when the distance between the resonant surface increases. The transition occurs at $x_s/a \sim (k_y a)^{-11/15} R^{-1/15}$. The $R^{-1/5}$ is shown to be closely correlated with violation of the contant-ψ approximation. It is also shown that the high saturated sheared poloidal velocity may be a trigger for the formation of transport barriers observed in advanced tokamaks.

Development of Electron Holes and Anomalous Resistivity in 3-D Magnetic Reconnection

J. F. Drake, M. Swisdak and M. A. Shay
University of Maryland
C. Cattell
University of Minnesota
B. N. Rogers
Dartmouth College
A. Zeiler
MPI für Plasmaphysik, Garching, Germany

Magnetic reconnection with a guide field is explored with full particle simulations and theory to understand the development of turbulence and anomalous resistivity and its impact on the rate of reconnection and particle heating (1). Electrons around the magnetic x-line and separatrices are accelerated to high velocity by the reconnection electric field. The resulting magnetic-field-aligned electron beams are unstable to Buneman as well as current driven lower-hybrid waves. The Buneman instability evolves into distinct nonlinear structures consisting of localized regions of bipolar parallel electric field with net positive charge, "electron holes". The electron holes are localized both parallel and transverse to the magnetic field with scale lengths of 10's of Debye lengths. The holes couple strongly to a current driven lower-hybrid wave. The complex nonlinear interaction bewteen the electron holes and lower hybrid wave controls both the lifetime and the spatial distribution of electron holes parallel to the magnetic field. The interaction of the electron beam with the turbulence produces extended tails on the electron velocity distributions. The turbulence induced anomalous resistivity is spatially patchy and highly time dependent. Comparisons are made with recent observations of electron holes at the Earth's magnetopause. An important parallel between the problem of anomalous resistivity during magnetic reconnection and lower hybrid current drive is established. Implications for magnetic reconnection and particle energization in laboratory and astrophysical plasmas are discussed.

1. J. F. Drake, M. Swisdak, M. A. Shay, C. Cattell, B. Rogers and A. Zeiler, Science **299**, 873, 2003.

1C41

Generation and Analysis of Multiple Phase Space Structures

D. Yu. Eremin and H. L. Berk

Institute for Fusion Studies, University of Texas at Austin
Austin, Texas, 78712

Numerical simulations are performed where a single linear mode is destabilized by a weakly inverted population of kinetic particles to produce a primary and secondary hole-clump phase space structures. As a result the secondary phase space structures reduces the amplitude of the primary phase space nonlinear mode. To understand this effect, a reduced equation governing the evolution of a mode amplitude in the presence of another mode is derived. When the separation of the two modes in phase space is accounted for when there is only a modest amount of stochasticity in the particle orbits, the amplitude is calculated to be smaller than in case of one mode alone. Results are in agreement with the numerical simulations. Stochastic effects reduces the amplitude even further when the phase velocities of adjacent modes are closer to each other.

This work is supported by the U.S. Department of Energy Contract No. DE-FG03-96ER-54346.

1C42

Role of Trapped Electron Mode Turbulence in Density Profile Control with ICRH in Alcator C-Mod

D. R. Ernst, P. T. Bonoli, P. Catto, W. Dorland,[2] C. L. Fiore, M. Greenwald, A. Hubbard, J. Irby, E. Marmar, D. Mossessian, M. Redi,[1] J. Rice, S. Wolfe, S. Wukitch, K. Zhurovich, and the Alcator C-Mod Group

Plasma Science and Fusion Center, Massachusetts Institute of Technology, Cambridge, MA 02139
[1]Princeton Plasma Physics Laboratory, Princeton, NJ 08543
[2]University of Maryland, College Park, MD 20742

Abstract

Recent experiments[1] on Alcator C-Mod, using off-axis ICRH, have produced very peaked density profiles without core fueling, following the transition to EDA H-Mode. As the density peaks, the temperature profile remains relatively unaffected. Adding modest levels of central ICRH arrests the density peaking. Similar results are seen in DIII-D in the QDB regime, where off-axis ECH flattens peaked density profiles.[2] The degree of density peaking is set by adjusting the central heating power, demonstrating density profile control via external tools. This mode is produced without core fueling, reverse shear, large Shafranov shift, central auxiliary heating, or external torques. This provides a unique opportunity to study the fundamental turbulent and collisional processes underlying particle transport in an isolated context. The relevant electron continuity equation is simply $\partial_t n + \nabla \cdot (\Gamma_p^{neo} + \Gamma_{turb}) = 0$, where Γ_p^{neo} is the collisional neoclassical pinch, and Γ_{turb} is the particle flux due to TEM turbulence. This work aims to determine the basic processes controlling particle transport in the steep gradient region, making quantitative comparisons between experiments, neoclassical codes, and nonlinear GS2[3,4] gyrokinetic turbulence simulations.

Transport analysis shows the neoclassical (Ware) pinch exceeds the inflow required to peak the density profile. Early in time, when the temperature profile is peaked and the density profile is relatively flat, GS2 simulations show a turbulent pinch similar in magnitude to the neoclassical pinch. As the density profile peaks, this turbulent inflow reverses to become an outflow. Toroidal ion temperature gradient driven modes are suppressed inside the half-radius (nominally the "foot" of the internal transport barrier), and dominant in the outer half-radius. As the density gradient further steepens, non-resonant collisionless trapped electron modes (TEM) are driven unstable. Gyrokinetic stability analysis shows the modes are driven by the density gradient, have wavelengths of order twice the ion gyroradius, and are partially damped by collisions. After the TEM onset, the turbulent outflow strongly increases with the density gradient. This outflow balances the inward neoclassical pinch at the same time the density gradient scale length comes to steady state. Further, the turbulent particle diffusivity from nonlinear GS2 simulations comes close to the experimental value inferred from the continuity equation, using measured density profile data and the calculated neoclassical pinch. This turbulent diffusivity exhibits a strong unfavorable temperature dependence, enabling control with central heating.

[1] S. J. Wukitch *et al.*, Phys. Plasmas 9(5), 2149 (2002).
[2] E. J. Doyle *et al.*, Bull. Am. Phys. Soc. **47** (9), 301 (2002).
[3] W. Dorland *et al.*, Phys. Rev. Lett. **85**, 5579 (2000).
[4] M. Kotschenreuther *et al.*, Comp. Phys. Comm. **88**,128 (1995).

1C43

Multi–Wave Model for Plasma–Wave Interaction

E. G. Evstatiev, W. Horton, P. J. Morrison
Physics Department and Institute for Fusion Studies, University of Texas at Austin, Austin, TX 78712

Abstract

The problem of accelerating particles in a laser driven plasma is considered. A model is presented that describes the interaction of electrons with waves in a cold plasma. Starting from the Lagrangian for the system of fields, background plasma, and particles, a finite dimensional self-consistent model is derived using the envelope approximation for the waves. The (squared) wave amplitudes and phases form action-angle variables in the closed system of M waves and N_p particles. The system conserves energy and momentum, and thus is natural for solving the beam-loading problem. Numerical simulations are performed and some further simplifying approximations are considered to compare with earlier electrostatic problems.

This work was supported by the U.S. Department of Energy Contract No. DE–FG03–96ER–54346.

1C44

Continuing Inquiries Into R/S–like Dynamic Scaling Measures

Willis Ferenbaugh[1], D. E. Newman[1], P. W. Terry[2]
[1] U. of Alaska–Fairbanks, Department of Physics, Fairbanks, AK
[2] U. of Wisconsin–Madison, Madison, WI

Abstract

Fusion research, like most scientific pursuits, generates streams of data from experiments and numerical simulations. Information is extracted from the numbers, in order to characterize the data set and gain insight into the source, as well as comparing the results from different sources. Statistical moments describe the distribution of a set, and dynamical measures (power spectra, correlations, etc.) describe particular features in the ordering of a series. Studies of chaotic and complex systems have led to many measures of scaling and self–similarity, including the Hurst exponent[1].

The Hurst exponent is a measure of correlations in a data series – correlations which may occur on all time scales. Rescaled range (R/S) analysis is the original method for finding the Hurst exponent, and this poster further investigates the dynamical information contained in this analysis. Many algorithms to produce fractional Gaussian noise (fGn – correlated data with a Gaussian distribution) have been developed; the construction of correlated data with an arbitrary distribution is examined. Also, artificial data sets have been designed to have other specific characteristics, such as multiple Hurst exponent regimes. Finally, there is a continuing effort to distill additional dynamical information with new R/S–like analyses, and the fruits of these efforts are also presented herein. The hope is that the dynamical properties of a data set can be more/completely described by hierarchy of Hurst–like measures.

[1]H. E. Hurst, Trans. Am. Soc. Civ. Eng. **116**, 770 (1951).

1C45

Turbulence in low-β reconnection events

N. M. Ferraro, B. N. Rogers
Dartmouth College, Hanover, NH 03755

Abstract

Using a two-dimensional, two fluid, numerical model with finite electron inertia, we have observed turbulence to occur in plasmas undergoing magnetic reconnection when the plasma β parameter is sufficiently small. This turbulence occurs in the outflow region downstream from the magnetic X-point, where a large out-of-plane current gradient is observed to develop. We show that ion force balance, in conjunction with the distortion of the field lines of the magnetic island, is the mechanism responsible for the formation of this current gradient. Furthermore, we show that this current gradient is the primary factor causing instability. We derive a local linear dispersion relation for this instability from the two-dimensional MHD equations, and also explore the nonlocal, nonlinear behavior of the system.

1C46

Control of Nonlinear Resistive Wall Modes

John M. Finn[1] and Luis Chacon[1]

[1] Los Alamos National Laboratory

Abstract

We have studied feedback control of resistive wall instabilities in linear and nonlinear theory. The control is idealized in two ways. 1) the normal component of the magnetic field is measured at the resistive wall, and it is assumed that the relevant single Fourier harmonic is measured; 2) the control is applied as a single harmonic at a larger radius. With these idealizations, we have shown that real gain (zero phase shift) is equivalent to having a perfectly conducting wall between the actual resistive wall and the radius where the control is applied. We have also shown that imaginary gain (/2 phase shift) is equivalent to rotating the resistive wall, which is in turn equivalent to plasma rotation, and that complex gain is equivalent to both effects together. These equivalences are exact in 2D linear theory, and serve as useful guidance in 3D linear theory and in nonlinear theory. Further, we have shown that "mode control", a type of feedback used in DIII-D, is equivalent to higher real gain. We have performed 2D nonlinear simulations of control of resistive wall modes driven by current and pressure. The results indicate that the amount of gain, either real or imaginary, required to give a benign saturation of the nonlinear resistive wall MHD modes is of order half the gain required for linear stabilization. We will also discuss integral and derivative gain (and the usual combination PID, proportional-integral-derivative, gain) and the possible application of the Kalman filter to such problems.

Critical Importance of Nonlinear Processes for the Onset of Internal Modes*

M.-C. Firpo and B. Coppi
Massachusetts Institute of Technology, Cambridge, MA 02139

The large scale dynamics and confinement properties of magnetically plasmas depend intimately on the behavior of macroscopic internal modes. Understanding and predicting the development of these modes into the nonlinear regime is of special importance for the design of meaningful fusion burn experiments that should operate at best close to the marginal stability of the m=1, n=1 MHD ideal mode [1].

This problem is addressed analytically in the simplest relevant framework of resistive low-beta reduced MHD equations. We present a dynamical analysis [2] that takes into account self-consistently the motion of the critical layer, in which the magnetic field reconnects, in order to describe how the m=1, n=1 resistive internal mode [3] develops in the nonlinear regime. The amplitude threshold marking the onset of strong nonlinearities due to a balance between convective and mode coupling terms is identified. We predict quantitatively the early nonlinear growth rate of the m=1, n=1 mode below this threshold. These predictions are in good agreement with the numerical results obtained by A.Y. Aydemir [4]. Most important, this approach should be generally applicable to model the early nonlinear evolution of internal toroidal modes involving more realistic (and complex) MHD sets of equations.

*Sponsored in part by the U.S. Department of Energy.

[1] B. Coppi et al., paper FT/P2-10, 19th IAEA Fusion Energy Conference, Lyon (2002) (Publ. IAEA, Vienna 2002).
[2] M.-C. Firpo and B. Coppi, "Dynamical analysis of the nonlinear growth of the m=1, n=1 resistive internal mode", to appear in *Phys. Rev. Letters* (2003).
[3] B. Coppi, R. Galvão, M. N. Rosenbluth, and P. H. Rutherford, *Sov. J. Plasma Phys.* **2**, 3276 (1976); G. Ara et al., *Ann. Physics* **112**, 443 (1978).
[4] A.Y. Aydemir, *Phys. Rev. Lett.* **78**, 4406 (1997).

1C48

Scaling of forced magnetic reconnection in the Hall-MHD Taylor problem

Richard Fitzpatrick
IFS, UT Austin

Two-dimensional, nonlinear Hall-MHD simulations are used to investigate the scaling of the rate of forced magnetic reconnection in the so-called Taylor problem. In this problem, a small amplitude boundary perturbation is suddenly applied to a tearing stable, slab plasma equilibrium; the perturbation being such as to drive magnetic reconnection within the plasma. This type of reconnection, which is not due to an intrinsic plasma instability, is generally known as "forced reconnection". The inclusion of the Hall term in the plasma Ohm's law is found to greatly accelerate the rate of magnetic reconnection. In the linear Hall-MHD regime, the peak reconnection rate is found to scale like $d\Psi/dt \sim d_i\,\eta^{1/3}\,\Xi_0$, where Ψ is the reconnected magnetic flux, d_i the collisionless ion skin-depth, η the resistivity, and Ξ_0 the amplitude of the boundary perturbation. In the nonlinear Hall-MHD regime, the peak reconnection rate is found to scale like $d\Psi/dt \sim d_i^{3/2}\,\Xi_0^2$.

1C49

Explosion of laser-irradiated micro-clusters

M. Fomytsíkyi, A. Arefiev, and B. Breizman

Institute for Fusion Studies, The University of Texas at Austin, Austin, TX 78712

Abstract

This work has been motivated by desktop laser fusion experiments, in which fusion reactions were produced by the irradiation of deuterium micro-clusters with a very short laser beam [1]. The observed phenomenon is associated with ion acceleration in the process of cluster explosion. There are two conceivable scenarios for such an explosion: an electrical and a thermal one. Although both scenarios involve the space-charge electric field as an accelerating force for the ions, the essential difference between the two is that the thermal scenario preserves quasi-neutrality whereas the electrical scenario does not. The choice between these two scenarios depends on how the cluster electrons respond to the laser field. There is a natural trend for the electron population to have a two-components distribution function [2]: a cold core that responds to the laser field adiabatically and a halo that undergoes stochastic heating [3].

We have carried out 2D PIC simulations to study the explosion of a single filament-like cluster. The simulations confirm the development of a two-component electron distribution in the expected parameter range. We also find that the explosion scenario (electrical vs. thermal) affects the symmetry of the ion expansion. In the electrical scenario, the asymmetry is caused by the cold electron core oscillations inside the cluster in the direction of the laser field. The cluster expansion in the direction of the laser field is therefore somewhat suppressed and the cluster expands primarily in the plane perpendicular to the laser field. In contrast, in the thermal scenario, electron pressure is anisotropic, with a typically larger pressure along the laser electric field. As a result, the ions expand predominantly along the electric field. A new code is being developed to simulate expansion of axisymmetric 3D clusters to allow quantitative comparison with experimental results.

Research is supported in part by FOCUS.

[1] T. Ditmire, J. Zweiback, V.P. Yanovsky, T.E. Cowan, G. Hays, and K.B. Wharton, Nature **398**, 489 (1999).
[2] B. Breizman and A. Arefiev, IFS report-950 (To be published in Plasma Physics Reports) http://peaches.ph.utexas.edu/ifs/ifsreports/950_Breizman.pdf
[3] F. Brunel, Phys. Rev. Lett. **59**, 52 (1987).

1C50

A full radius gyro-kinetic stability analysis for large aspect ratio high-β tokamaks : role of $\tilde{B}_{||}$

R. Ganesh, P. Angelino, J. Vaclavik and L. Villard
rajaraman.ganesh@epfl.ch

Centre de Recherches en Physique des Plasmas,
Association EURATOM - Confédération Suisse,
Ecole Polytechnique Fédérale de Lausanne,
1015 Lausanne, Switzerland

Abstract

Microinstabilities play a prominent role in our understanding of transport in Tokamaks. Though it is known in general that $\tilde{B}_{||}$ which becomes significant at high-β's helps stabilize high frequency microinstabilities such as Alfvén-ITG (AITG)[1] or kinetic ballooning mode (KBM's), a complete linear gyro-kinetic study in a full radius tokamak geometry is still lacking.

In the present work, a gyro-kinetic approach with 3 potentials $[\tilde{\varphi}, \tilde{A}_{||}, \tilde{A}_{\perp}]$ as formulated in Ref.[2], is used to study the linear stability over the entire minor radius for a simple geometry of large aspect ratio tokamaks. For the first time, the eigenmode structure of high frequency modes such as AITG's including $\tilde{B}_{||}$ fluctuations is presented. Growth rates thus obtained may serve as estimates of linear transport coefficients and for benchmarking of existing & future electromagnetic, gyrokinetic, time evolution codes.

[1] G. L. Falchetto, J. Vaclavik and L. Villard, "Global gyro-kinetic study of finite-β effects on linear microinstabilties", To appear in Physics of Plasmas 2003.

[2] R. Ganesh, J. Vaclavik, L. Villard, "Effect of parallel magnetic field fluctuations (finite-β) in linear gyrokinetic stability analysis of drift waves", Varenna-Lausanne International Workshop on **Theory of fusion plasmas**, Eds J. W. Connor, O. Sauter and E. Sindoni, Societa Italiana Di Fisica, Page:261-267, August 2002

For the Sherwood Meeting, Corpus Christi, Texas, April 28-30, 2003

1C51

Power plant study of compact stellarators

P.R. Garabedian
Courant Institute of Mathematical Sciences
New York University
New York, NY 10012

Abstract

The NSTAB code has been run to show that the LHD stellarator is linearly unstable, but remains nonlinearly stable, at the β of 3.2% achieved experimentally. At observed temperatures of 3 keV the TRAN code predicts an energy confinement time of 160 ms that agrees with measured values. Predictions of ballooning stability for the LHD are more pessimistic than estimates from bifurcated solutions calculated over 1, 2, 5 or 10 periods.

Good correlation of computations with observations in the LHD have been applied to assess equilibrium, stability, and transport for a quasiaxially symmetric MHH2 stellarator. A reactor has been designed that has major radius 9~m and plasma radius 3~m. The β limit is 4.5%, and 12 only moderately twisted coils provide robust magnetic surfaces.

Work supported by U.S. Department of Energy Grant No. DE-FG02-86ER53223.

1C52

Dynamic Electrical Conductivity In A Bumpy Cylinder Magnetic Field*

A. L. García-Perciante, J. D. Callen, K. C. Shaing and C. C. Hegna

University of Wisconsin-Madison, Madison WI 53706-1609

In the banana collisionality regime, the parallel electrical conductivity in a toroidal plasma is affected by interactions between trapped and passing particles. In a fluid moment approach this effect is introduced through the parallel viscous force $B \cdot \nabla \cdot \Pi$. What we seek here, is a functional form for this term for a dynamically varying case. The equilibrium and time dependent cases have been dealt with by various authors [1]-[5] with different approaches and results. We present a discussion of these procedures as well as advances in a new model based on a Chapman-Enskog-like approach [4, 5].

In the spirit of developing an appropiate expression for this parallel viscous force, we consider the simple case of a cylindrical magnetic field with periodic bumps. The viscous force in equilibrium ($\frac{\partial}{\partial t} \to 0$) has already been solved and recovers the known result. For the dynamic problem, an eigenmode expansion procedure already developed [6] has been used. We present a deductive approach within this context based on a large aspect ratio expansion that simplifies the response. High and low frequency limits relative to the collision frequency are being investigated.

The calculation seeks a real space, time-dependent analytical solution, convenient for facilitating use in future numerical computations in codes like NIMROD. A transformation to frequency space makes it possible to compare the results for relaxation rates with those in the literature mentioned above.

*Research supported by DoE grant DE-FG02-86ER53218.

References

[1] F. L. Hinton and R. D. Hazeltine, Rev. Mod. Phys. **48**, 239 (1976).

[2] S. P. Hirshman and D. J. Sigmar, Nucl. Fusion **21**, 1079 (1981).

[3] F. L. Hinton and C. Oberman, Nucl. Fusion **9**, 319 (1969).

[4] J.P. Wang and J.D. Callen, Phys. Fluids B **4**, 1139(1992).

[5] J.P. Wang and J.D. Callen, Phys. Fluids B **5**, 3207 (1993).

[6] C.T. Hsu, K.C. Shaing and R. Gormley, Phys. Plasmas **1**, 132 (1994).

1C53

Insight in the stabilization of a resistive wall mode by plasma rotation*

A.M. Garofalo,[1] T.H. Jensen,[2] M.S. Chu,[2] G.A. Navratil,[1] M. Okabayashi,[3] H. Reimerdes,[1] and E.J. Strait[2]

[1]Columbia University, New York, New York
[2]General Atomics, P.O. Box 85608, San Diego, California 92186-5608
[3]Princeton Plasma Physics Laboratory, Princeton, New Jersey.

Abstract

Measurements of the resistive wall mode (RWM) response to external resonant fields are used for describing the effects of error fields on a high-β tokamak plasma, as well as the RWM dispersion relation in the parameter range explored. We have generalized an ideal MHD model [1] to include the effects of plasma rotation and dissipation, and we find that the new model can explain quantitatively the experimental observations. In particular, we have analyzed the measurements of the RWM characteristics vs. the plasma β, at $\beta > \beta^{\text{no-wall}}$. Rotation of the RWM with respect to the wall is often described as an essential feature of the mechanism by which plasma rotation stabilizes the RWM [2-4]. This common understanding of the rotational stabilization of the RWM appears inconsistent with the recent experimental evidence from DIII-D. We find that the stabilization by plasma rotation is due principally to dissipation in the plasma, not to dissipation in the resistive wall. In this scenario, the theoretically predicted mode rotation with respect to the wall is not needed for stabilization, and is just a negligible consequence of torque balance in the absence of non-axisymmetric external magnetic-fields.

[1] A.M. Garofalo, T.H. Jensen, and E.J. Strait, Phys. Plasmas **9**, 4573 (2002).
[2] A.H. Boozer, Phys. Plasmas **2**, 4521 (1995).
[3] R. Fitzpatrick, A.Y. Aydemir, Nucl. Fusion **36**, 11 (1996).
[4] M. Okabayashi, J. Bialek, M.S. Chance, et al., Phys. Plasmas **8**, 2071 (2001).

*Work supported by the U.S. Department of Energy under Grant Nos. DE-FG02-89ER53297 and DE-FG03-95ER54309 and Contract Nos. DE-AC03-99ER54463 and DE-AC02-76CH03073.

1C54

Effect of conserved angular momentum on minimum energy states*

Preston Geren
Geren Consulting Services, Shoreline, Washington

Loren Steinhauer
University of Washington, Redmond Plasma Physics Laboratory

Minimum-energy theory has proved useful in predicting the structural properties of some magnetically-confined plasmas. The most widely-known theory of this type is based on the principle of conserved magnetic helicity, K_m, and leads to what are commonly called Taylor States. More recently, a more general theory has been developed based on the two-fluid model. It has *two* helicity constraints, one for each species (K_e for electrons and K_i for ions). In general, adding another constraint raises the minimum energy and modifies the structure of the minimum-energy state. For example, adding the ion helicity allows finite beta, which is not allowed in a Taylor state. Another constraint that may apply in many cases is the angular momentum, L_z, a constraint that has largely been ignored in minimum-energy studies to date. Likewise in general, including it as a constraint raises the minimum energy and modifies the plasma structure.

The minimum-energy theory with constraints on the two helicities and the angular momentum is presented. Assuming an incompressible plasma and using a Fourier-Beltrami (FB) expansion, a FB spectrum of solutions is determined. These full-spectrum solutions differ markedly from the one-point (Taylor-like states) or two-point (double-Beltrami) solutions that appear when angular momentum conservation is ignored.

An important property of the full-spectrum solutions is that they are axisymmetric. This implies that no member of this class of solutions can be kinked, "sausaged", tilted, "ballooned", fluted or otherwise manifesting the persistence of an instability. On the other hand, the one-point or two-point spectrum solutions *can* be non-axisymmetric, and thus can represent the nonlinear end-state of a fully-developed instability. The question then is which solution type applies for a given set of constraints $\{K_e, K_i, L_z\}$.

The full-spectrum solutions are presented and compared with the one- and two-point solutions developed previously. The issue of which specific combinations of the invariants (two helicities, angular momentum) is also investigated. For this purpose the two-dimensional helicity map K_e-K_i is used to classify the states and identify the regions of stability and instability.

*This work is supported by USDOE Grant DE-FG03-98ER54480.

1C55

Progress in the Development of the SEL Macroscopic Modeling Code

A. H. Glasser and X. Z. Tang
Los Alamos National Laboratory, Los Alamos, NM 87545

SEL is a recently-developed, massively-parallel, time-dependent, nonlinear macroscopic fluid modeling code. Spatial discretization uses high-order Spectral ELements on a logically rectangular grid. Spectral elements exhibit the same exponential convergence of spatial truncation error as global spectral methods while also allowing domain decomposition for parallization and grid adaptation to localized structure and complex geometry. Time discretization uses a full, nonlinearly-implicit time step, allowing efficient treatment of problems with strong flow and 2-fluid effects. Nonlinear system solution uses Newton-Krylov methods based on the PETSc and MPI libraries. All physical equations are expressed in conservative, flux-source form, allowing details of discretization to be separated from specification of these equations and facilitating the formulation of new physics problems. 1D and 2D versions of the code are fully operational. The 1D code uses a version of Adaptive Mesh Refinement (AMR), automatically concentrating the grid in regions of sharp gradients, optimizing the use of the available grid while minimizing its size.

Two major improvements have been made to the code over the past year. The first concerns efficient parallel operation. Static condensation has been implemented for effective preconditioning of the Krylov subspace methods. Higher-order finite elements are eliminated in terms of the lower-order terms by means of small, local, direct solves which parallelize perfectly, reducing the size and condition number of the matrix requiring global iterative solution. The number of dependent variables is reduced by a factor of order $np/2$, with np the degree of the Jacobi polynomial basis functions used, reflecting the volume-to-surface ratio of each grid cell. Iterative solution of the condensed global matrix is further accelerated by exploiting advanced methods available in the PETSc library. An additive Schwarz incomplete LU factorization with generous overlap and moderate fill-in is found to be a very effective preconditioner for the GMRES Krylov-subspace method. These improvfed methods also avoid limits previously encountered on convergence for large time steps. The speed of the code has improved since last year by a factor of order 200.

The second improvement, still under the development, concerns 2D and 3D adaptive gridding. An essential feature of magnetic plasma confinement is a very high degree of anistropy. Magnetic fields are very effective at restraining the motion of plasmas across magnetic fields, but almost totally ineffective at restraining it along the field. As a result, both wave propagation speeds and diffusive transport coefficients can differ by many orders of magnitude along and across the field. If a small amount of the large parallel flows is allowed to numerically corrupt the much smaller transverse flows, the results can be meaningless. Conventional AMR methods in 2D and 3D, using a grid oblique to the magnetic field, fail to resolve this anisotropy. The most effective approach is the use of magnetic flux coordinate grids. Such grids have been used effectively, for example in the NIMROD code, based on a static, axisymmetric initial equilibrium field. If the simulation is followed for a sufficiently long time, the dominant field can develop helical distortion, requiring new methods of automatically aligning the grid with the evolving, non-axisymmetric field. Since non-axisymmetric fields do not in general possess nice, nested flux surfaces, an exact point-wise flux coordinate system is not achievable. We are developing a variational approach to grid alignment, designed to give a best-fit solution while effectively dealing with regions of multiple small islands and stochasticity. Approximate flux surfaces constitute the null space of a large, sparse, real, symmetric, semi-definite matrix. Efficient numerical methods for deteremining this null space are being developed, based on the PARPACK library. Visualization techniques are used to verify that the resulting coordinate system is reasonable. Once this is done, the solution can be periodically interpolated to the newly aligned grid, using high-order spectral elements to minimize interpolation error. Adaptation can then be achieved by packing the grid in one dimension, normal to the approximate flux surfaces, using methods developed in the 1D version of the code.

Operation of the code will be illustrated with examples of 2D incompressible magnetic reconnection in the presence of strong flow shear, driven by combined tearing and Kelvin-Helmholtz instabilities.

Monday Afternoon, April 28

13:30 to 15:30

Corpus Christi Ballroom C

Oral Session 1D

1D01

The three-dimensional MHD dynamics of ac helicity injection

F. Ebrahimi and S. C. Prager
University of Wisconsin-Madison, Madison, Wisconsin 53706

Abstract

AC helicity injection is a technique to sustain current in plasmas in which the current distribution relaxes by internal processes. The dissipation of magnetic helicity is balanced by magnetic helicity injected by oscillating the surface poloidal and toroidal loop voltages.[1] The technique is considered for current sustainment in the reversed field pinch (RFP), and similar helicity injection techniques are being studied for the spherical tokamak and spheromak. The efficiency of the current drive, the resulting current profile, and the magnetic fluctuations in these configurations are determined by 3-D MHD dynamics. We have completed a comprehensive 3-D MHD computational study of helicity injection in the RFP.[2] Our results are compared with analytical solution of 1-D models. In a classical 1-D plasma, the oscillating voltages produce a steady current in the plasma, driven by the dynamo effect associated with the oscillating axisymmetric velocity and magnetic fields. This current is localized to the plasma edge region. With full 3-D dynamics, tearing fluctuations relax the plasma current toward the core, by the tearing mode dynamo, yielding a steady plasma current over the entire cross-section. The tearing fluctuations are comparable in magnitude to those that occur in standard RFP plasmas, although a global mode resonant at the edge occurs. We have also studied partial current drive by helicity injection, and find that ac helicity injection at appropriate frequency flattens the current density profile such that magnetic fluctuations are reduced.

[1] M. K. Bevir and J. W. Gray, in Proceedings of the Reversed-Field Pinch Theory Workshop, Los Alamos, NM, 1981, Vol. III, p. A-3.
[2] F. Ebrahimi, S. C. Prager, J. S. Sarff, and J. C. Wright, to appear in Phys. Plasmas 10 (2003).

1D02

Relaxation current drive in spheromaks as a forward energy cascade requiring sufficient Lundquist number

V.A. Izzo and T.R. Jarboe

Aerospace and Energetics Research Program, University of Washington
Seattle, WA 98195

The minimum Lundquist number required for relaxation current drive in a spheromak is determined from the results of decaying spheromak simulations performed with the NIMROD code, where S is varied over one order of magnitude. As the spheromak decays, a relaxation event occurs, which is a transition from the initial hollow current configuration to a more uniform current configuration. The Sweet-Parker reconnection time is found to be the governing time scale for relaxation based both on the loss time of the $n = 0$ magnetic energy and the full-width half maximum of the $n = 1$ magnetic energy. For sufficiently high S, poloidal flux generation occurs as a result of relaxation and toroidal current increases. During the transition, energy in the $n = 1$ mode is dominant over higher n modes, but all non-axisymmetric modes decay rapidly toward zero after the relaxation event has occurred. The $n = 1$ distortion is apparent in the flux surfaces during relaxation, but significant regions of closed flux persist throughout the evolution. The NIMROD results can be understood in terms of a cascade of the free magnetic energy while helicity is conserved. The cascade model is described by three simple equations governing the flow of magnetic energy between spatial scales. When these equations are integrated numerically, the $n = 1$ and $n = 0$ energy evolutions closely match the NIRMOD results, supporting the 0-D analytic model as a good description of the 3-D nonlinear dynamics computed with NIMROD.

1D03

Stability Properties of Field-Reversed Configurations [1]

E. V. Belova, R. C. Davidson, H. Ji, and M. Yamada
Princeton Plasma Physics Laboratory, Princeton NJ 08543

Abstract

New computational results are presented which advance the understanding of the stability properties of the Field-Reversed Configuration (FRC). We present results of hybrid and two-fluid (Hall-MHD) simulations of prolate FRCs in strongly kinetic and small-gyroradius, MHD-like regimes. The n=1 tilt instability mechanism and growth rate reduction mechanisms are investigated in detail including nonlinear and resonant particle effects, finite Larmor radius and Hall stabilization, and profile effects. It is shown that the Hall effect determines the mode rotation and the change in the linear mode structure in the kinetic regime; however, the reduction in the growth rate is mostly due to finite Larmor radius effects. Resonant wave-particle interactions are studied as a function of (a) elongation, (b) the kinetic parameter S*, which is proportional to the ratio of the separatrix radius to the thermal ion Larmor radius, and (c) the separatrix shape. It is demonstrated that, contrary to the usually assumed stochasticity of the ion orbits in the FRC, a large fraction of the orbits are regular in long configurations when S* is small. A stochasticity condition is found, and a scaling with the S* parameter is presented. Resonant particle effects are shown to maintain the instability in the large gyroradius regime. The nonlinear evolution of unstable modes in both kinetic and small-gyroradius FRCs is shown to be considerably slower than that in MHD simulations. Our simulation results demonstrate that a combination of kinetic and nonlinear effects is a key for understanding the experimentally observed FRC stability properties.

[1] Research supported by the Department of Energy Contract No. DE-AC02-76-CHO-3073

1D04

The behavior of current/vortex sheets in extended MHD: a system-scale theory for fast reconnection?

L. Chacón, D. A. Knoll, and J. M. Finn

Theoretical Division, Los Alamos National Laboratory, Los Alamos, NM 87545

Abstract

Magnetic reconnection is a fundamental process whereby magnetic energy stored in sheared magnetic fields is released and converted into plasma energy. Of particular relevance is understanding fast (explosive) reconnection phenomena. It is now generally accepted that electron Hall physics is the culprit of fast reconnection physics [1]. Recent work [2] has shown that the reconnection rate in Hall MHD scales as $(d_i/\delta)^{1/2}$, where d_i is the ion skin depth, and δ is the current sheet thickness. However, there are still situations (e.g., the solar corona) in which fast reconnection is frequently observed but $d_i \ll \delta$, and hence the importance of Hall physics cannot be justified *a priori*.

Since fast Hall reconnection requires $d_i \sim \delta$, a successful system-level theory of fast magnetic reconnection for such situations should provide a viable mechanism for self-consistent, dynamic current sheet "thinning" to Hall-relevant scales. Here, we propose current-vortex sheets (in which a sheared magnetic field and a sheared flow co-exist) as the basis for such a mechanism.

In the configuration of interest, the magnetic and ion velocity fields are parallel and identically sheared. We have studied the nonlinear behavior of this current-vortex sheet configuration numerically in the framework of 2D incompressible resistive and Hall MHD. In resistive MHD ($d_i \ll \delta$), KHI occurs for super-Alfvénic sheared flow, and a tearing mode instability (TMI) occurs otherwise. Resistive MHD results [3] demonstrate that, in the KHI-dominated regime, fast reconnection rates (in the KHI time scale) are possible which are independent of resistivity η for a large range of resistivity, and that the current sheet thickness δ at the time of the maximum reconnection rate scales as $\eta^{1/2}$. Therefore, KHI in the resistive MHD limit is in fact a very effective current sheet thinning mechanism when η is small.

The thinning process may stall due to magnetic pressure buildup. Determining the conditions under which this occurs before $d_i \sim \delta$ is still subject of ongoing research. However, once δ is comparable to d_i, Hall MHD allows electrons and ions to decouple within the ion skin depth, enriching both the linear and nonlinear behavior of the current-vortex sheet configuration [4]. Linearly, both modes are allowed to grow in a wide range of sub- and super-Alfvénic flows. This implies that a collisionless (fast) electron TM can grow in the presence of a strong ion flow, which is fundamental to allow fast reconnection to proceed. Nonlinearly, both a magnetic island and an ion flow vortex are present at saturation, and the electron flow shows very good alignment with the magnetic field. This saturation state is remarkably independent of the magnitude of the ion shear flow, being observed for both sub- and super-Alfvénic flows.

[1] J. Birn et al., *J. Geophys. Res.* **106**, 3715 (2001).

[2] X. Wang et al., *Phys. Rev. Lett.* **87**, art. no. 265003 (2001); J. Dorelli, in preparation (2003).

[3] D. A. Knoll and L. Chacon, *Phys. Rev. Lett.* **88**, art. no. 215003 (2002).

[4] L. Chacon, D. A. Knoll, J. M. Finn, *Phys. Lett.: A* **308**, 187 (2003).

Monday Afternoon, April 28

15:30 to 17:30

Corpus Christi Ballroom AB

Poster Session 1E

1E01

Combined Parallel Gradient and Collisional Decorrelation Effects in the Absorption of RF Waves

Brent Goode [1], John R. Cary [1], and L. A. Berry [2],

[1] Center for Integrated Plasma Studies, University of Colorado
Boulder, CO 80309

[2] Oak Ridge National laboratory
Oak Ridge, TN 37831–8071

Abstract

We examine the effects on RF wave absorption of two different types of particle wave resonance decorrelation. These two mechanisms are collisions and parallel gradients in the magnetic field. A careful treatment of collisions shows that in the integrand for the plasma dispersion function there is an interaction term which couples both decorrelation mechanisms. In toroidal fusion devices each type of decorrelation dominates in a certain region of space. Of special interest is the region where magnetic field lines intersect the resonant surface with low angle of incidence. In this region neither decorrelation mechanisms dominates over the other, and the combination of the two produces different absorption physics than either mechanism separately.

1E02

Theory of Sub-cyclotron Instabilities of Alfvén Eigenmodes due to Energetic Ions in Low Aspect Ratio Plasmas

N. N. Gorelenkov, E. Fredrickson, E. Belova, C. Z. Cheng

Princeton Plasma Physics Laboratory, Princeton University

Abstract

Spherical tokamaks present new regimes for fast particle confinement, which include low Alfvén speed, large FLR and orbit width, low aspect ratio, high plasma and fast ion betas.

Recent observations of rich sub-cyclotron frequency MHD activity in NSTX suggest that Alfvén eigenmodes (AE) are destabilized in the presence of $80keV$ NBI [1, 2], which has an injection velocity three times larger then the Alfvén velocity. The frequency of observed AEs correlates with the characteristic Alfvén velocity as shown in Fig. 1 (a). A new theory is developed to identify the observed instabilities as Compressional Alfvén Eigenmodes (CAE) and Global shear Alfvén Eigenmodes (GAE frequency is shown in Figure 1) and a comparison of the CAE and GAE dispersions with experimental measurements is made. These AEs are destabilized by free energy in the energetic ion velocity space via Doppler shifted cyclotron resonances with beam ions. CAEs are typically localized at the edge whereas GAEs are localized near the center. The local growth rates of these modes are derived and shown to be small with $\gamma_b/|\omega| \simeq n_{bt}/n_i \leq 1\%$. A broad spectrum of these AEs may be excited at the same time, providing a channel for the energy transfer from the beam ions to the modes and then to the background ions [3]. The main damping mechanism is the continuum damping of GAEs which is small if poloidal mode numbers are high with $m \geq 5$. We have also performed nonlinear simulations of GAE/CAEs with the hybrid kinetic MHD code HYM. The mode structure and frequencies agree with the analytical theory and with the measured frequencies and are shown in figure 1 (b).

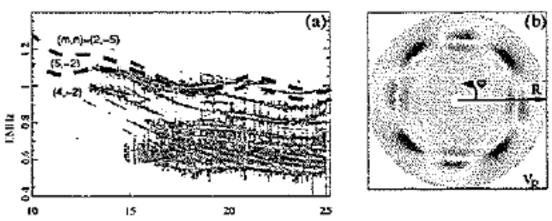


Figure 1: *High frequency spectrum of magnetic coil signal from NSTX plasma showing correlation of simplified GAE dispersion for different* (m,n) *pairs*, $\omega_{GAE} \simeq v_{A0}(m - nq_0)/q_0R$, and *frequency peaks of the instabilities (a). Figure (b) shows the perturbed plasma velocity of GAE mode as modeled by HYM.*

[1] FREDRICKSON, E., et. al., Phys. Rev. Lett. 87 (2001) 145001.

[2] GORELENKOV, et. al., Nucl.Fusion 42 (2002) 977.

[3] GATES, D. A., et. al., Phys. Rev. Lett. 87 (2001) 205003.

1E03

A Modified Semi-Lagrangian scheme for non-linear Drift-Kinetic simulations of SLAB-ITG

V. Grandgirard, M. Brunetti[1], P. Bertrand[2], P. Ghendrih, X. Garbet, G. Manfredi[2], M. Ottaviani, Y. Sarazin, O. Sauter[1], J. Vaclavik[1], L. Villard[1]

DRFC, Association Euratom-CEA, CEA Cadarache, 13108 St Paul-lez-Durance, France.
[1]CRPP, Association Euratom-Confédération Suisse, EPFL, 1015 Lausanne, Switzerland.
[2]LPMIA, Université Henri Poincaré-Nancy 1, BP 239, 54506 Vandoeuvre-les-Nancy, France.

Understanding turbulent transport in magnetically confined fusion plasmas remains a key issue for present and future devices. The instabilities driven by ion temperature gradients (ITG) are one of the main instabilities held responsible for anomalous transport. This work focuses on non-linear global simulations of SLAB-ITG in an inhomogeneous collisionless plasma confined by a strong uniform magnetic field. In the drift-kinetic electrostatic model presented, the electrons are assumed adiabatic and the Larmor radius effects are neglected. With these assumptions the ion distribution function depends on the three cylindrical coordinates and on the parallel velocity.

While the linear theory is well established concerning the ITG modes, the non-linear evolution of these modes is a much more difficult problem to analyse. One of the important challenge for the non-linear codes is the energy conservation which is recognized as a key test of validity. The particularity of our massively parallel code is to solve the 4D non-linear Vlasov equation, which describe the evolution of the ion distribution function, by using a semi-lagrangian (SL) method. In the SL approach the particle motions are approximated by second order trajectories and the Vlasov equation is directly treated on a phase space grid which is fixed in time. Compared to PIC codes, one achieves a strong reduction of the numerical noise, especially in the regions of the phase space populated by the fast particles. Furthermore the energy conservation is achieved with reasonable accuracy ($\sim 15\%$).

We present here the new results obtained with a so called "modified semi-lagrangian (MSL) scheme" where the parabolic trajectory approximation has been replaced by an extrapolation of the trajectories with a Bulirsch-Stoer algorithm. The accuracy of this modified scheme is particularly convincing in the non-linear saturation phase. With a relative error on the energy conservation smaller than $2,5\%$, the MSL scheme appears to be an appropriate means to solve non-linear gyrokinetic problems with good control of the energy conservation property. This allows one to analyse the influence of energy conservation on the physical results.

1E04

MHD equilibria with arbitrary flow

L. Guazzotto, R. Betti
Laboratory for Laser Energetics, University of Rochester
Rochester, NY 14623

Abstract

In the last few years, an increasing interest has been devoted to plasma equilibria with macroscopic flow. As toroidal and poloidal rotation velocities have been measured in modern tokamak plasmas, their effects on the equilibrium need to be determined. As a basis for our analysis, we use Maxwell equations and Ohm's law for the fields, and continuity and momentum equations for the macroscopic fluid quantities. Plasma resistivity is neglected. Under the assumption of axisymmetry the previous set of equations can be reduced to 2 (3 for the anisotropic case) equations, depending on a certain number of free functions of the magnetic flux Ψ (5 for the isotropic, and 6 for the anisotropic case) [1] [2] [3]. More precisely, those are an equation for the magnetic flux, analogous to the classical Grad-Shafranov (GS) equation, one for the density, analogous to the Bernoulli equation, and in the anisotropic case an equation for the toroidal component of the magnetic field B_φ. The models of [1], [2] and [3] can be shown to be equivalent, the free functions of each of them being reducible to the functions of the others by the means of simple algebraic relations. The natural choice of free functions for the numerical solution of the equilibrium problem is then clearly to use the most easily implemented ones in the numerical solver, and the ones most easily related to meaningful physical quantities, such as density, pressures and sonic Mach numbers as input for the code. The code FLOW –developed at Rochester- is capable to compute anisotropic equilibria with arbitrary flow. FLOW has been applied to compute toroidally rotating anisotropic NSTX equilibria. Here the centrifugal force can produce a remarkable outward shift of the density profile if the rotation is sufficiently fast ($V_\varphi \sim C_s$). The density profile is also influenced by the anisotropy. Namely, the outward shift of the density is increased if $\beta_\| < \beta_\perp$, decreased if $\beta_\| > \beta_\perp$. FLOW has also been used to determine equilibria with poloidal flow. When the poloidal flow is of the order of the poloidal sound speed [$C_{s\theta} = C_s B_\theta / B$], the pressure, density and velocity profiles develop radial discontinuities at the transonic surface. When the poloidal flow is even faster, exceeding the poloidal Alfven velocity, a different kind of equilibrium can arise, with the magnetic axis moving to the inboard side, i.e. on the opposite side with respect to the traditional Shafranov shift. Examples of all these equilibria computed with FLOW are shown and discussed.

[1] E. Hameiri, Phys. Fluids **26**, 230 (1983)
[2] R. Iacono, A. Bondeson, F. Troyon and R. Gruber, Phys. Fluids B **2**, 1794 (1990)
[3] R. Betti and J. P. Freidberg, Phys Plasmas **7**, 2439 (2000)

1E05

Nonlinear Dynamics of Shear-Localized Interchange Instabilities *

Sangeeta Gupta, J. D. Callen and C. C. Hegna
University of Wisconsin, Department of Engineering Physics
1500 Engineering Drive, Madison, Wisconsin 53706-1609

The Suydam and Mercier criteria define the instability boundary of a toroidally confined plasma for a magnetic-shear-localized ideal MHD pressure-gradient-driven interchange instability. In this work, we present the nonlinear evolution properties of these instabilities when the stability boundary is violated. For studying the nonlinear fate of the shear-localized ideal interchange mode, the nonlinear vorticity equation coupled with the ideal Ohm's law and pressure evolution equation are solved numerically for three scalar quantities, the electrostatic potential, the parallel vector potential and the perturbed pressure. The perturbed quantities are expanded in Fourier modes in y-direction. Then, each Fourier mode is evolved in both x and time where x is the direction of the equilibrium pressure gradient. The numerical results indicate that for these instabilities the magnetic perturbations play a dominant role in the nonlinear saturation. This is in contrast to the effects observed in the usual shear-free ideal interchange instability where the pressure flattening effects cause the nonlinear saturation. A current sheet/layer develops away from the mode rational surface during the nonlinear phase. The current layer moves radially outwards in time and reaches a maximum distance at the location where the radial velocity vanishes. In the region of sharp current gradient, magnetic reconnection occurs and magnetic islands forms. A discussion of the numerical results and their explanation will be presented.

*Research supported by DoE grant DE-FG02-86ER53218.

1E06

Generation of zonal flows and fields in tokamak edge plasmas: application to DIII-D and effects of ion temperature

P. N. Guzdar[1], R. G. Kleva[1], R. J. Groebner[2], P. Gohil[2], N. Chakrabarti[3]

[1]Institute for Research in Electronics and Applied Physics, University of Maryland
College Park, MD 20742

[2]General Atomics, P.O. Box 85608
San Diego, CA 92186

[3]Saha Institute for Nuclear Physics
Kolkata 700064, India

Recently we have developed a theory for the generation of zonal flow and field driven by finite drift waves and have obtained a criterion for L-H transition in tokamaks[1] and have applied it specifically to DIII-D [2]. The predicted threshold based on this theory shows very good agreement with edge measurements on discharges undergoing L-H transitions in DIII-D. The observed differences in the transitions with the reversal of the toroidal magnetic field are reconciled in terms of this criterion. The theory also provides an explanation for lowered threshold power, pellet injection H modes in DIII-D, thereby unifying seemingly unconnected methods for accomplishing the transition. The earlier theory was for zero ion temperature. We have extended the theory to include finite temperature effects. The modified criterion retains the same basic dependences on the crucial parameters for the transition. For the specific case when $T_i/T_e=1$, the threshold electron temperature is reduced and the scaling with plasma parameters remains exactly the same as that derived in our earlier work [2].

[1]P. N. Guzdar et al., Phys. Rev. Lett. **87**, 015001 (2001).
[2]P. N. Guzdar et al., Phys. Rev. Lett. **89**, 265004 (2002).

1E07

Dynamically accessible perturbations and MHD stability

Eliezer Hameiri
Courant Institute of Mathematical Sciences
New York University
New York, NY 10012
Email: hameiri@cims.nyu.edu

Abstract

It is shown that restricting the perturbations of an MHD equilibrium state with flow to variations that are dynamically accessible[1] yields exactly the same stability criterion as the one obtained by minimizing the plasma energy subject to given values of all constants of the motion.[2] This result is in disagreement with a claim made recently, but is not surprising that we show that all constants of the motion used in Ref. 2 are Casimirs. The stability criterion under consideration is sharper than the classical one[3] that is based on the positivity of the second variation of the potential energy (δW). An extension of this result to classical fluids will be given.

Work supported by U.S. Department of Energy Grant No. DE-FG02-86ER53223.

[1] P.J. Morrison and D. Pfirsch, Phys. Fluids B **2**, 1105 (1990).
[2] E. Hameiri, Phys. Plasmas **5**, 3270 (1998).
[3] E. Frieman and M. Rotenberg, Rev. Mod. Phys. **32**, 898 (1960).

1E08

Equilibrium Reconstruction in Stellarators: V3FIT.

James D. Hanson[1], Steven P. Hirshman[2], Stephen F. Knowlton[1], Lang Lao[3], and Edward A. Lazarus[2].

[1] *Physics Department, Auburn University, Auburn, AL 36849*
[2] *Oak Ridge National Laboratory, Oak Ridge, TN 37831*
[3] *General Atomics, San Diego, CA 92186*

Abstract

The V3FIT code, currently under development, will do fast, accurate equilibrium reconstruction for stellarators. In a typical large tokamak experiment, data from diagnostics is used to accurately reconstruct the MHD equilibrium at many time slices during a discharge. This gives experimentalists information about the plasma position, flux surface shape and radial profiles as the discharge evolves. This information can be used to control the plasma position and to analyze the stability and transport properties. The EFIT [1] code is the most widely used tool for axisymmetric equilibrium reconstruction. Our goal is for V3FIT to be as helpful for stellarators as EFIT is for tokamaks.

The equilibrium reconstruction (ER) will use data from magnetic diagnostics to constrain an MHD equilibrium so that the magnetic fields computed from the equilibrium are as consistent as possible with the measured diagnostic signals. One portion of the ER problem is to compute the expected signal in a magnetic diagnostic coil, given an assumed MHD equilibrium. We have written two codes, V3RFUN and V3POST, that do these calculations. V3RFUN takes information about a magnetic field coil set and a magnetic diagnostic set, and calculates a) the mutual inductances between the diagnostic and the field coils, and b) the plasma response function of each magnetic diagnostic. The V3POST code takes as input a VMEC [2] equilibrium, and plasma response functions, and computes expected signals in the magnetic diagnostic coils. The V3RFUN and V3POST codes are currently being used to design magnetic diagnostic coil sets for the CTH and NCSX experiments. Preliminary results will be shown.

To be most useful for experiments, the ER codes will need to a) run rapidly, b) be flexible, and c) be extensible. Considerable effort has gone into designing the codes to achieve these ends. For the Equilibrium Reconstruction to be rapid, the magnetic signal calculation will need to be tightly coupled to the iterative equilibrium solution. Currently, efforts are concentrated on the VMEC equilibrium solver, which is the most widely used 3D equilibrium code. Our thoughts on iteration schemes for V3FIT will be shown.

Work supported by the U. S. Department of Energy.

[1] L.L. Lao, et al, Nucl. Fusion **25**, 1611 (1985).
[2] S. P. Hirshman and D. K. Lee, Comput. Phys. Commun. **39**, 161 (1986).

1E09

Equilibrium of a rotating mirror plasma – I

R. D. Hazeltine, S. M. Mahajan, H. Quevedo, and P. M. Valanju

Institute for Fusion Studies, The University of Texas at Austin

Isothermal, axisymmetric equilibrium in a rotating mirror experiment is derived and the results are compared with data. In contrast to earlier papers, our formalism determines (1) the two-dimensional structure of the electrostatic potential, which is nonlinearly coupled to the rotation; and (2) the nature and quality of the resulting confinement. We find that the plasma is confined into a toroidal ring shape by centrifugal and electrostatic forces, and has a "spatial loss cone" along the axis. We discuss the limits of validity and possible applications of our results to centrifugally confined fusion plasmas and ion mass filters.

1E10

Seed island formation of neoclassical tearing modes via transient transport events*

C. C. Hegna
Dept. of Engineering Physics, University of Wisconsin
Madison, WI 53706-1687

Abstract

One of the crucial problems for predicting the onset of neoclassical tearing modes (NTMs) in high temperature tokamaks is to understand the nature of the seeding process, whereby a magnetic perturbation of sufficient amplitude is required in order to exceed the threshold width for NTM excitation. We present a simple model for this process based on the neoclassical polarization current threshold mechanism and a heuristic model for the island frequency evolution.

Neoclassical polarization currents can be stabilizing to island growth [1]. For islands widths smaller than a critical width of order the ion banana width, the stabilizing polarization mechanism dominates the destabilizing bootstrap current drive and island growth is inhibited. A crucial feature of the neoclassical polarization threshold model is that stability properties depend upon the island rotation frequency, with stability occuring in the range $\omega_i^* < \omega < 0^*$ in the $\mathbf{E}\times\mathbf{B}$ rest frame. The island frequency depends upon transport properties in the island region. As such, we introduce the relation $D(\omega-\omega_e^*)+\gamma_I w^2(\omega-\omega_i^*) = 0$ to track the island frequency, where the first term represents transport processes in the plasma that tend to cause the island to rotate in the electron drift direction [2] while the last term represents transport processes on ions that arise through island induced toroidal viscosity where γ_I depends upon the ion collisionality [3]. A simultaneous solution of the island evolution and frequency equations uncovers a critical parameter of order $D/(\gamma_I \rho_{\theta,i}^2)$. For sufficiently small values of this parameter, the polarization effect is stabilizing and can provide a threshold. As the value of this parameter rises, the frequency tends toward the destabilizing electron drift direction and at a sufficiently high value, the polarization threshold mechanism is eliminated. As such, seed islands may form when the background plasma transport rises with a transient MHD event such as a sawtooth crash or an ELM.

References

[1] H. R. Wilson, et al, Phys. Plasmas **3**, 248 (1996).
[2] A. Smolyakov, Plasma Phys. Controlled Fusion **35**, 657 (1993); J. W. Connor et al Phys. Plasmas **8**, 2835 (2001).
[3] K. C. Shaing, et al, Proceedings of the 19th IAEA Fusion Energy Conference, 2002.

*Research supported by U. S. DoE under grant no. DE-FG02-86ER53218.

1E11

Neoclassical Tearing Mode Simulations with Integral Heat Flow Closures *

E. D. Held

Physics Department, Utah State University
Logan, UT 84322-4415

Abstract

The rapid thermal motion of electrons and ions along magnetic field lines represents a dominant process in astrophysical and terrestrial plasmas. In this work, we describe the incorporation of this dominant physics in toroidal plasma fluid simulations of neoclassical tearing modes (NTMs). Pressure flattening across magnetic islands is responsible for the bootstrap current perturbation that drives NTMs. This pressure evolution is dominated by the large anisotropy in the parallel and perpendicular heat transport. The higher-order-element formulation of the NIMROD code [1] is able to account for anisotropies greater than $\kappa_\parallel/\kappa_\perp \sim 10^{10}$ in the form of a diffusive operator which relates the parallel heat flows to local thermodynamic gradients. Using this formulation, we present numerical convergence studies of a NIMROD NTM simulation of DIII-D discharge 86144. In this discharge a 3/2 NTM is presumably excited above the threshold island width via coupling to a 1/1 mode. Once above the threshold, the NTM in the experiment grows and saturates at an island width of about 1/10 the minor radius. Comparative simulations are also performed using a quantitative, integral form for the parallel heat flow closure that incorporates the kinetic effects of free-streaming, pitch-angle scattering and particle trapping [2]. This closure has recently been implemented in NIMROD's ion and electron temperature equations. In plasmas where different components of the magnetic spectrum overlap radially, temperature variations along magnetic field lines possess multiple scale lengths. In such instances, the integral closure predicts comparable heat flows from all scale lengths for nearly collisionless plasmas of interest. In contrast, because the diffusive form for the closure relies on the local parallel gradient, it underestimates temperature flattening over longer scale lengths [2]. This result is borne out in converged simulations using the diffusive closure where pressure flattening is only able to drive the 3/2 island to about a $2cm$ saturated width. Results showing the enhanced NTM drive provided by the integral form for the parallel heat flow closure are presented.

References

[1] C. R. Sovinec, et al, UW CPTC Report 02-5 (2003).
[2] E. D. Held, J. D. Callen, C. C. Hegna and C. R. Sovinec, Phys. Plasmas 8, 1171 (2001).

*Research supported by the U.S DOE under grants no. DE-FG03-01ER54618.

1E12

Multi-Scale Temperature Gradient Driven Turbulence in Tokamaks

W. Horton
Institute for Fusion Studies
The University of Texas at Austin
Austin, Texas 78712

Transport in tokamaks with high-power auxiliary is predicted to occur through a mixture of mesoscale ion temperature gradient (ITG) turbulence and microscale electron temperature gradient turbulence (ETG). Renormalized turbulence theory gives an analytic method of studying correlation lengths and spectra in the bi-modal system within the limits of near-gaussian statistics in a stationary state of turbulence. To include coherent structures and intermittency, direct numerical simulations (DNS) are required on large grids. For this purpose, synthesized toroidal ITG-ETG models suitable for $(1024)^2$ pseudo-spectral simulations are examined with four dynamical pdes and several constraint equations. The system parameters are $R/L_{T_i}, R/L_{T_e}, T_e/T_i, m_i/m_e$ and ω_{pe}/ω_{ce}. For $(m_i/m_e)^{1/2} = 40$ the box size $(20\pi\rho_i)^2$ resolves scales down to λ_{De} and ρ_e. The inverse cascades, the formation of streamers and vortices and the cross-scale coupling of γ_i, W_i, q_i and γ_e, W_e, q_e are then objects of comparison between the DNS and turbulence theory.

This work is supported by the U.S. Dept. of Energy Contract No. DE-FG03-96ER-54346.

1E13

Hybrid Simulations of Alfvenic Instabilities Excited by Bounce-Precession Resonances in Tokamaks

S. Hu and Liu Chen
Department of Physics and Astronomy, University of California, Irvine

Resonant excitations of Alfvenic instabilities excited by energetic ions in toroidal plasmas have been investigated using a linear gyrokinetic-magnetohydrodynamic hybrid code which solves the coupled vorticity and energetic-ion gyrokinetic equations by the numerical scheme developed in Zheng et al. [2000]. Motivated by recent NSTX observations, instability excitation associated with the bounce resonance is delineated by purposely suppressing the usual precession resonance through reversing its direction with respect to the diamagnetic drift. In the low-β tokamak plasmas, this drift reversal is achieved by making the turning points of trapped ions fall in the strong-B (good curvature) side so that the usual energetic-particle mode (EPM) due to the precession resonance becomes a new type due to the bounce-precession resonance. In the high-β case, such as in NSTX, the drift reversal can also be achieved due to pressure gradients. Investigations on the new EPM in the high-β regime as well as details of the simulation scheme and results will be presented.

Work supported by DOE and NSF Grants.

1E14

MHD Stability of Centrifugally Confined Plasmas

Yi-Min Huang and A. B. Hassam

University of Maryland, College Park, Maryland 20742

An idea currently under investigation is to use the centrifugal force of a rotating plasma to augment magnetic confinement for thermonuclear fusion plasmas.[1] One of the key issues for the success of this approach is the MHD stability. We performed a 3D MHD simulation for a low β, low $M_A(\equiv u_\phi/V_A)$ centrifuge, which showed velocity shear stabilization of flute interchanges at $M_S \sim 4$ ($M_S \equiv u_\phi/C_S$). [2] For a high β, high M_A centrifuge, the magnetorotational instability (MRI) could be a concern. To resolve this issue, we studied the stability of a simplified, straight-field Dean flow model via eigenmode analysis.[3] In this model system, two distinct but coupled destabilization mechanisms are present: flow shear (magnetorotational instability) and magnetic buoyancy (Parker instability). The system is shown to be unstable for long axial wavelength modes when $M_S M_A \gtrsim \pi R/a$ (R/a is the aspect ratio). However, the fact that the system is stable in the incompressible limit (therefore the magnetic buoyancy is precluded) suggests that the instability won't lead to the typical turbulent behavior of the MRI; instead, it should behave as the Parker instability. This was confirmed by 2D simulations, in which a uniform plasma was seen to break and saturate into clumps. The clumping behavior of the instability indicates a spontaneous centrifugal confinement out of a straight-field configuration, rather than poses a limit to a centrifugal confinement device. Hence, one could expect a high β, high M_A centrfuge free of MHD instabilites to be possible.

[1] R. F. Ellis, A. B. Hassam, S. Messer, and B. R. Osborn, Phys. Plasmas **8**, 2057 (2001).

[2] Y. M. Huang and A. B. Hassam, Phys. Rev. Lett. **87**, 235002 (2001).

[3] Y. M. Huang and A. B. Hassam, Phys. Plasmas **10**, 204 (2003).

1E15

ELIMINATING ISLANDS IN HIGH-PRESSURE FREE-BOUNDARY STELLARATOR MAGNETOHYDRODYNAMIC EQUILIBRIUM SOLUTIONS.

S.R.Hudson[1], D.A.Monticello[1], A.H.Reiman[1], A.H.Boozer[2], D.J.Strickler[3], S.P.Hirshman[3], and M.C.Zarnstorff[1]
1) Princeton Plasma Physics Laboratory, P.O. Box 451, Princeton NJ 08543, USA.
2) Columbia University, New York, New York 10027, USA. and
3) Oak Ridge National Laboratory, P.O. Box 2009, Oak Ridge TN 37831, USA.
(Dated: February 26, 2003)

For the (non-axisymmetric) stellarator class of plasma confinement devices to be feasible candidates for fusion power stations it is essential that, to a good approximation, the magnetic field lines lie on nested flux surfaces; however, the inherent lack of a continuous symmetry implies that magnetic islands responsible for breaking the smooth topology of the flux surfaces are guaranteed to exist.

Thus, the suppression of magnetic islands is a critical issue for stellarator design, particularly for small aspect ratio devices. Pfirsch-Schlüter currents, diamagnetic currents and resonant coil fields contribute to the formation of magnetic islands, and the challenge is to design the plasma and coils such that these effects cancel.

A new procedure, termed island 'healing', for suppressing magnetic islands in free-boundary high-pressure full-current stellarator magnetohydrodynamic equilibria is developed. The algorithm is based on the Princeton Iterative Equilibrium Solver [Comp. Phys. Comm., 43:157, 1986] which iterates the equilibrium equations to obtain the plasma equilibrium. At each iteration, changes to a Fourier representation of the coil geometry are made to cancel resonant fields produced by the plasma.

The coils are constrained to satisfy certain measures of engineering acceptability. Also, the plasma is constrained to ensure kink and ballooning stability. As the iterations continue, the coil geometry and the plasma simultaneously converge to a 'build-able' coil set that supports a stable equilibrium in which the island content is negligible.

The method played an important role in the successful plasma and coil design for the National Compact Stellarator eXperiment, a three field-period compact quasi-axisymmetric stellarator of major radius $1.4m$ with $\beta \approx 4\%$. Comparisons of the equilibrium magnetic field structure before and after 'healing' will be presented.

1E16

Analysis of Nonaxisymmetric Modes in Accretion Disks at Marginal Stability with Nonlinear Diffusion and Dissipation*

T. Islam and B. Coppi

Massachusetts Institute of Technology, Cambridge, MA 02139

A class of unstable modes with azimuthal wavenumber, in accretion disks with an equilibrium magnetic field $\mathbf{B} \cong B_\phi(R,z)\mathbf{e}_\phi + B_z(R,z)\mathbf{e}_z$, that can transport angular momentum have the following properties: they are radially localized over distances much smaller than R; they require the effects of finite pressure for their excitation; they possess two sets of singularities in the MHD approximation; and they require a localized diffusion or dissipation operator to resolve the inner singularity [1, 2]. The spectrum of modes about marginal stability was analyzed numerically for linear operators and reported in Ref. 3, where the existence of separate classes of solutions with different numbers of nodes in the radial direction was demonstrated.

Nonlinear diffusion and dissipation operators have been proposed on the basis of the fact that within the inner singularity, pressures and densities tend to become infinite and therefore nonlinear effects become important [4]. The MHD equation describing the radially ballooning nonaxisymmetric modes [1, 2, 5] is modified into one that smoothly connects the solution within the transition regions to the MHD solution outside the transition regions [3]. The physical basis of nonlinear operators described in a previous report [4] is discussed. For the nonlinear operators, the marginal stability condition is analyzed by taking the ratio δ of the width of the transition layer to the radial extent of the mode to be much less than 1, and the growth rate to be of order δ relative to the orbital frequency. A spectrum of modes, with different numbers of radial nodes, is mapped for each of the nonlinear operators.

*Sponsored in part by the U. S. Department of Energy

[1] B. Coppi and P.S. Coppi, *Ann. Phys.*, **291**, 134 (2001).
[2] B. Coppi and P.S. Coppi, *Phys. Rev. Lett.*, **87**, 051101-1 (2001).
[3] R. Bhatt, B. Coppi, I. Dimov, and J. Gagnon, *Bull. Am. Phys. Soc.*, **45**, 38 (2000).
[4] B. Coppi and P.S. Coppi, MIT (R.L.E.) Report PTP-01/04 (2001).
[5] B. Coppi and P.S. Coppi, *Phys. Lett. A*, **239**, 261 (1998); B. Coppi and P.S. Coppi, MIT (R.L.E.) Report PTP-97/08 (1998).

1E17

Electron Heat Confinement in Reversed Field Pinches *

J. W. James, E. D. Held
Physics Department, Utah State University
Logan, UT 84322-4415

Abstract

We present predictions for electron heat confinement times in Reversed Field Pinches (RFPs) using two different closures for the parallel electron heat flow in the plasma electron energy equation. The first model relates $q_{\parallel}$ to the local parallel gradient in electron temperature multiplied by a large ($> 10^5$) effective parallel conductivity to capture qualitatively the large anisotropy between electron heat flow parallel vs. perpendicular to the magnetic field in moderately collisional plasmas. The second model uses an integral closure[1] that gives electron heat flow along the magnetic field for arbitrary collisionallity. Unlike the diffusive closure which only uses the local temperature gradient to calculate heat flow, the integral closure involves temperature perturbations with multiple scale lengths along the magnetic field. We show that since the diffusive closure depends on a single scale length, it underestimates the parallel electron heat flow in plasmas with multiple scale lengths such as those present in the chaotic magnetic field structures of some RFP discharges.

We use the high-order element version of the plasma fluid code NIMROD[2] to calculate effective electron heat diffusivities utilizing the two closure schemes. One calculation is done in a magnetic field characterized by large amounts of field line chaos. We evolve the flow and magnetic field to a steady state, and then keeping the flow and magnetic field fixed, evolve the electron energy equation with a resistive heating term. Using the steady-state electron temperature profile (which is appropriate since the resistive time is long compared to the parallel transport timescale), we then calculate effective electron heat diffusivities and compare with analytical results from Rechester and Rosenbluth[3]. The second calculation is done in a magnetic field that resembles those seen in RFPs when edge current drive is used to mitigate the effects of micro-tearing instabilities leading to improved electron heat confinement. We effect this by simply turning down the amplitude of the modes causing our chaotic field. The heat diffusivities we calculate using the two closure schemes in this magnetic field are then compared to results of O'Connell et al..[4] We show that the integral closure more accurately predicts electron heat flow in plasmas with multiple gradient scale lengths. We also comment on numerical stability, feasibility and scalability properties of the implementation of the integral closure in the NIMROD code.

References

[1] E. D. Held, J. D. Callen, C. C. Hegna and C. R. Sovinec, Phys. Plasmas 8, 1171 (2001).
[2] C. R. Sovinec, et al., UW CPTC Report 02-5 (2003)
[3] A. B. Rechester and M. N. Rosenbluth, Phys. Rev. Lett. 40, 38 (1978).
[4] R. O'Connell et. al., APS DPP BI1 6, 2002

*Research supported by the U.S DOE under grant no. DE-FG03-01ER54618.

1E18

Transition from Rutherford to Sweet-Parker Reconnection

B. D. Jemella, M. A. Shay and J. F. Drake
University of Maryland
College Park, MD 20742
B. N. Rogers
Dartmouth College
Hanover, NH

Magnetic reconnection is explored in a 2-D MHD model to understand the transition between the Rutherford and Sweet-Parker description. The calculations are carried out in a double current layer with a large guide field where the value of the tearing mode stability parameter Δ' can be calculated and systematically varied. Current sheets form in the vicinity of the x-line for all but the smallest values of Δ' and increase in length with this parameter. It is suggested that the formation of these sheets is a consequence of magnetic flux conservation as discussed by Waelbroeck for the case of the $m = 1$ mode and, consistent with this idea, self-similarity of the structure of the current layer is obtained for strongly unstable cases. Above modest values of Δ' the plasma outflow from the x-line is limited by the upstream Alfvén speed as in the Sweet-Parker theory and the reconnection rate exhibits the Sweet-Parker scaling with resistivity. For modest island widths a modified Sweet-Parker theory is developed in which island growth remains exponential and the length of the current layer scales linearly with Δ'. The results suggest that since the values of Δ' in cylindrical and toroidal plasmas can be large, care should be exercised in applying Rutherford theory to fusion plasma systems. The impact of these results on the growth of neoclassical tearing modes should be explored.

1E19

Closures of the Vlasov-Poisson System

Christopher S. Jones*, Philip J. Morrison
Institute for Fusion Studies, Dept. of Physics, UT Austin

Closure refers to the process of generating a fluid description of a system, which evolves functions of space and time such as density, fluid velocity and pressure, from kinetic theory, which is a probabilistic description of the classical dynamical evolution of positions and momenta. In the case of the Vlasov-Poisson system, a kinetic theoretical description of a one-dimensional electrostatic plasma, there exist closures for which the fluid equations locally exactly describe the full kinetic description. These exact closures, called water bag models or contour dynamics, have an algebraic structure that presents itself in the equations of motion of the moments of the distribution function. We discuss this structure and what happens to it as inexactness is introduced.

*This work is supported by the U.S. Department of Energy under Contract No. DE-FG03-96ER-54346

1E20

The triple helix in two-dimensional linear wave conversion

Allan N Kaufman[a], Eugene R Tracy[b]

[a]LBNL & UC Berkeley
Berkeley, CA 94720

[b]College of William & Mary,
Williamsburg, VA 23187

Resonant linear wave conversion, in a weakly nonuniform plasma, occurs in a region where the wave-vectors of two wave-types locally match. The evolution of their complex amplitudes is governed by a 2x2 Hermitian dispersion matrix [1], whose determinant is the Hamiltonian for ray tracing. We show that, if the coupling parameter is non-trivially complex, and if the spatial dimension is two or greater, then typically a ray undergoing conversion will not be confined to a plane in phase space, but will have a helical orbit. All three rays (incident, converted, transmitted) will thus be helices.

[1] E R Tracy, A N Kaufman, & A Jaun, Physics Letters A279, 309 (2001)

Work supported by USDOE/OFES. Presented at the Sherwood Meeting, Corpus Christi, April 28-30, 2003.

1E21

Helium-Catalyzed D-D Fusion in a Levitated Dipole

J. Kesner, L. Bromberg
Massachusetts Institute of Technology

D.T. Garnier, A. Hansen, M. Mauel
Columbia University

Fusion research has focused on the goal of a fusion power source that utilizes tritium because the D-T reaction cross section is relatively large. Fusion reactors based on the D-D reaction, however, would be superior to D-T based reactors in so far as they minimize the power produced in neutrons and do not requires the breeding of tritium. The D-D cycle is difficult in a traditional fusion confinement device such as a tokamak because good energy confinement is accompanied by good particle confinement which would lead to a build up of ash making ignition difficult[1]. Therefore D-D fusion requires a magnetic bottle that exhibits excellent energy confinement but poor particle confinement.

We find that a levitated dipole may be meet the necessary requirements for practical D-D fusion power. We have explored a fuel cycle which we call ``helium catalyzed D-D" in which the tritium produced from one branch of the D-D reaction is removed after it has deposited its energy into the background plasma (< 8 % of tritons fuse during slowing down). A dipole is expected to exhibit excellent energy confinement when the pressure gradient does not exceed a critical value. When such a closed field line system ignites it is expected that the pressure gradient will tend to exceed its critical value giving rise to convective flows that serve to maintain the critical gradient and also to cause a rapid circulation of particles between the plasma core and edge[2].

We present detailed calculations of reactor relevant dipole equilibria (β_{max} ~3) and Monte Carlo neutron transport calculations that indicate that the neutron heat deposited into the superconductor of the floating coil (which is internal to the plasma) can be extracted by an internal refrigerator. The heat is then radiated via black-body radiation to the cooled vacuum chamber walls. Additionally a levitated dipole device would be intrinsically steady state and extract power as surface heating permitting a thin walled vacuum vessel and eliminating the need for a massive neutron shield. In addition we will discuss a small D-T based dipole ignition experiment in which an inertially cooled coil would float for ~10 minutes.

[1] W.M. Nevins, Journal of Fusion Energy 17 (1998) 25.
[2] V.P. Pastukhov and N.V. Chudin, Plasma Physics Reports 27, (2001) 907.

1E22

Ballooning Modes in Thin Accretion Disks*

E.A. Keyes, B. Coppi

Massachachusetts Institute of Technology
Cambridge, MA 02139

Abstract

In astrophysical accretion disks, the observed rate of angular momentum transport is often explained by appealing to turbulence excited by plasma collective modes such as the Magneto-Rotational Instability,[1,2] originally derived as "long-cylinder" modes in a differentially rotating MHD fluid. When confined to a geometrically thin disk, however, these axisymmetric modes instead become of the ballooning type[3] and take on a much more limited character with a discrete spectrum and reduced growth rates, as shown by Coppi & Coppi.[4] Their excitation requires that the magnetic energy be considerably lower than the thermal energy, and while they are well-localized in the vertical direction, they acquire a characteristic oscillatory profile in the radial direction, leaving open the problem of identifying a physical factor which can make them radially localized.

The normal mode equation describing the modes is derived, and its solutions are shown to be of two types: a discrete spectrum of modes which are vertically well-localized compared to the disk height, and a continuous spectrum of quasi-localized modes which decay more slowly at the boundaries of the disk but which may leave open the possibility of constructing wave packets for radial localization. However, the power-law profiles of the quasi-localized modes are too gradual to be physically realistic except possibly in a narrow range of mode wavelengths for cases where the magnetic energy is extremely small.

We are currently verifying these results through numerical simulations of thin Keplerian MHD disks, a case that has not often been treated in other simulations in the field, which typically use vertically periodic or "fat torus" geometries.

* Sponsored in part by the U.S. Department of Energy.

[1] Velikhov, E.P. 1959, *Soviet Phys*, JETP, **36**, 995
[2] Balbus, S.A., and Hawley, J.F. 1991, *Ap J*, **376**, 2
[3] Coppi, B. 1977, *Phys Rev Let*, **39**, 939
[4] Coppi, B., and Coppi, P.S. 2001, *Phys Rev Let*, **87**, 5, 051101-1

1E23

Hybrid Kinetic-MHD Simulations in General Geometry

Charlson C. Kim and Scott E. Parker
Center for Integrated Plasma Studies
University of Colorado, Boulder
and
The NIMROD Team

Abstract

The dynamics of fusion plasmas lead to instabilities that can spontaneously erupt and degrade confinement and sometimes lead to catastrophic disruptions of the entire plasma itself. These instabilities occur in a broad range of spatial and temporal scales, spanning many orders of magnitude, often resulting from nonlinear interactions. Computational simulations are crucial to understanding these phenomena.

NIMROD(NonIdeal MHD with Rotation - Open Discussion) is a massively parallel three dimensional magnetohydrodynamic simulation utilizing finite elements (**FE**) to represent the poloidal plane and a fourier decomposition in the toroidal direction. The use of finite elements allows flexibility in the representation of the simulation domain. The ability to model experimental shots with NIMROD provides a platform to test new ideas of plasma behavior. To expand the physics capabilities of NIMROD, kinetic effects have been added to NIMROD by the addition of delta-f PIC(Particle in Cell) module. The addition of kinetic particle effects captures essential wave-particle interactions important in the saturation of various MHD instabilities such as the internal kink mode, sawtooth and fishbone instabilities, and toroidal Alfven eigenmodes. Particle simulation capabilities in NIMROD can also be extended to simulate various phenomena such as neutral beam injection, ion cyclotron resonance heating, and anomalous loss mechanisms. In addition, this hybrid kinetic-MHD technique lays the foundations for a kinetic closure to the MHD equations.

This poster will briefly introduce NIMROD and delta-f PIC in general, then detail the development of PIC in finite elements and their implementation and present preliminary results.

1E24

Edge transport in tokamaks with noncircular flux surfaces

R.G. Kleva, P.N. Guzdar, W. Dorland, and J.F. Drake

University of Maryland, College Park, MD 20742

Three dimensional simulations[1] of the Braginskii equations demonstrate that transport in the edge of tokamaks is controlled by two parameters: (1) the MHD ballooning parameter $\alpha_{MHD}=\beta q^2R/L_n$, where q is the safety factor, R is the major radius, L_n is the density scale length, and β is the ratio of the plasma pressure to the magnetic field pressure, and (2) the diamagnetic parameter α_d which is proportional to the diamagnetic drift frequency. A curve in the two-dimensional parameter space α_{MHD} vs. α_d delineates regions where typical L-mode levels of transport arise from regions where the plasma exhibits improved H-mode confinement. An analytic expression for this critical curve has been obtained from a theory[2] based on zonal flow generation in a finite β plasma. The theory yields a threshold curve for zonal flow generation of the form $\alpha_{MHD}\,\alpha_d^2 \sim 0.1$. This analytic criterion can be rewritten in terms of a critical threshold parameter proportional to $T_e/L_n^{1/2}$ for the generation of zonal flow, where T_e is the electron temperature. This threshold parameter shows excellent agreement with edge measurements on discharges undergoing L-H transitions in the DIII-D tokamak[3]. The edge simulations in Ref. 1 were carried out for equilibria with circular flux surfaces in the large aspect ratio limit. We now investigate the effect of noncircular equilibria in a finite aspect ratio torus on edge transport in tokamaks. The noncircular equilibria are characterized by an elongation κ in the vertical direction in the poloidal cross-section along with a triangularity δ. Edge confinement is improved as the triangularity and elongation of the plasma is increased, in both the H-mode and L-mode regimes.

[1]B.N. Rogers, J.F. Drake, and A. Zeiler, Phys. Rev. Lett. **81**, 4396 (1998).
[2]P.N. Guzdar, R.G. Kleva, A. Das, and P.K. Kaw, Phys. Rev. Lett **87**, 015001-1 (2001).
[3]P.N. Guzdar, R.G. Kleva, R.J. Groebner, and P. Gohil, Phys. Rev. Lett. **89**, 265004-1 (2002).

1E25

Gyrokinetic Particle-In-Cell Calculations of Ion Temperature Gradient Driven Turbulence with Parallel Nonlinearity and Strong Flow Corrections*

James C. Kniep, Jean-Noel Leboeuf and Viktor K. Decyk
Department of Physics and Astronomy
University of California at Los Angeles
Los Angeles, CA 90095-1547

Abstract

Nonlinear gyrokinetic calculations have been performed with the three-dimensional, global, toroidal, particle-in-cell, delta-f, UCAN code[1] to study the effects of parallel nonlinearity and strong (externally imposed) flow corrections on ion temperature gradient driven turbulence. These calculations are electrostatic and adiabatic electrons are used. An equilibrium ion temperature gradient only is imposed, along with a generic parabolic q-profile appropriate to a large aspect ratio tokamak. The strong flow corrections derived by T. S. Hahm[2] have been added to the usual orbit and weight equations used in the UCAN code. The parallel nonlinearity[3] has been reactivated as well in the same equations. To examine the effect of strong flow corrections, the calculations have been performed with fluctuations-generated flows or zonal flows arbitrarily set to zero but with externally imposed sheared flows obeying a variety of profiles more or less localized in radius and with various flow magnitudes. The calculations show that the strong flow corrections have a qualitative effect on the saturation level of the fluctuations and on the steady-state heat flux even at the highest flow magnitudes used. The re-activated parallel nonlinearity, with no externally imposed flow but with fluctuations-generated or zonal flows allowed to self-consistently evolve in the calculations, does however make a significant quantitative difference in the saturation level of the fluctuations and in the saturated flux. The presence of the parallel nonlinearity leads to a reduction in both, in apparent agreement with the results of Villard and colleagues[3].

[1] R. D. Sydora, V. K. Decyk, and J. M. Dawson, "Fluctuation-induced heat transport results from a large global 3D toroidal particle model", Plasma Physics and Controlled Fusion **38**, A281-94 (1996); J.-N. Leboeuf, J. M. Dawson, V. K. Decyk, M. W. Kissick, T. L. Rhodes, and R. D. Sydora, "Effect of externally imposed and self-generated flows on turbulence and magnetohydrodynamic activity in tokamak plasmas", Phys. Plasmas 7, 1795-1801 (2000).

[2] T. S. Hahm, "Nonlinear gyrokinetic equations for turbulence in core transport barriers", Phys. Plasmas 3, 4658-4664 (1996).

[3] L. Villard, S. J. Allfrey, A. Botino, M. Brunetti, G. L. Falchetto, V. Grandgirard, R. Hatzky, J. Nuhrenberg, A. G. Peeters, O. Sauter, S. Sorge, and J. Vaclavik, "Full radius linear and nonlinear gyrokinetic simulations for tokamaks and stellarators: Zonal flows, applied ExB flows, trapped electrons and finite beta", Paper **TH/1-3**, 19th IAEA Fusion Energy Conference, Lyon, France, 14 - 19 October 2002. Submitted to Nuclear Fusion.

* Work supported at UCLA by USDOE Grant No. DE-FG03-01ER54617. This work is also part of the SciDAC Plasma Microturbulence Project.

1E26

Physics-based Preconditioning and Newton-Krylov methods for Extended MHD

D.A. Knoll and L. Chacón

Theoretical Division, Los Alamos National Laboratory, Los Alamos NM 87545

Abstract

The equations of extended MHD present significant challenges for accurate and efficient time integration. The equation system contains multiple time scales, multiple waves, and nonlinear anisotropic transport coefficients. We have been developing the algorithmic approach of physics-based preconditioning and Jacobian-free Newton-Krylov methods with the goal of overcoming some of these numerical challenges. In this presentation, we will cover some of our recent progress and outline our future directions. In computational MHD, one would like to follow the dynamical time scale on which the system is evolving. This time scale is typically much slower than many of the normal mode time scales in the system. Recent work has shown that second-order-in-time, nonlinearly-converged, implicit methods can use time steps on the order of the dynamical time scale while achieving high accuracy [1].

In physics-based preconditioning we employ the classic semi-implicit method for stiff waves. Thus while the outer Jacobian-free Newton-Krylov method is working on a stiff, ill-conditioned, hyperbolic system, the preconditioning matrix comes from a parabolic problem with an improved condition number. The methodology behind, and the effectiveness of, physics-based preconditioning has been established. The first stiff-wave systems considered were the shallow water equations [2] and the reduced MHD equations [3]. While each system only supports one wave, the reduced MHD problem is more complicated as a result of anisotropic wave propagation. More recently, a physics-based preconditioner has been developed for the Hall MHD system, including the stiff whistler wave [4]. Currently we are developing a preconditioner for an equation system which describes low-β collisionless reconnection. Additionally, we will describe our strategy for developing a preconditioner for 3-D compressible MHD, and nonlinear anisotropic electron conduction. The depth and variety of equations systems which have been solved by this approach indicates that it is becoming a mature technology waiting to be utilized by a larger computational physics community.

[1] D.A. Knoll , et. al., *J. Comput. Phys.* vol. 185, pp. 583-611 (2003)

[2] V. Mousseau, et. al., *Mon. Wea. Rev.*, vol. 130, pp. 2611-2625 (2002)

[3] L. Chacón, et. al., *J. Comput. Phys.*, vol. 178, pp. 15-36 (2002)

[4] L. Chacón and D.A. Knoll, " A 2-D incompressible Hall MHD implicit nonlinear solver " (accepted to *J. Comput. Phys.*, 2003)

1E27

Novel divertor designs and their motivation

M. Kotschenreuther, L. Zheng

Institute for Fusion Studies, University of Texas, TX 78712

Abstract

Divertor designs based on novel magnetic geometries are explored. We estimate that such designs may be required for reactors if:

1) recent experimental results which imply that main chamber recycling dominates over divertor recycling are found to extrapolate to reactors

2) extreme requirements for reliability of very high heat flux components in unprecedented neutron environments cannot be met

3) fusion reactors with very large power output (e.g. for hydrogen production) are considered

Two novel geometries are considered: 1) the extraction of the separatrix flux to outside the TF coils and 2) inducing a *second* x point along the separatrix some distance outside the main plasma, but in vessel. These innovations could enable operation with reduced SOL density and radiation near the plasma, and reduced engineering heat fluxes. We estimate that these may be crucial advantages if blob transport leads to strong main chamber recycling in reactors, which could lead to unacceptable erosion and helium recycling for more conventional divertor concepts. Also, the challenges with conventional divertors increase for larger reactor power levels. Liquid wall and divertor concepts are also considered as potential solutions.

1E28

On electron heat transport in spherically symmetric geometry*

S. I. Krasheninnikov[1] and P. J. Catto[2]

[1]University of California at San Diego, La Jolla, 9500 Gilman Dr., CA 92093, USA
[2]PSFC, Massachusetts Institute of Technology, Cambridge, MA 02139, USA

Abstract

Electron heat transport plays an important role in many plasmas ranging from astrophysics to control fusion. It is well known that due to specifics of Coulomb collisions, the applicability of the classical Spitzer-Harm expression for electron heat flux is limited to very small ratios of the electron mean free path to the scale length of electron temperature variation, $\gamma < 0.01$. At larger γ nonlocal kinetic effects play a very important role in heat transfer and alter the Spitzer-Harm expression. Numerous analytical attempts to improve the Spitzer-Harm expression have focused on the study of slab geometry. Here we report the results of our investigation of nonlocal effects of electron heat transport for the spherically symmetric case. We start with a kinetic equation for the electron distribution function $f(\mathbf{v},\mathbf{r})$ neglecting electron-ion energy exchange and assuming zero averaged ion velocity. We assume spherical symmetry in $\mathbf{r}$ space and introduce local spherical coordinates in velocity space, v and μ, where $\mu = \mathbf{r}\,\square\,\mathbf{v}/rv$, so that $f(\mathbf{v},\mathbf{r}) = f(v,\mu,r)$. For the heat flux going from the origin to infinity we notice that keeping only convection term in kinetic equation implies $f(v,\mu,r) = f(v, r^2(1-\mu^2))$, which shows that $f(v,\mu,r\quad)$ can be strongly peaked at $\mu = 1$ solely due to geometry.

To analyze the electron kinetic equation for arbitrary γ we follow Ref. 1 and introduce the self-similar variable $\mathbf{w} = \mathbf{v}(m/2T(r))^{1/2}$ and use the following anzatz for electron distribution function $f(v,\mu,r) = F(w,\mu)(T(r))^{-\alpha}$. Hereafter e, m, T(r), and $n_e(r) \propto (T(r))^{3/2-\alpha}$ are the electron charge, mass, effective temperature and density, and α is an adjustable parameter. For T(r) profiles such that $T^{\alpha+1/2}(d\ln T/dr) = \text{const.}$ we find $\gamma = -T^2(d\ln T/dr)/(2\pi e^4 \Lambda n_e) = \text{const.}$, where Λ is the Coulomb logarithm. For such T(r) profiles electron kinetic equation can be written as follows

$$\gamma w\left\{\mu\left(\alpha F + (w/2)\ {}_{w}F\right) - (\alpha+1/2)(1-\mu^2)\ {}_{w}F\right\} - (\gamma_E/2)\left(\mu\ {}_{w}F + (1-\mu^2)w^{-1}\ {}_{\mu}F\right)$$
$$= (1/4)\left\{C_{ee}(\mathbf{w},F) + Z_{eff}w^{-3}\ {}_{\mu}\left((1-\mu^2)\ {}_{\mu}F\right)\right\}, \qquad (1)$$

where $C_{ee}(\mathbf{w},f) = \ {}_{w_\alpha}\ \ F(\mathbf{w})\ {}_{w'_\beta}F(\mathbf{w}') - F(\mathbf{w}')\ {}_{w_\beta}F(\mathbf{w})\ U_{\alpha\beta}d\mathbf{w}'$, $U_{\alpha\beta} = \left(u^2\delta_{\alpha\beta} - u_\alpha u_\beta\right)u^{-3}$, $\mathbf{u} = \mathbf{w} - \mathbf{w}'$, $\gamma_E = eET/(2\pi e^4\Lambda n_e) = \text{const.}$, and E(r) is the ambipolar electric field which can be found from a zero electron flux condition. Note that the conservation of Spitzer-Harm heat flux through a spherically symmetric surface gives $Q \propto r^2T^{5/2}(dT/dr) = \text{const.}$, resulting in $T(r) \propto r^{-2/7}$ and corresponding to $\alpha = -4$.

We solve Eq. (1) for different regions of w and then match these solutions at the boundaries of these regions. For large w we find that unlike the slab case[1], peaking of $f(v,\mu,r)$ at $\mu = 1$ requires taking into account not only streaming but also pitch-scattering terms. As a result at large w we find $F(w,\mu) \propto w^{2(\alpha+3)}\exp\left([(3+2\alpha)2\gamma/(1+Z_{eff})](1-\mu)w^4\right)$ and, like in slab case[1], the heat flux which would stay constant for Spitzer-Harm heat conductivity ($\alpha = -4$) is, actually diverges logarithmically, $Q \propto\ \ F(w,\mu)w^5dwd\mu \propto\ \ w^{2\alpha+7}dw \propto\ \ w^{-1}dw$.

[1]S. I. Krasheninnikov Sov. Phys. JETP **67** (1988) 2483.

* Work supported by U.S. DOE

1E29

A Darwin Fluid Model

Todd Krause and P.J. Morrison
Physics Department and Institute for Fusion Studies, University of Texas at Austin,
Austin, TX 78712

Abstract

The Darwin model of particle interaction is a second order (in v/c) approximation to the fully relativistic theory of particle interaction in which retardation effects are replaced by modified action-at-a-distance interactions. The approximation has proved most useful in computer simulations of plasmas in which fast waves (with group velocity on the order of c) are neglected due to the small time steps required. Some attention has been paid to the Darwin approximation as a self-consistent particle theory, but little has been said about its applications to continuum theories. We study the Darwin system as a self-consistent continuum theory derived from an action principle. Specifically, the action for particles interacting via fields, which are themselves required to be solutions of Maxwell's equations, is rendered as a continuum action in Lagrangian variables. This is then taken as the *a priori* action for a fluid theory which is studied in both Lagrangian and Eulerian variables.

1E30

Simulations and Stability Analysis of ELMs in JET Discharges

Arnold H. Kritz[1], Thawatchai Onjun[1], Vassili Parail[2], Glenn Bateman[1], Johnny Lönnroth[3], Guido Huysmans[4]

[1]Lehigh University Physics Department
16 Memorial Drive East, Bethlehem, PA, 18015, USA

[2]Euratom/UKAEA, Fusion Association, Culham Science Centre, Abingdon, OX14 3DB, United Kingdom

[3]Association EURATOM-Tekes, Helsinki University of Technology, Finland

[4]Association Euratom-CEA, CEA Cadarache, France

Abstract

The JETTO predictive integrated modeling code and the MISKHA MHD stability code are used to investigate the edge instabilities in JET tokamak plasmas. For a JET power scan, it is concluded that the crash of the edge localized modes (ELMs) can be triggered either by pressure-driven (ballooning) modes or by current-driven (peeling) modes. The availability of both modes is required for the simulation and experimental stored energy to agree. If the criterion for triggering ELMs is satisfied, transport in the pedestal region is increased significantly in the simulation. ELM durations and frequencies obtained in the simulation are compared with experimental values. It appears that in simulations where ELMs are triggered by the peeling mode instability, the duration of the ELM is longer than that found experimentally. The simulated duration of the ELM is not decreased by increasing transport in the ELM region since this alone does not result in a rapid redistribution of edge plasma current. For the high power discharge, it is found that the first few ELM crashes after the transition from L-mode to H-mode and a short ELM-free period are usually triggered by ballooning modes, while subsequent ELM crashes are usually triggered by peeling modes. The JETTO simulations provide edge equilibrium information, such as pressure gradient and plasma geometry, which are then used as input for the MISKA code. This code yields an s-α diagram which provides information regarding the stability of the edge plasma. It is found that the discharges in the power scan considered have access to second stability and that the pressure gradient is limited either by the finite n ballooning modes or by the peeling mode.

1E31

NIMROD Simulations of a High Beta Disruption in the DIII-D Tokamak

S.E. Kruger, D.D. Schnack
Science Applications International Corporation
San Diego, CA 92121

Abstract

Linear ideal magnetohydrodynamic codes have long been used to predict the operating limits of tokamak experiments. As accurate equilibrium reconstructions have become available, the ability to compare the spatial structure of the linear eigenfunctions with diagnostic measurements for ideal modes has been possible [1]. An analytic theory has been put forth [2] to explain the time dependence of an ideal mode as it was heated past the marginal stability point. Combined with the linear results from GATO, this theory explained many of the features observed in the disruption of DIII-D shot #87009. In the present work, initial-value, nonlinear simulations of DIII-D shot #87009 are performed with the NIMROD code. The simulations include the region beyond the separatrix to provide an opportunity to do unprecedented theoretical-experimental comparisons. Starting with an equilibrium that is submarginal to the ideal mode, a heating source is applied to heat it above the marginal threshold. As predicted by the analytic theory, the mode grows faster than exponential on a time scale that is hybrid between the heating time scale and an ideal MHD time scale. As the plasma becomes nonlinear, forced reconnection causes stochasticity to occur, primarily near the X-points where the fields are most susceptible. Because of high anisotropic heat conduction, the heat load to the walls occurs primarily in the divertor region.

[1] A.D. Turnbull et.al. In the Proceeding of the 18th Fusion Energy Conference, IAEA, Sorrento, Italy (2000)

[2] J.D. Callen et.al., Phys. Plas. 6 ,2963 (1999)

1E32

Magnetic Reconnection: effects of the 3rd dimension

G. Lapenta [1,2], P. Ricci [1,3], and J.U. Brackbill [2]

[1] Istituto Nazionale per la Fisica della Materia, Dipartimento di Fisica,
Corso Duca degli Abruzzi 24, 10129 Torino, Italy
[2] Theoretical Division, Los Alamos National Laboratory, 87545 Los Alamos NM, USA
[3] Dipartimento di Energetica, Politecnico di Torino,
Corso Duca degli Abruzzi 24, 10129 Torino, Italy

Abstract

Understanding 3D reconnection is a challenge. For two reasons.
First, the simulations are very expensive. To obtain reliable first principle results one has to rely on kinetic PIC simulations that are prohibitively expensive in 3D. The widely different time and length scales of electrons and ions prevents explicit formulations from being able to study systems of sufficient size for sufficiently long times at realistic mass ratios. We have a solution to this problem: implicit PIC [1]. Implicit PIC allows us to remove the following three constraints: 1) the need to resolve the electron plasma frequency; 2) the need to follow the speed of light propagation; 3) the need to resolve the electron Debye length. For reconnection studies, we are not concerned by any of these three scales and yet explicit PIC has to resolve them to prevent instability and loss of energy conservation. But implicit PIC can step over the scales above and worry only about the true scales of interest: the time step is selected to resolve the electron cyclotron frequency (allowing time steps 40 times larger than in explicit codes) and the electron skin depth (allowing grid spacing 10 times larger than in explicit codes). Previous studies have compared explicit and implicit PIC [2]. The accuracy of implicit codes is limited for high frequency and short wavelength processes but is as accurate as that of explicit codes for the larger scales processes involved in reconnection. Second, the wealth of physics presence in 3D simulations is breathtaking. Yet recently some new insight has occurred, like the coupling of the lower hybrid drift instability with the presence of kinking of current sheet (probably a Kelvin-Helmholtz instability, KHI) [3], the existence of KHI driven reconnection [4], the existence of reconnection waves [5] and electron holes [6] propagating in the current direction.
In the present work, we report the conclusions of our simulations in this field focusing particularly on two issues: 1) the difference between 2D and 3D reconnection induced by waves and instabilities propagating in the current aligned direction; 2) the effect of the guide field on such differences, showing that some 3D effects are suppressed by the guide field.

[1] H.X. Vu, J.U. Brackbill, Comp. Phys. Commun. 69, 253 (1992).
[2] G. Lapenta, J.U. Brackbill, and W.S. Daughton, Phys. Plasmas, in press.
[3] G. Lapenta, J.U. Brackbill, Phys. Plasmas 9, 1544 (2002).
[4] J.U. Brackbill, D.A.Knoll, Phys. Rev. Lett. 86, 2329 (2001).
[5] J.D. Huba, L.I. Rudakov, Phys. Plasmas 9, 4435 (2002).
[6] J.F. Drake et al., Science 299, 873 (2001).

1E33

Tests of General Geometry Capabilities in the Summit Gyrokinetic Framework*

J. N. Leboeuf[1], V. K. Decyk[1], A. Dimits[2], and D. Shumaker[2]
[1] University of California at Los Angeles, Los Angeles, CA 90095-1547
[2] Lawrence Livermore National Laboratory, Livermore, CA 94550-9234

Abstract

Rapid progress[1] is being made in including electrons and electromagnetic effects in the Summit gyrokinetic framework[2]. In parallel, general geometry, realistic equilibria capabilities are also in the process of being incorporated in the Summit gyrokinetic framework through the pg3eq_nc module, itself an extension of the circular geometry pg3eq module[3]. These modules use quasi-ballooning coordinates to solve the three-dimensional, toroidal, delta-f, gyrokinetic equations for ions in order to model ion temperature gradient driven turbulence. Realistic geometry is introduced through an interface to data from the EFIT equilibrium code[4]. Massively parallel implementation has been effected using MPI. Linear and nonlinear tests are currently under way between the general geometry and circular geometry modules. These tests are being performed with a circular equilibrium which can be accommodated in both modules. Results from these tests will be reported.

[1] Yang Chen and Scott E. Parker, "Simulations of Electromagnetic Microtubulence with Kinetic Electrons", This meeting.
[2] http://www.nersc.gov/scidac/summit/
[3] A. M. Dimits, T. J. Williams, J. A. Byers, and B. I. Cohen, "Scalings of Ion-Temperature-Gradient-Driven Anomalous Transport in Tokamaks", Phys. Rev. Letts. 77, 71-74 (1996).
[4] http://fusion.gat.com/efit/

* This work is part of the US Department of Energy SciDAC Plasma Microturbulence Project and is being carried out with Summit gyrokinetic collaborators Yang Chen, Bruce Cohen, Bill Nevins and Scott Parker.

1E34

Shear and Compressional Alfven Waves in Gyrokinetic Plasmas*

W. W. Lee, J. L. V. Lewandowski, H. Qin and T. Jenkins
Princeton Plasma Physics Laboratory
Princeton, NJ 08543

Theoretical and numerical properties of shear Alfven and compressional Alfven waves in gyrokinetic plasmas in toroidal geometry are presented:

1) We will show that the difference in treating the polarization drift between the MHD and gyrokinetic formalism leads a totally different relationship between the two branches of Alfven waves. In the gyrokinetic formalism, there is a natural separation between them through frequency ordering, whereas, in the MHD limit, the separation can only be achieved through geometric ordering. The simple treatment presented here helps to understand the underlying physics and is in agreement with the previous analyses based on the more formal procedures of gyrokinetic ordering.[1,2]

2) We have also extended the original split-weight particle simulation scheme[3] based on $F = F_0+\psi F_0+\delta h$ within the $v_\parallel$ formalism to a more general geometry, where $\psi = \phi + (1/c)\int A_\parallel dx_{\parallel 0}$ is calculated along the unperturbed orbit. A more complete derivation for toroidal plasmas will be presented elsewhere.[4]

3) The possibility of simulating microturbulence in the transport time scale based on gyrokinetic particle simulation will also be explored. It involves the interplay between 1) shear Alfven physics in the presence of spatial inhomogeneity, 2) profile modification, 3) pressure balance equation, and 4) changing magnetic equilibria. Details will be discussed.

* Work supported by US DoE.

[1] W. W. Lee, Phys. Fluids (1983).

[2] H. Qin, W. M. Tang , W. W. Lee and R. Rewoldt, Phys. Plasmas **6**, 1575 (1999).

[3] W. W. Lee, J. L. V. Lewandowski, T. S. Hahm, and Z. Lin, Phys. Plasmas **8**, 4435 (2001).

[4] J. Lewandowski, private communication.

1E35

Magnetic Dissipation in Force-Free Magnetic Fields — 3D PIC Simulation of a Sheet-Pinch Configuration

H. Li, K. Nishimura and X. Z. Tang
Los Alamos National Laboratory, Los Alamos, NM 87545

Many astrophysical plasma environments are low β and nearly force-free, with the magnetic free energy stored in the twists of the field lines. Observations have strongly suggested that magnetic energy has been continuously released to heat and accelerate plasmas. We will present 2D and 3D Particle-in-Cell (PIC) simulation results of magnetic reconnection in a force-free plasma, which is modeled by a sheet pinch configuration. This configuration is unstable to the collisionless tearing instability. We will present the nonlinear evolution of this system. In 3D, there exist multiple resonant layers that are unstable to the collisionless tearing. Layer-layer interaction plays a dominant role in determining the overall magnetic dissipation process. We also show that the system evolves from an initially homogeneous state to a state populated with highly anisotropic structures, such as current and vorticity filaments. We will discuss the role of these intermittent regions in the overall magnetic energy dissipation process.

1E36

Neoclassical Bootstrap Current in High β_p Tokamak Plasmas

Y.R. Lin-Liu[1], F.L. Hinton[2], F.W. Perkins[3]

[1]Department of Physics, National Dong Hwa University, Taiwan

[2]General Atomics, San Diego, CA

[3]Princeton – DIII-D collaboration

One of the most important predictions of neoclassical transport theory is the existence of bootstrap current. With the advent of advanced tokamak concept, vigorous study of non-inductive current in the past decade has diminished any doubt of its existence. It becomes increasingly evident that an economically feasible steady-state tokamak reactor will rely on the bootstrap effect to drive most of its plasma current. Moreover, it is believed that bootstrap current plays an important role in determining edge stability of the H-mode plasmas. Although various formulas for the bootstrap current coefficients were derived based on approximate analytic theories or exact numerical calculations, their dependence on plasma β's has not been systematically explored. In this work, we wish to point out that the bootstrap current coefficients are decreasing functions of poloidal $\beta(\beta_p)$ and have a strong dependence while the plasma is near its equilibrium β_p limit. The large Shafranov shift in a high β_p equilibrium effectively decreases the depth of magnetic well and the inverse aspect ratio ε of a flux surface under consideration, hence, particle trapping effects and bootstrap current. Another important feature of a high β_p equilibrium is weakening of the in-board poloidal magnetic field which makes the field line lingering on the high-field side longer. This in turn reduces collisional coupling between trapped and passing particles, therefore, bootstrap current. To quantitatively demonstrate the effects described above, we make use of the large aspect ratio Hass-Freidberg model equilibrium to calculate the bootstrap current coefficients of the Lorentz gas in the banana regime. It is shown that at the equilibrium β_p limit the edge bootstrap current vanishes in the leading order of $\sqrt{\varepsilon}$. This drastic dependence can be correlated to the appearance of a separatrix at the high-field side of the plasma at the equilibrium limit. Implications of the results obtained for the edge bootstrap current in diverted tokamak plasmas will be discussed.

1E37

MH4D: an MHD Algorithm on an Unstructured Tetrahedral Grid

R. Lionello, D.D. Schnack
Science Applications International Corporation
San Diego, CA 92121

Abstract

MH4D (Magnetohydrodynamics on a TETRAhedral Domain) is a massively-parallel, device-independent numerical code for the solution of the resistive and viscous MHD equations on an unstructured grid of tetrahedra. The unstructured grid allows the computanional domain to be of arbitrary shape and the resolution to be increased in the regions of physical interest. Consequently, plasma confinement devices of complex shape (e.g. stellcrators) can be modeled and problems with a wide range of spatial scales can be studied. A variational formulation of the differential operators ensures accuracy and the preservation of the analytical properties of the operators ($\nabla \cdot \mathbf{B}=0$), and self-adjointness of the resistive and viscous operators. The combined semi-implicit treatment of the waves and implicit formulation of the diffusive operators can accommodate the wide range of time scales present in the solar corona. The capability of mesh refinement and coarsening is also included. MH4D is capable of solving the resistive diffusion equation and the equations of hydrodynamics. We are currently implementing the MHD operators and will present preliminary results..

1E38

The Effects of Energetic Ions on Magnetic Islands in Toroidal Plasmas

X.Liu, C.C.Hegna
Dept. of Engineering Physics, University of Wisconsin
Madison, WI 53706

Studies of a kinetic theory for the interaction of an energetic ion population with an isolated magnetic island in a tokamak plasma are presented. Energetic trapped ions can influence the nonlinear dynamics of magnetic islands and excite small scale magnetic islands. The characteristic island width under study is taken to be smaller than the ion banana width. By solving the drift kinetic equation for both electrons and ions, and by considering mechanisms such as ion pressional drift and Landau resonances for the energetic ions, self-consistent equations for the islands' width, *w*, and its propagation frequency, ?, are determined. The results are to be compared with those for large island width so as to yield a description of magnetic island width evolution from sub-banana width to macroscopic scale lengths.

*Research supported by US DoE under grant No. DE-FG02-86ER53218.

1E39

OVERVIEW OF THE QPS EXPERIMENT

J.F. Lyon[1], L.A. Berry[1], M.J. Cole[1], S.P. Hirshman[1], B.E. Nelson[1], D.A. Spong[1], D.J. Strickler[1], A.S. Ware[2], D.E. Williamson[1], E. Barcikowskii[2], P.J. Fogarty[1], G.Y. Fu[3], P. Goranson[1], D. Mikkelsen[3], P.K. Mioduszewski[1], D.A. Monticello[3], R. Sanchez[4], D. Westerly[2]

[1]Oak Ridge National Laboratory, P.O. Box 2009, Oak Ridge, TN 37831-8073
[2]Department of Physics and Astronomy, University of Montana, Missoula, MT, 59812
[3]Princeton Plasma Physics Laboratory, P.O. Box 451, Princeton, NJ 08502
[4]Universidad Carlos III de Madrid, Madrid, Spain

A quasi-poloidal stellarator with very low plasma aspect ratio ($<R>/<a> \sim 2.7$, 1/2-1/4 that of existing stellarators) is a new magnetic confinement approach that could ultimately lead to a high-beta ($<\beta> = 7\text{-}15\%$) disruption-free compact stellarator reactor. In this approach the dominant components in the magnetic field spectrum are poloidally symmetric in flux coordinates. The degree of quasi-poloidal symmetry decreases with radius but increases with β. In the plasma core the magnetic energy in non-poloidally symmetric field components is less than 10% of that in the poloidally symmetric field components and rises to 30% at the plasma edge. The quasi-poloidal symmetry leads locally to small B x grad B drifts out of a flux surface over most of the plasma cross section and reduced neoclassical transport at low collisionality. The high degree of quasi-poloidal symmetry and the reduced effective field ripple may also reduce poloidal viscosity, enhancing the naturally occurring E x B poloidal drifts and allowing larger poloidal flows for possible shear damping reduction of anomalous transport. For exact poloidal (θ) symmetry, the canonical angular momentum p_θ would be conserved and: (1) the orbit excursions from a flux surface would be limited to the gyroradius in the *toroidal* magnetic field ρ_T rather than in the *poloidal* magnetic field ρ_p (the banana width) where $\rho_T << \rho_p$; (2) there would be no flow damping in the poloidal direction; and (3) the bootstrap current would be reduced by ι/N where ι is the rotational transform ($= 1/q$) and N is the number of field periods. The magnetic configuration is relatively insensitive to increasing beta and is similar to that in the W7-X approach, but at 1/4 the plasma aspect ratio. In contrast to W7-X, a self-consistent bootstrap current is included in the configuration optimization and a different physics mechanism is responsible for the reduced neoclassical transport.

The Quasi-Poloidal Stellarator (QPS) experiment [1] is being developed to test key features of this approach. QPS has $<R_{plasma}> = 0.9\text{-}1$ m, $<a_{plasma}> = 0.3\text{-}0.4$ m, $<B_{axis}> = 1$ T for a 1.5-s pulse, and $P_{heating} = 1\text{-}3$ MW. The experiment is designed to study regimes in which either anomalous transport or neoclassical transport is dominant, equilibrium robustness at finite beta, and stability limits at $<\beta> \sim 2.5\%$. Kink and vertical modes are stable at $<\beta> \sim 5\%$ without feedback or close conducting walls. The poster will address the physics basis for the QPS approach, the relationship with other stellarator concepts, the key features of the proposed QPS experiment, and the connection to higher-beta quasi-poloidal-stellarator configurations.

Work supported by U.S. Department of Energy under Contract DE-AC05-00OR22725 with UT-Battelle, LLC.

[1] J. F. Lyon and the QPS team, "QPS, A Low Aspect Ratio Quasi-Poloidal Concept Exploration Experiment", http://qps.fed.ornl.gov/, April 2001.

1E40

Nested Grids in Lattice Boltzmann Representation of Resistive MHD

A.I.D. Macnab[1], G. Vahala[1], L. Vahala[2]
[1] Department of Physics, College of William and Mary
Williamsburg, VA 23221
[2] Department of Electrical and Computer Engineering, Old Dominion University
Norfolk, VA 23529

Abstract

Lattice Boltzmann methods provide a novel kinetic algorithm for nonlinear macroscopic systems governed by conservation laws. The simplest form of the Lattice Boltzmann technique utilizes the linearized BGK collision operator. The algorithm to temporally evolve the particle distribution function on a discrete lattice involves (a) free streaming from spatial node to spatial node, and (b) local (macroscopically nonlinear) collisions. The strengths of lattice Boltzmann methods lie in 1) the avoidance of the nonlinear convective derivatives that typically consume most of the computation time in standard finite difference, finite volume and finite element simulations, 2) the ability to model systems in complex physical geometries, 3) the incorporation of newly developing methods in non-uniform and adaptive meshes that focus computational effort around structures of interest such as current sheets and shocks, and 4) the simple computational algorithms which lend themselves to ideal parallelization on multiple PE platforms.

Here we apply the lattice Boltzmann method to resistive MHD. Using a scalar distribution function to recover the density, velocity field and momentum flux tensor and a vector distribution function to recover the magnetic field and magnetic flux tensor decouples the viscosity from the resistivity. This scalar-vector distribution function approach also allows greater freedom in choosing expansion coefficients for the distribution functions resulting in better numerical stability. The incorporation of non-uniform grid methods resolve the regions containing shocks and current sheets with higher precision so that dynamic behavior on a fine scale can be examined.

Results for both one-dimensional and two dimensional resistive MHD simulations are presented. The one-dimensional simulations use a reduced form of the MHD equations containing a single component of the velocity field and two perpendicular components of the magnetic field. The formation of shocks and the exchange of kinetic and magnetic energies are examined. Two-dimensional simulations are presented for the Orszag-Tang vortex, a set of simple two dimensional initial conditions characterized by two alternating X and O points of vorticity and four varying current layers. These initial conditions give rise to most of the notable features of MHD turbulence such as magnetic reconnection and the formulation of jets.

1E41

A Two-Field Model of the L→H Bifurcation

M.A. Malkov, P.H. Diamond, M.N. Rosenbluth, I. Gruzinov

Department of Physics, University of California, San Diego, La Jolla, CA 92093-0319

Abstract

A two field model of the L→H bifurcation, originally proposed by Hinton and Staebler[1], is solved analytically. This model evolves density and temperature profiles, with sources. Exact criteria for phase 'co-existence' and confinement bifurcation are derived. In the case where $\chi_L/\chi_H = D_L/D_H$, for which the channels effectively decouple, the co-existence criterion is equivalent to the Maxwell construction. This conclusion differs significantly from that of previous studies. The coupled channel problem is solved as well. Criteria for the origin and nature of hysteresis are discussed. Numerical work is ongoing. Results from that will be discussed.

[1] F.L. Hinton and G.M. Staebler, Phys. Fluids. **5**, 1281 (1993)

1E42

MHD Simulation of the HIT-SI Experiment

G. J. Marklin

NumerEx, 2309 Renard Place SE, suite 220, Albuquerque, NM 87106

Abstract

The Helicity Injected Torus (HIT) experiment at the University of Washington has been reconfigured into a high beta spheromak with steady state AC current drive[1]. Helicity is injected by two half torus Reversed Field Pinches (RFP's) connected to the ends of the cylindrically symmetric flux conserver, rotated by 90 degrees from each other. The RFP's are driven with sinusoidally varying voltage and flux. Each side has its voltage and flux in phase, but is 90 degrees out of phase from the other side. The helicity injection rate, which is proportional to the voltage times the flux, goes like $\sin^2(\omega t)$ on one side and $\cos^2(\omega t)$ on the other, making the total injection rate constant in time.

The complex multiply connected 3-dimensional geometry of this device make it difficult to simulate with existing codes. This poster will report on progress to develop a new 3D MHD code with an unstructured finite element mesh and use it to simulate the HIT-SI experiment. The mesh is generated using the Los Alamos Grid Generation Tool[2] (LaGriT). It creates an unstructured finite element mesh from a CAD-like description of an arbitrary arrangement of 3D geometrical objects. The MHD code is completely separate. It reads in the mesh and solves the MHD equations using physical and numerical models that are similar to the existing code, MACH3, developed by the AFRL.

---

[1] T. R. Jarboe, Fusion Technology **36**, p. 85, 1999

[2] http://www.t12.lanl.gov/home/lagrit/

1E43

Non-local Electron Parallel Heat Transport in Divertor Plasmas and Atomic Physics Rates

J.P. Matte[1], F.Allais[1], C.-G. Kim[1], F.Alouani-Bibi[1], D.Stotler[2], T.D Rognlien[3],

[1] INRS-Énergie, Matériaux et Télécommunications, Varennes, Québec, Canada.

[2]Princeton Plasma Physics Laboratory, Princeton, NJ, USA.

[3]Lawrence Livermore National Laboratory, Livermore, CA, USA.

Abstract

The problem of simulating steep parallel electron temperature gradients in divertor plasmas with the fluid code UEDGE [1] is addressed. Previously, an electron kinetic code, FPI, has been used to develop non-local heat flow formulas by running in a perturbation mode, i.e. by imposing small modulations of temperature or of a heater field and analyzing the resulting heat flux, to obtain the kernel of the non-local convolution formula, and this was validated by doing runs with large temperature gradients [2]. This formula is being implemented into UEDGE. The electron kinetic code (FPI), now includes inelastic collisions (ionization, excitation, recombination) of atomic hydrogen, using a set of cross sections [3] such that the rates precisely match those used in UEDGE when the distribution is Maxwellian. This will be used to further improve the formula for non-local heat flow in the presence of neutrals. Validation will be by comparing 1-D UEDGE runs to FPI simulations. The effects of the non-Maxwellian distribution functions on rates (both for hydrogen and for trace impurities of boron) will also be illustrated, and the use of non-local formulas to compute them in a fluid code such as UEDGE will be discussed.

[1] T.D. Rognlien *et al.*, Contrib. Plasma Phys. 34, 362 (1994)

[2] F. Alouani Bibi and J.-P. Matte, Phys. Rev. E 66, 066414 (2002)

[3] R.K. Janev , J.J. Smith, Atomic and Plasma-Material Interaction Data for Fusion (Supplement to Nuclear Fusion), Vol. 4 (1993)).

1E44

Effect of Dynamo On Electric Field And Current Density In Reversed Field Pinches

V.V.Mirnov, C.C.Hegna, S.C.Prager
University of Wisconsin--Madison, WI 53706

Abstract

In high temperature laboratory experiments with plasma self-organization (reversed field pinches, spheromaks, and field reversed configurations), large scale magnetic and electric fields applied to plasma externally provide the free energy sources to drive tearing instabilities. These instabilities support a mechanism for the relaxation process to equilibrium states close to the Taylor's state of minimum energy. Standard regimes of Madison Symmetric Torus (MST) RFP experiments are characterized by the periodic sawtooth fluctuations in the plasma velocity and magnetic field. The corresponding nonlinear $\mathbf{v} \quad \mathbf{B}$ dynamo effect produces mean electric field and current density, all of which are well measured in the MST near the reversal surface. This motivates our interest to: (1) provide an explanation of the experimental results, and (2) calculate the quasilinear contribution of the mean parallel current to analyze its feedback effect on the tearing mode stability. The problem is treated on the basis of parallel (to unperturbed magnetic field) component of flux surface average Ohm's law: $\langle \mathbf{E} \rangle_{\parallel} + (1/c) \langle \mathbf{v}^{(1)} \quad \mathbf{B}^{(1)} \rangle_{\parallel} = \eta \langle \mathbf{j} \rangle_{\parallel}$, where $\mathbf{v}^{(1)}$ and $\mathbf{B}^{(1)}$ are tearing eigenfunctions for plasma velocity and magnetic field. The above equation does not address the question as to what fraction the contribution from $\langle \mathbf{v}^{(1)} \quad \mathbf{B}^{(1)} \rangle_{\parallel}$ term is shared between the mean electric field $\langle \mathbf{E} \rangle_{\parallel}$ and the mean current density $\langle \mathbf{j} \rangle_{\parallel}$. Simple 1D cylindrical temporal model is used to find these functions separately. In highly conductive case, the self-inductance of the tearing layer prevents fast changes in the mean parallel current, thus, providing a "stiffness" with respect to perturbations. This is observed in the MST experiments where the mean electric field is measured to be balanced by the dynamo term during a sawtooth crash.

This research is supported by U. S. DoE under the grant number DE-FG02-85ER53212

1E45

Simulated Injection of Relativistic Electrons

M. J. Mithaiwala, W. Horton, Wei-Tai Lin

Institute for Fusion Studies, University of Texas at Austin

Relativistic particles in space plasmas, particularly electrons, pose a serious hazard to both man and machine. The energization mechanism of these particles, which occurs during magnetic substorms, is not well understood. Following *Li et al.* [1], we try to understand this process as a result of magnetic field dipolarization with an induced electric field. We integrate ensmebles of test particles using the relativistic guiding center equations of motion, where the first adiabatic invariant is conserved, to estimate the fluxes of energetic electrons at geosynchronous orbit. We also integrate ensembles of protons comparing the guiding center orbits with the full Lorentz force orbits. We attempt to estimate the fraction of protons starting in the geotail that become trapped in the inner magnetosphere compared with the fraction that leave the system through the dayside magnetopause.

References

[1] Xinlin Li, D. N. Baker, M. Temerin, G. D. Reeves, R. D. Belian. Simulation of dispersionless injections and drift echoes of energetic electrons associated with substorms. GRL **25**, 20, 3763-3766.

This work was supported by the U.S. Department of Energy Contract No. DE-FG03-96ER-54346 and the National Science Foundation Grant ATM-9907637.

1E46

Self consistent theory of zonal flows in ion temperature gradient turbulence

Robert Moestam and Dastgeer Sheikh[1] and Jan Weiland

Department of Electromagnetics and EURATOM-VR Association
Chalmers University of Technology
SE-41296 Göteborg, Sweden

Abstract

Sheared poloidal flows of plasma are known to damp ion temperature gradient driven turbulence in tokamaks. The mechanism for the nonlinearly generated part of the poloidal flow, zonal flows, is less known. Therefore a self-consistent theory of nonlinearly excited zonal flows amidst complex background of ion temperature gradient (ITG) turbulence is presented. Starting with a reactive fluid model, Weiland model, utilizing Taniutis reductive perturbation method a set of coupled nonlinear equations is obtained. The nonlinear equations has a form resembling Zakharov equations. The equations represent dynamical evolution of nonlinearly excited zonal flows and potential fluctuations of ITG turbulence. The zonal flows and ITG turbulence fluctuations are shown to couple through the nonlinearities. For Cyclone Base Case parameters, it is shown that zonal flows are resonantly excited through terms originating from the nonlinearity in the ion energy equation. Using a gyro-Landau fluid model the effect of closure of the fluid hierarchy on the resonant excitation of zonal flows is investigated. It is thereby concluded that even though different fluid models have similar values of the thresholds and growthrates, defining the transport in quasilinear models, the mechanism generating zonal flows is sensitive to the closure of the fluid hierarchy.

[1]current address: University of California, Riverside, Riverside, 1432 Geology Building, IGGP, California 92521, USA

1E47

Self-organization in radiative plasmas

D.Kh. Morozov[1] and M. Pekker[2]

[1]Institute of Nuclear Fusion, Moscow, Russia

[2]Institute for Fusion Studies, The University of Texas at Austin, Austin, TX 78712

Abstract

Nonlinear self-sustained oscillations of Belousov-Zhabotinsky type were predicted for radiative plasmas theoretically [1]. Inharmonic oscillating solutions for incompressible carbon plasmas were obtained using expansion in series over oscillation amplitudes. It was shown also that purely harmonic oscillations might take a place. In this work the nonlinear oscillations are found in compressible radiative plasmas for exact functions for ionization-recombination rates and radiation intensities. The averaged temperature for compressible plasmas is lower than for incompressible one. Pure harmonic nonlinear oscillations are found. As it shown in Ref. [2], the temperature oscillations produce the nonlinear shift of ionization equilibrium without any decrease of input power. Hence, the self-sustained oscillations may be used in order to increase the ionization level in plasma shooters and to enhance their efficiency.

[1] D.Kh. Morozov 29th EPS Conf. On Plasma Phys. and Contr. Fusion, v. 26B, P-1.002 (2002).
[2] V.I. Gervids and D.Kh. Morozov, Plasma Phys. Rep., v. 25, p.1998 (1999).

1E48

On the Fluctuation Spectrum of Plasma

P.J. Morrison[1] and B.A. Shadwick[2]
[1]Institute for Fusion Studies and Department of Physics
The University of Texas at Austin
Austin, TX 78712
[2]Center for Beam Physics
Lawrence Berkeley National Laboratory
University of California, Berkeley
94720 CPB-LBNL, Berkeley, CA 94720

Abstract

The spectrum of electron phase space density fluctuations of a plasma is calculated by a novel method that parallels conventional calculations of the partition function in statistical physics. Expressions for the electric field fluctuations and the closely related form factor agree with existing results. The method clears up ambiguous statements about equipartition and provides a new expression for the spectrum of phase space density fluctuations about stable non-Maxwellian equilibria.

This work was supported by the U.S. Department of Energy Contract No. DE–FG03–96ER–54346.

1E49

Experimental and Theoretical Studies of Electrostatic Confinement on the Intense Neutron Source (INS-e) Device

R. A. Nebel, J. Park, W. Rellergert, M. Sekora, S. Stange
Los Alamos National Laboratory
Los Alamos, New Mexico 87545

Abstract

Theoretical works by Barnes and Nebel [1,2] have suggested that a tiny oscillating ion cloud may undergo a self-similar collapse in a harmonic oscillator potential formed by a uniform electron background. By tuning the external radio-frequency (rf) electric fields to this naturally occurring mode, it is then possible to heat the ions to obtain very high densities and temperatures simultaneously during the collapse phase of the oscillation through adiabatic compression. However, a major uncertainty in this oscillating plasma scheme is the dynamics and stability of the background electrons in the virtual cathode. Here we describe an Inertial Electrostatic Confinement (IEC) device at Los Alamos National Laboratory that is being used to test the electron dynamics in a virtual cathode and will subsequently be used to verify this heating and compression scheme. Results from the device operation will be presented including the formation of deep potential wells and bifurcations in the potential equilibria. A simple model is used to explain this bifurcation.

[1.] R. A. Nebel, D. C. Barnes, *Fusion Technology* **38**, 28 (1998)
[2.] D. C. Barnes, R. A. Nebel, *Phys. Plasmas* **5**, 2498 (1998)

1E50

Simulation of electron-Bernstein wave absorption using VORPAL

C. Nieter[1], J. R. Cary[1], R. W. Harvey[2], R. Dominguez[2], A. P. Smirnov[2]

[1]Center for Integrated Plasma Studies, University of Colorado
Boulder, CO 80303

[2]CompX
Del Mar, CA 92014

Abstract

In certain high density toroidal devices, the electron plasma frequency may be larger than the electron cyclotron frequency. Since electron cyclotron waves cannot propagate below the plasma frequency, electron-Bernstein waves (EBW) can provide an alternative method for RF heating near the electron cyclotron frequency. Preliminary runs of electron-Bernstein wave absorption have been done using the versatile plasma simulation code VORPAL. VORPAL allows the study of wave absorption from first principles using a PIC model for the plasma electrons and a full finite difference Maxwell solver for the electromagnetic fields. Simulations using parameters typical for spherical tokamaks such as NSTX will be presented along with possible additions to the code which will expand the parameter space that can be studied and allow for studies of current drive.

1E51

Nonlinear stability of drift-tearing magnetic islands

M. Ottaviani[1], F. Porcelli[2], D. Grasso[2]
[1] Association EURATOM-CEA Cadarache, 13108 St. Paul-lez-Durance, France
[2] Burning Plasma Research Group, INFM, Politecnico di Torino, Italy

Abstract

The stability of drift-tearing magnetic islands in semi-collisional regimes is investigated on the basis of a fluid four-field model, which includes the effects associated with the electron compressibility and the ion motion along magnetic field lines. In a recent paper [1], we have shown that small-amplitude drift-tearing modes are stable even for positive and relatively large values of the tearing mode stability parameter, Δ', provided that the electron beta parameter, $\beta = (v_s/v_A)^2$, exceeds a threshold value determined by the electron drift wave frequency normalized to the Alfven frequency, ω_*/ω_A, and the normalized ion sound Larmor radius, $\rho = v_s/L_s\Omega_{ci}$. Here, $v_s = (T/m_i)^{1/2}$ is the sound speed, T is the electron temperature, $v_A = \omega_A L_s$ is the Alfven speed, L_s is the equilibrium magnetic shear length and Ω_{ci} is the ion cyclotron frequency. The electron beta parameter measures the strength of the coupling between drift-tearing modes and drift-acoustic waves, associated with the parallel ion motion.

In this presentation, the nonlinear stability properties are investigated numerically in regimes with positive Δ' of order unity. We find that magnetic islands of finite width can be suppressed for values of beta in the neighborhood of the linear threshold. Nearly steady-state magnetic island solutions obtained at zero β are such that the electron pressure gradient is somewhat reduced within the island region and the island is nearly stationary (i.e. non-rotating) in the plasma rest frame. Nevertheless, diamagnetic effects are felt nonlinearly, as these solutions exhibit a localized zonal flow comparable with the electron diamagnetic drift velocity associated with the equilibrium pressure gradient. Nonlinear numerical simulations are suggestive of a complex bifurcation diagram for these equilibrium solutions, depending on the ratio between the sound Larmor radius and the saturated island width, w_s, attained at $\beta = 0$. Magnetic islands are suppressed when this ratio is of order unity and the coupling to the parallel ion motion (i.e. finite beta) is switched on. Saturated islands persist at larger values of w_s/ρ, even when beta exceeds the linear threshold value. Thus, in these situations where linear stability theory indicates that small amplitude tearing perturbations are stable, sufficiently large initial perturbations can still develop into finite size magnetic islands.

[1] Grasso, D., Ottaviani, M., and Porcelli, F., *Nuclear Fusion* **42** (2002) 1-8.

1E52

Evaluation of Models for L-H Transition in Tokamak Plasmas

Alexei Pankin[1], Glenn Bateman[1], Parvez Guzdar[2], Robert Kleva[2], Arnold Kritz[1], and Thawatchai Onjun[1]

[1]Physics Department, Lehigh University, Bethlehem, PA 18015

[2]Institute for Research in Electronics and Applied Physics, University of Maryland, College Park, MD 20742

Abstract

A model for the transition from L-mode to H-mode is required for use in predictive integrated modeling codes in order to simulate the time dependence of tokamak discharges that include the L-H transition. In order to develop and test a model for the L-H transition, two theories for the transition are analyzed and the resulting criteria for the transition are compared. One theory considered is based on the stabilization of a strongly ballooning resistive mode by the ion diamagnetic drift [1]. This theory provides the condition for the L-H transition in terms of $\eta_i = L_n/L_T$ (where L_n is the density scale length and L_T is the tempreture scale length) and indicates that the transition to H-mode can occur without toroidal rotation, when the ion temperature gradients are sufficiently steep at the edge of the plasma. The second L-H theory is based on the idea of the generation of flow shear by finite β drift waves [2]. In this case, the criterion for L-H transition is expressed in the terms of electron temperature. This criterion depends on the electron density gradients, but does not depend on the ion or electron temperature gradients. To test the latter theory, an analytical expression for the critical value of electron temperature is employed in the BALDUR code. The critical electron temperature depends on the global plasma parameters such as major radius, toroidal magnetic field, and effective impurity content. Discharges with a variety of values of these parameters are considered in order to form systematic scans and to test the model in the different operational regimes. Also implemented in the BALDUR code is an empirical model in which the condition for the L-H transition is expressed in terms of a critical value for the heating power [3]. The theory model based on flow shear and the empirical model are tested against each other and against experimental data from the Alcator C-Mod, DIII-D, and JET tokamaks. Simulation results obtained with the theory-based model and some experimental observations [4] suggest that edge plasma profile gradients are responsible for the L-H transition. Future work will include developing and applying a model associated with theory for the L-H transition, which is based on the stabilization of resistive edge modes [1].

Work supported by US DOE contract DE-FG02-92-ER-5414.

---

[1] J. Weiland, H. Nordman, and R. Singh, in *Proc. of the 17th IAEA Int. Conference - Yokohama, Japan, October 1998* (IAEA, 1999), vol. 4, p. 1537.

[2] P. N. Guzdar, R. G. Kleva, R. J. Gloebner, and P. Gohil, Phys. Rev. Lett. **89**, 265004 (2002).

[3] Y. Shimomura, R. Aymar, V. A. Chuyanov, and et. al., Nuclear Fusion **41**, 309 (2001).

[4] R. Groebner, D. M. Thomas, and R. D. Deranian, Phys. Plasmas **8**, 2722 (2001).

Presented at the Sherwood Meeting, Corpus Christi, TX, April 28-30

1E53

Characteristics and Features of Electromagnetic Microtubulence with Kinetic Electrons[1]

S.E. Parker and Y. Chen
University of Colorado, Boulder, CO 80309

W.M. Nevins and B.I. Cohen
Lawrence Livermore National Laboratory, Livermore, CA 94551

A new algorithm has been developed that can simulate electromagnetic tokamak microturbulence with experimental values of plasma β and drift-kinetic electrons using gyrokinetic δf particle-in-cell (PIC) simulation methods.[2] PIC methods of this type have the computational advantage of resolving particle-wave resonance effects using only a three-dimensional spatial grid. This allows for high velocity space resolution in local flux-tube simulation domains to ensure numerical convergence with respect to all five phase space dimensions and time. The simulation is massively-parallel and includes electron-ion collisions. Here, electromagnetic, kinetic electron simulation results are analyzed and compared with both adiabatic electron and electrostatic kinetic electron results. Spectral analysis shows that the residual zonal flow is less stationary in electromagnetic turbulence thereby leading to small transient bursts in energy flux. In addition, a plausible explanation is given for why gyrokinetic turbulence simulations produce energy fluxes that are much too high for typical H-mode parameters. Tokamaks operate in such a way to avoid the ballooning limit while maximizing β. This puts such plasmas in a "pocket" of good confinement where ion-temperature-gradient driven turbulence is reduced due to finite-β stabilization.

---

[1]work supported by the US Department of Energy SciDAC Plasma Microturbulence Project

[2]Y. Chen and S.E. Parker, submitted to J. Comput. Phys. 2002.

1E54

Neoclassical Tearing Modes: Revisting Theoretical Foundations *

F. W. Perkins[1], R. Harvey[2], M.Chu[3]. R. LaHaye[3], R. Prater[4]

[1]Princeton – DIII-D Collabotoration, PO Box 451, PPPL, Princeton, NJ, 08543
[2]CompX, 12839 Via Grimaldi, Del Mar, CA, 92014
[3]General Atomics, PO Box 85608, San Diego, CA, 921286-5608

Tearing modes, especially Neoclassical Tearing Modes (NTMs), are large-scale, symmetry-breaking, magnetic-island structures that spontaneously arise in many tokmak experiments and degrade confinement. The Rutherford island evolution equation has provided a very productive framework for understanding NTMs, especially the island size, the time scale for evolution, which is governed by classical flux difusion., and the level of Electron Cyclotron Current Drive (ECCD) power required to supress fully saturated islands. Previous results based on appropriate helical averages of the ECCD level required for supression of NTMS are extended to include offsets between of the current drive layer and the mode rational surface. The Rutherford equation, however, is only an approximate solution to island evolution: it utilizes just one Fourier harmonic to describe the island shape, and it ignores changes in Δ' resulting from island size and/or the effect of ECCD on equilibrium current density profile and hence on Δ'. Stochastic regions, driven by toroidicity, should be present along the boundaries of the helical islands and, in turn, alter bootstrap current profiles and the growth of small islands. This contribution revisits the theoretical foundations of the Rutherford equation and casts the tearing mode problem as a flux-diffusion evolution through a series of helical states, each one in mechanical equilibrium. The goal is to address the deficiencies noted above thereby improving agreement with observations and strengthening extrapolation to an ITER-class facility.

*Work supported by U.S. Department of Energy under Contracts DE-AC02-76CH03073, DE-AC03-99ER54463, and W-7405-ENG-48.

1E55

Bounds on the Dissipation Rate in Sheared MHD Flows

F. Pétrélis[1], A. Alexandros[2],
C.R. Doering[3], and P.J. Morrison[4]
[1]Laboratoire de Physique Statistique
ENS, 24 rue Lhomond
75005 Paris, France
[2]Department of Physics
University of Chicago
Chicago, IL 60637
[3]Department of Mathematics
University of Michigan
Ann Arbor, MI 48109
[4]Institute for Fusion Studies and Department of Physics
The University of Texas at Austin
Austin, TX 78712

Abstract

The total dissipation rate for MHD flows in plane geometry with both velocity and magnetic shear is studied. For some boundary conditions it is shown that the lower bound on the dissipation rate is achieved by the equivalent of Stokes flow for MHD. Using the 'background method' (Doering & Constantin, Phys. Rev. Lett. 69, 1648–1651 (1992)) upper bounds for the dissipation rate are calculated. For a shear layer, with both velocity and magnetic shear, parameter dependence of the upper bound is obtained. As a by-product of this calculation, an 'energy stability' domain is calculated. A sheet pinch is also studied, and it is shown that the upper bound tends to zero as the resistivity tends to zero. Thus, an antiturbulence result is obtained. (Additional results are given in the poster by Alexandros et al.)

This work was supported in part by the U.S. Department of Energy Contract No. DE–FG03–96ER–54346.

Tuesday Morning, April 29

8:30 to 9:30

Corpus Christi Ballroom C

Review Talk 2A

2A01

The Earth Simulator and Its Impact on Science and Technology

Tetsuya SATO
The Earth Simulator Center, Japan Marine Science and Technology Center
3173-25 Showamachi, Kanazawa-ku, Yokohama, 236-0001, Japan

Abstract

The Earth Simulator Research Project started in March 2002 with primary objective of producing reliable prediction data for the global environmental change. Within a couple of months after the start of operation, the Earth Simulator achieved an amazing performance of 35.86 Teraflops (about 90% of the peak performance of 40.92 Teraflops) for the Linpack benchmark test and, more surprisingly, 26.58 Teraflops for a typical application program of global atmospheric circulation (AFES) with a horizontal resolution of 10 kilometers. Global atmospheric and oceanic circulation simulations we have obtained for the first year's operation of the Earth Simulator clearly indicate its superior ability. Other products such as the seismic wave propagation near the pacific side of Japan and carbon-nano-tube dynamics also indicate the excellence of the Earth Simulator, some of which will be presented in this talk. These facts are good enough that the Earth Simulator would make a real revolution in science, industry, and human thinking, as well as finding the best human's wisdom to keep a sustainable symbiotic relationship with nature.

Tuesday Morning, April 29

9:30 to 10:00

Corpus Christi Ballroom C

Oral Session 2B

2B01

Linear theory and chaos: breakthrough in the description of wave-particle interaction in plasmas

D.F. Escande and Y. Elskens
UMR6633 CNRS-Université de Provence, Marseilles, France

Landau damping was discovered in 1946, but textbooks still give unprecise and sometimes wrong physical pictures of its physical nature. Quasilinear (QL) theory was derived in 1962, but a controversy is still unsettled about its validity in the saturation regime it was meant to describe. At a moment where the development of gyrokinetic codes is of paramount importance for the study of transport in magnetic fusion plasmas, it is necessary to clarify the nature of wave-particle interaction and to provide analytical tools enabling its rigorous description, at least for basic examples. This is done in a book describing a non Vlasovian approach to Langmuir wave-particle interaction published recently [1]. This approach relies upon a symmetrical description of the interaction of M>>1 Langmuir waves with N>>1 particles in a Hamiltonian setting originally derived for the cold beam-plasma instability [2].

The Landau and van Kampen theories are recovered with analytical tools not more difficult than the finite Fourier sum. In the linear regime, Landau damping or growth of a single wave with a rate γ_L turns out to correspond to the synchronization of particles with a velocity within $|\gamma_L|/k$ of the wave phase velocity; trapping plays no role at all, which rules out the surfer model to explain the Landau effect. The wave damping does not correspond to an eigenmode, but is the result of the phase mixing of many van Kampen modes. If the spectrum of Langmuir waves is broad, in the linear regime the Landau effect corresponds to the QL diffusion of particles.

In the nonlinear regime where the time of spreading due to diffusion is shorter than the wave growth time γ_L^{-1}, chaos is important and precludes the use of any "close to linear" technique. The description of chaotic diffusion is first tackled in the case of a prescribed spectrum of Langmuir waves. Two new techniques enable to prove rigorously that a QL diffusion occurs in the limit of a continuous spectrum (strong resonance overlap) [1,3]. The QL estimate in this limit is shown to be due to a cross-over between an initial non chaotic QL diffusion and a final chaotic diffusion which is not quasilinear by essence, but which is linked to a rigorous version of Dupree's resonance broadening effect.

In the wave-particle self-consistent case a non rigorous version of the same two techniques enables the derivation of the QL equations in the saturation regime of the weak warm beam-plasma instability [1,3,4]. The calculation is made up of a few explicit steps which can be easily followed by a graduate student. This might help settling the QL controversy.

[1] Y. Elskens et D.F. Escande, Microscopic Dynamics of Plasmas and Chaos (IOP, Bristol, 2002).
[2] I.N. Onishchenko, A.R. Linetskii, N.G. Matsiborko, V.D. Shapiro, and V.I. Shevchenko, ZhETF Pis. Red. 12, 407 (1970) [JETP Lett. 12, 281 (1970)]; T.M. O'Neil, J.H. Winfrey, and J.H. Malmberg, Phys. Fluids 14, 1204 (1971); H.E. Mynick and A.N. Kaufman, Phys. Fluids 21, 653 (1978).
[3] D.F. Escande and Y. Elskens, Phys. Lett. A302, 110 (2002).
[4] D.F. Escande and Y. Elskens, to be published in Phys. Plasmas (May 2003).

Tuesday Morning, April 29

10:00 to 12:00

Corpus Christi Ballroom AB

Poster Session 2C

2C01

On non-diffusive plasma transport at tokamak edge[*]

A. Yu. Pigarov[1], G. Q. Yu[1], S. I. Krasheninnikov[1], D. A. D'Ippolito[2], J. R. Myra[2], D. R. McCarthy[3], T. D. Rognlien[4], J. A. Boedo[1], D. L. Rudakov[1], W. P. West[5], B.LaBombard[6], B. Lipschultz[6], R. Maingi[7], and V. Soukhanovsky[7]

[1]University of California San Diego; [2]Lodestar Research Corporation; [3]Southeastern Louisiana University; [4]Lawrence Livermore National Laboratory; [5]General Atomics, [6]Massachusetts Institute of Technology, [7]Princeton Plasma Physics Laboratory

Abstract

Recent analysis of experimental data from different tokamaks suggests that the plasma coming into the scrape-off layer (SOL) from the bulk recycles at the wall of the main chamber[1], rather than flowing into the divertor and recycling there as the conventional picture of edge plasma flows would suggest. It implies rather fast radial plasma transport in the SOL of main chamber. Moreover, it seems that to be compatible with experimental observations radial transport should be convective rather than diffusive[1]. One of the possible mechanisms of fast convective plasma transport in the SOL can be associated with plasma blobs[2] observed in experiments[3]. The origin of these blobs in the SOL can be rather strong plasma turbulence in the separatrix region. The B drift of charged particles in the SOL and the effective "sheath resistivity"[4] caused by plasma contact with the divertor target result in **E** **B** plasma radial flow. Estimates[2] of radial velocity of the blobs with a scale length ~ 1cm give ~1000m/s which is in a reasonable agreement with recent experimental observations[5]. In this paper we present:

a) 2D Modeling of blob/dip propagation. 2D modeling of blob propagation with the one fluid equations clearly show that for the DIII-D plasma parameters blobs with radial scale length ~ 1cm can propagate radially as a coherent structure at a distance ~ 10 cm. Blobs with larger radial scale lengths are the subjects of flute instability causing "fingering" effects. Nevertheless, "fingers" continue to propagate radially on large distances. Blobs with smaller radial scale are strongly affected by vorticity effects but still propagate radially on large distances. (On stability of the blobs see also D. A. D'Ippolito et al. this meeting) We also present our results on the modeling of dip (holes in plasma density) propagation.

b) Macroscopic transport modeling of the edge plasma transport in tokamaks. We incorporate into the 2D edge transport code UEDGE a cross-field plasma transport model which includes both diffusive and outward convective terms for the cross-field plasma particle flux. Poloidally-varying outward convective term, describing the effect of blobby anomalous transport at the outer side of the torus, was tested on Alcator C-Mod, DIII-D, and NSTX discharges. The results of the modeling confirm the crucial importance of convective transport for the edge plasma. They clearly demonstrate that convective transport has a significant effect on the averaged plasma characteristics in both the main chamber and divertor.

[1] M. Umansky, et al., Phys. Plasma **5** (1998) 3373; R. Schneider et al, 17th IAEA, Japan, 19-24 October 1998; B. Lipschultz et al., 18th IAEA, Italy, 4-10 October 2000.
[2] S. I. Krasheninnikov, Phys. Letters A, **283** (2001) 368; D. A. D'Ippolito, J. R. Myra, and S. I. Krasheninnikov, Physics of Plasmas **9** (2002) 222.
[3] S. J. Zweben Phys. Fluids **28** (1985) 974; M.V. Heller, et al., Phys. Plasmas **6** (1999) 846; J. L. Terry, R. Maqueda, C. S. Pitcher et al., J. Nuclear Material, **290-293** (2001) 757.
[4] A. V. Nedospasov, V. G. Petrov, and G. N. Fidel'man, Nuclear Fusion **25** (1985) 21.
[5] J. A. Boedo, D. L. Rudakov, R. Moyer *et al.*, Phys. Plasmas **8** (2001) 4826; S. J. Zweben, D. P. Stotler, J. L. Terry et al., Phys. Plasmas **9** (2002) 1981

---

[*] Work supported by U.S. DOE

2C02

Test particle approach for transport studies in the RFP

I. Predebon[1,2], L. Marrelli[1], R.B. White[3] and P. Martin[1]

[1] Consorzio RFX, Associazione Euratom-Enea sulla fusione, Padova, Italy
[2] Dipartimento di Ingegneria Elettrica, Università di Padova, Italy
[3] Princeton Plasma Physics Laboratory, Princeton, NJ, USA

Abstract

We present the results of a numerical study concerning the magnetic field topology and the particle transport in various regimes of the Reversed Field Pinch (RFP) configuration. The study has been realized by means of the code ORBIT, whose outputs have been compared with experimental measurements taken in the RFX and MST reversed field pinch devices. The Hamiltonian guiding center calculation of particle motion implemented in the code [1] is designed to follow test particles trajectories for long integration times. Single particle motion and particle diffusion in different background particle distributions and magnetic fields may be studied.

The toroidal RFP equilibrium has been described using the $\mu\&p$ model with a 2^{nd} order Shafranov correction. Radial magnetic field eigenfunctions of m=1 and m=0 modes have been obtained by solving the Newcomb equation. In particular we examine the standard Multiple Helicity states (flat n spectrum), the Quasi Single Helicity states (peaked spectrum) [2], and the low magnetic turbulence regimes obtained in Pulsed Poloidal Current Drive experiments [3]. Analysing the Poincare plots corresponding to these conditions, clear evidence of islands with conserved flux surfaces is found in QSH regimes. Such structures are well correlated with experimental data, in particular with the soft X-ray tomographic reconstructions of the plasma.

The presence of coherent helical magnetic structures, hotter than the background, is a clear indication of the existence of a region of reduced transport in the plasma core. In order to model the observed confinement changes in QSH spectra and to predict what would happen if a pure SH could be reached, a numerical study of particle transport has been performed, taking into account the effect of the interactions with the background plasma particles. The collision operator includes both the pitch angle scattering [4] and the classical scattering.

The diffusion of ensembles of mono-energetic test particles, with random initial pitch distribution, has been studied computing the loss time, defined as the time needed to lose 50% of the particles deposited in the plasma core out from a preset ψ =const surface. Losses resulting from static magnetic perturbations or magnetohydrodynamic fluctuations can be quantified, and a detailed analysis in the SH, QSH and MH conditions has been done, showing in particular the benefit of the conserved flux surfaces inside the magnetic islands with respect to the chaotic (and highly diffusive) MH configurations. Electrons and ions test particles are characterized by different loss times when no electric field is present, so the latter must be introduced to make the quasi-neutrality approximation valid.

[1] R. White, Phys. Fluids 2, 845 1990.
[2] D.F. Escande et al., Phys. Rev. Lett. 85 (2000) 1662.
[3] Bartiromo et al. Phys. Rev. Lett 82 (1999) 1462.
[4] Boozer A. and G.K. Kuo-Petraivic, Phys. Fluids. 24, 851 (1981).

2C03

Simulation of ECE from MAST

J. Preinhaelter[1], V. Shevchenko[2], M. Valovic[2], P. Pavlo[1], L. Vahala[3], G. Vahala[4], and the MAST team[2]

1) EURATOM/IPP.CR Association, Institute of Plasma Physics, 182 21 Prague, Czech Republic
2) EURATOM/UKAEA Fusion Association, Culham Science Centre, Abingdon, OX14 3DB, UK
3) Old Dominion University, Norfolk, VA 23529, USA
4) College of William & Mary, Williamsburg, VA 23185, USA

Abstract

The characteristic low magnetic field and high plasma density of a spherical tokamak do not permit the typical radiation of O and X modes from the first five electron cyclotron harmonics. Thus only electron Bernstein modes, (modes not subject to a density limit) which mode convert into electromagnetic waves in the upper hybrid resonance region, can be responsible for any observed ECE radiation.

To interpret the experimental results we develop a realistic 3D model of the MAST plasma. The instantaneous magnetic field and its spatial derivatives are reconstructed from a 2D splining of two potentials determined by an EFIT equilibrium reconstruction code, assuming toroidal symmetry. The plasma density and temperature profiles in the whole RZ cross-section of the plasma are obtained from mapping the high spatial resolution Thomson scattering measurements on magnetic surfaces and then interpolating between the low and high field side values.

About 50 rays represent an antenna, receiving an oblique - with respect to the magnetic field at the plasma surface - Gaussian beam. For each ray, we determine the corresponding spot on the separatrix as well as the EBW-X-O conversion efficiency in the transport barrier. The intensity of the inciden electron Bernstein wave from the plasma interior is determined from studying the absorption of the reciprocal EBW ray (incident from the UHR as it propagates into the plasma interior) in the vicinity of electron cyclotron harmonics. Non-local absorption characteristics ($N_{||}$ profoundly oscillates for rays launched near the equatorial plane) calls for the introduction of an effective temperature determined by the integration of the equation for radiative transfer [1] above the ray. The resulting intensity of EBW is than determined from the Rayleigh-Jeans black body radiation law using the effective radiative temperature, which takes into account reabsorption. In this way we can simulate relative amplitudes and field polarization detected by the ECE antenna.

The results of our simulations will be compared with recent ECE measurement in MAST. Moreover, this representation of the antenna can be used to determine optimal launching directions for the proposed 1 MW, 60 GHz source in MAST

[1] Bornatici et al., Nucl. Fusion 23 (1983), 1153

2C04

Influence of geometry on drift waves in tokamaks and stellarators

T Rafiq, M H Nasim, and M Persson

Department of Electromagnetics and Euratom/VR Association,
Chalmers University of Technology, S–41296 G□eborg, Sweden

Abstract

Linear stability of electron drift waves is investigated in the H1–NF and W7–X stellarators and the results are compared and contrasted with those of a JET like tokamak equilbria. Generally, the high frequency modes are found to be strongly localized and most unstable while the low frequency modes are found weakly localized and less unstable. In the stellarators, the most unstable modes are found where the stabilizing effect of local magnetic shear is minimum or where the coupling between the local magnetic shear and geodesic curvature is strong. However, this coupling is found to be weaker in W7–X and even more weak in tokamaks than in the H1–NF stellarator. In tokamak geometries, the existence of the high frequency modes and their frequencies and growth rates are found strongly dependent on the local shear of the magnetic field. The modes exist with their frequencies and growth rates inversely proportional to the magnitude of the shear, while, field line curvature has found less effective on these drift modes. The results of the JET–like equilibrium are also compared and contrasted with the results of a circular equilibrium with the same aspect ratio. However, in tokamaks with shaped cross section modes are found to be more localized than the modes in the circular equilibrium. Like in the stellarators, this is found to be due to the variation in the strength of the local magnetic shear, which localizes the modes along the field lines and constraints them.

2C05

Dynamic Evolution of the heat fluxes in a collisionless magnetized plasma. *

J.J. Ramos

Plasma Science and Fusion Center, MIT

The magnetofluid theory for collisionless magnetized plasmas is carried out one level beyond Chew-Goldberger-Low (CGL) analysis [1] in the hierarchy of fluid moment equations. The CGL parallel and perpendicular pressure evolution equations involve two heat flux variables that represent the parallel flow of parallel and perpendicular thermal energies respectively. Neglecting them yields the double-adiabatic closure. In the present work, the evolution equations for these two parallel heat fluxes are consistently derived and shown to reduce to a very compact form. This derivation, based on the fast gyromotion ordering, is not trivial because the contribution of the pressure tensor must be evaluated including the first gyroviscous terms, not just the zeroth order CGL terms. The heat flux evolution equations involve three higher moment variables, related to the energy-weighted and parallel-energy-weighted stress tensors. A heuristic relationship linking these to the parallel and perpendicular pressures and the density, thus providing a fluid closure, is provided.

* Work sponsored by the U. S. Department of Energy.

[1] G.L. Chew, M. L. Goldberger and F.E. Low, Proc. R. Soc. London, Sec. A, 236, 112 (1956).

2C06

Driven Poloidal Spin-Up with Rotating Magnetic Field

H. L. Rappaport

Austin, TX 78727

A driven plasma poloidal spin-up scheme is proposed. A combination of toroidal curvature and weak non-linearity induce axisymmetric poloidal rotation when a tokamak plasma is driven by a rotating poloidal magnetic field. The analysis presented here first shows that a circular cross-section plasma undergoing a stable axisymmetric vertical oscillation "twists" poloidally when first order in inverse aspect ratio curvature terms are retained in the mode's description. A simple argument shows that at nonlinear mode amplitudes a plasma shell with a poloidally rotating center of mass acquires a toroidal component of angular momentum about the center of mass.

2C07

Linear Gyrokinetic Calculations of Microturbulence in H-mode on NSTX

M. Redi[1], R. Bell[1], C. Bourdelle[3], W. Dorland[2], D. Gates[1], K. Hill[1], S. Kaye[1], B. LeBlanc[1], J. Menard[1], D. Mikkelsen[1], G. Rewoldt[1]

[1]PPPL, Princeton Univ., Princeton, NJ
[2]University of Maryland, College Park, MD
[3]Association Euratom-CEA, France

Gyrokinetic simulations of plasma turbulence with the massively parallel code GS2 [1,2] are being carried out to examine a low aspect ratio, H-mode experiment which exhibits unusual transport behavior, within flux tube geometry. NSTX is a low aspect ratio, high beta experiment to study transport and turbulence with additional diagnostic capability for fluctuations and q profile expected in future years. The q profiles for these simulations appear to be reversed in the plasma center. These initial simulations of NSTX are focussed on an H-mode experiment with resilient electron temperature profiles, in the presence of increasing density and decreasing ion temperature, to examine the role of critical temperature gradients and the existence of marginal stability.

Simulations have been carried out for three radii, at two times during the pulse. Linearly converged eigenmodes are found with eigenfunctions from $k_\perp \rho_i = 0.1$ to 80, extending from the ITG-TEM to the ETG range of frequencies. Initial simulations show that during the evolution of the discharge the dominant instabilities outside the core-region are ETG modes. ITG modes are either stabilized by plasma conditions of magnetic geometry and profiles, or by the large ExB shearing rates computed from plasma rotation. In the plasma core, in agreement with the observed remarkably good plasma confinement, both ETG and ITG modes are stable. Microtearing modes are found near the half-radius, but would be likely stabilized by ExB shearing. Resilient electron temperature profiles then may be connected with ETG modes as the plasma is far above marginal stability for these modes outside the half-radius. The experiment is characterized by acceptably low values of ρ^*, from 0.031 at r/a=0.25 to 0.0064 at r/a=0.80. While the criterion of $\rho^* \ll 1$ required for GS2 calculations holds, there are additional effects such as ρ^* stabilization by which profile effects mix different wavelengths, as will be examined with GYRO[3,4].

[1] M. Kotschenreuther, G. Rewoldt, W. M. Tang, Comp. Phys. Comm. **88** (1995) 128-140.
[2] W. Dorland et al., 1994 IAEA Proceedings (Seville) **3**, 463 (1994).
[3] J. Candy, R. Waltz, "An Eulerian Gyrokinetic-Maxwell Solver", J. Comp. Phys. in press.
[4] R. E. Waltz, J. M. Candy, M. N. Rosenbluth, Phys. Plas **9** (2002) 1938.

Supported by USDoE contract No. DE-AC02-76CH03073

2C08

Computational Studies of Magnetohydrodynamic Phenomena in the Reversed Field Pinch During PPCD*

Jim Reynolds and Carl Sovinec

Center for Plasma Theory and Computation, University of Wisconsin
1500 Engineering Drive, Madison WI 53706

Abstract

Magnetohydrodynamic phenomena present during application of Pulsed Poloidal Current Drive (PPCD) in the reversed-field pinch (RFP) configuration are investigated numerically with the 3D nonlinear simulation code NIMROD [1]. Preliminary simulations have demonstrated the global experimental observations of magnetic fluctuation reduction [2], increased instantaneous energy confinement time [2], and reduced magnetic stochasticity [3]. Recent simulation efforts focus on improving our understanding of the current profile evolution and the suppression of core-resonant tearing modes through numerical diagnostics and analysis.

Experimentally, probe measurements [4] near the plasma edge of the Madison Symmetric Torus (MST) [5] and equilibrium fits using data from Faraday rotation polarimetry [6] show migration of parallel current toward the core during the PPCD pulse. Through simulation and numerical diagnostics, we are able to track individual terms in Ohm's law, poloidal and toroidal flux evolution, and other effects related to the current profile evolution at various times during the electric field pulse. In addition, the role of the MHD fluctuations during the profile evolution is studied by varying the number of toroidal harmonics in different simulations. The results expose the relative roles played by the MHD pinching effect, reduced magnetic fluctuations, and resistive current diffusion in the parallel current profile temporal evolution. To demonstrate the sensitivity with respect to the initial state, we consider a parameter study with varied states of toroidal field reversal. Finally, a comparison of RFP simulations with PPCD in cylindrical and toroidal configurations examines geometric effects.

1. A.H. Glasser, et al, Plasma Phys. Control. Fusion **41**, A747 (1999).
2. J.A. Sarff, et al, Phys. Rev. Lett. **72**, 3670 (1994).
3. O'Connell, et al, "Observation of Velocity-Independent Electron Transport in The Reversed Field Pinch," submitted to Phys. Rev. Lett.
4. B.E. Chapman, et al, Phys. Plasmas 7, 3491 (2000).
5. R.N. Dexter, et al, Fusion Technol. **19**, 131 (1991).
6. D.L. Brower, et al, Phys. Rev. Lett. **88**, 185005-1 (2002).

---

*Work supported by the U.S. Dept. of Energy.

2C09

Collisionless reconnection in presence of a guide field

P. Ricci [1,2], G. Lapenta [1,3], and J.U. Brackbill [3]

[1] Istituto Nazionale per la Fisica della Materia, Dipartimento di Fisica,
Corso Duca degli Abruzzi 24, 10129 Torino, Italy
[2] Dipartimento di Energetica, Politecnico di Torino,
Corso Duca degli Abruzzi 24, 10129 Torino, Italy
[3] Theoretical Division, Los Alamos National Laboratory, 87545 Los Alamos NM, USA

Abstract

The aim of the Geospace Environment Modeling (GEM) magnetic reconnection challenge [1] was to understand the physics of fast magnetic reconnection in high β plasmas. The procedure adopted in the challenge was to investigate a standard 2-dimensional configuration based on a Harris current sheet. The GEM challenge project revealed that the primary mechanism which enables the break of the frozen-in conditions is given by the non-gyrotropic electron pressure terms. The reconnection rate is then enhanced thanks to the Hall term which gives rise to the whistler dynamics.
In the present work, we extend the simulation results by adding a guide field in order to study reconnection in low β plasmas.
The implicit Particle-in-Cell code CELESTE3D is used for this purpose. The implicit moment method is used to handle effectively multiple time and length scales processes: the relevant time and length scales are resolved while effectively averaging over faster time scales (e.g., electron plasma frequency) and shorter length scales (e.g., Debye length). The practical consequence is the ability to handle realistic mass ratios and to simulate macroscopic systems while retaining a kinetic description of both ions and electrons. In a previous work, we have applied CELESTE3D to investigate reconnection in high β plasmas, showing the ability to consider the physical mass ratio of 1836 [2].
Using simulations, we study how the reconnection rate scales with the guide field and the mass ratio. In general, the mass ratio has little importance on the reconnection rate, while the guide field diminishes it and decreases the reconnection saturation level. The ion and electron motion is strongly influenced by the presence of the guide field, which makes possible for ions and electrons to drift along directions otherwise not possible. In presence of a guide field, the whistler dynamics is suppressed, and thus the Hall effect and the quadrupolar structure of the guide field related to it vanish. The whistler dynamics is replaced by the Kinetic Alfvén Dynamics and the ion sound radius takes the place of the ion inertial length as the length scale of interest.

[1] J. Birn et al., J. Geophys. Res. 106, 3715 (2001).
[2] P.Ricci, G. Lapenta, J.U. Brackbill, Geophys. Res. Lett., 29, 10.1029/2002GL015314 (2002).

2C10

Coupled Turbulence and Transport Evolution for Magnetized Edge Plasmas*

T.D. Rognlien, X.Q. Xu, M.V. Umansky, R.H. Cohen, and W.M. Nevins

University of California Lawrence Livermore National Laboratory
P.O. Box 808, Livermore, CA 94551 USA

Abstract

Turbulence and transport simulations for the edge-plasma region in magnetic fusion devices are generally performed by independent codes; the 3D turbulence codes (e g , Ref. [1]) typically use fixed plasma pressure profiles to evolve the fluctuations to a steady state, while 2D transport codes (e g , Ref. [2]) use fixed diffusion or convection coefficients to evolve the plasma profiles and flows. In real devices, these two processes can be tightly coupled. In order to have a predictive model of the key element of edge transport barrier and pedestal formation in tokamaks, the turbulence and transport (profile evolution) must be made self-consistent. Progress on coupling the fluid turbulence code BOUT [1] and the transport code UEDGE [2] is reported, where both codes simulate the full x-point geometry of diverted tokamaks from the top of the pedestal to the far scrape-off layer. Neutrals and impurities that can have a strong influence on the profiles are included in the transport code. A central issue is the stability of the coupling, where turbulence-induced fluxes are passed to the transport code, which returns the updated profiles. Stable algorithms have been demonstrated for a simpler fluid plasma system using a time-relaxed average of the fluxes and profiles over many coupling steps [3], where the turbulence and transport codes are evolved on their own characteristic times. This approach is extended to the 3D BOUT, 2D UEDGE coupling. The impact on the convergence properties of the implicit UEDGE and the degree of relaxation required appear quite acceptable using a model turbulent flux that depends on profile gradients and has substantial levels of random noise. The behavior of BOUT with the full poloidal profiles from UEDGE, including strong gradients in the divertor region, is analyzed. The status of the direct BOUT/UEDGE coupling is presented, and the role of kinetic corrections is discussed.

---

*Work performed under auspices of US DOE by University of California Lawrence Livermore National Laboratory under contract No. W-7405-ENG-48.

[1] X.Q. Xu, R.H. Cohen, T.D. Rognlien, and J.R. Myra, Phys. Plasmas 7 (2000) 1951.

[2] T.D. Rognlien, D.D. Ryutov, N. Mattor and G.D. Porter, Phys. Plasmas 6 (1999) 1851.

[3] A.I. Shestakov, R.H. Cohen, J.A. Crotinger, L.L. LoDestro, A. Tarditi, and X.Q. Xu, J. Comp. Phys. 185 (2003) 399.

2C11

Relevance of the ITG Localized Modes to the Accretion Theory of Angular Momentum "Generation"*

V. Roytershteyn and B. Coppi

Massachusetts Institute of Technology, Cambridge, MA 02139, USA

The accretion theory [1] of the spontaneous rotation phenomenon discovered in magnetically confined axisymmetric plasmas has been quite successful in accounting for the most recent experimental observations. We note that experiments [2, 3] on the evolution of the radial velocity profile have confirmed some of the key predictions of the theory, particularly that the source of the rotation is at the edge of the plasma column and that the rotation propagates toward the center of the plasma column at a faster rate than predicted from the collisional transport theory. This is consistent with the assumption made within the accretion theory that Ion Temperature Gradient (ITG) driven modes, whose growth rates are enhanced by the radial gradient of the toroidal velocity in the outer region of the plasma column, are responsible for the inward momentum transport.

The relevance to the accretion theory of the ITG modes localized by the shear of the magnetic field is discussed. The role of the spectrum of the excited modes is addressed. It is demonstrated that this type of instabilities can successfully account for the inward transport of the angular momentum and outward transport of the thermal energy.

Some results of the ongoing work on a more detailed comparison of the theory with experiments are presented. Particularly, we use a model 1-D transport equation to simulate the evolution of the velocity profile during the transition as well as in the quasi-stationary phase of the discharge and estimate the magnitudes of the relevant diffusion coefficient and angular momentum inflow. These results are compared with the quasi-linear estimates of the transport coefficients evaluated for the relevant ITG modes.

*Sponsored by the U.S. Department of Energy

[1] B. Coppi, *Nucl. Fus.*, **41**, 12, 1 (2002)
[2] J.E. Rice et al., in Proceedings of the 2002 International Conference on Fusion Energy, Paper EX/C3-7Ra (Publ. I.A.E.A., Vienna, 2002)
[3] E.S. Marmar et al., in Proceedings of the 2002 International Conference on Fusion Energy, Paper OV/4-1 (Publ. I.A.E.A., Vienna, 2002)

2C12

Stability analysis for a finite aspect ratio screw pinch

D.D. Ryutov, R.H. Cohen, L.D. Pearlstein

Lawrence Livermore National Laboratory, Livermore, CA 94551

Abstract

We consider the ideal MHD stability of a cylindrical screw pinch of a finite length, limited by two parallel perfectly conducting plates in the axial direction, without making any assumptions regarding the ratio of the length L to the pinch radius a and the radius of the cylindrical outer shell b. Despite the simple geometry, the problem is much more complex than that for a long pinch, where one can easily separate the axial and the radial variables. Our interest in this problem is driven by its potential relevance to the performance of the Livermore spheromak SSPX [1], where instabilities of the central plasma column are thought to affect plasma confinement in some regimes. Based on the standard energy principle, we derive several alternative expressions for the energy perturbation and reduce them to the form suitable for the iterative analysis. In the particular case of a skin current, we obtain a one-dimensional eigen-equation for the radial displacement of the plasma boundary and recover Kruskal-Shafranov criterion in the appropriate limit. In the general case, the pinch becomes more stable. Bearing in mind possible modifications of the shape of the SSPX vacuum vessel, we consider also a more complex geometry, with a plasma column sitting on the top of a cylindrical pedestal (so that the length of the pinch is less than L), and the geometry of a hard-core pinch.

1. Hooper E.B. Pearlstein L.D. Bulmer R.H. Nucl. Fusion. **39**, 863, 1999

2C13

Rationale for the Columbus Experiment*

M. Salvetti and B. Coppi
Massachusetts Institute of Technology, Cambridge, MA 02139

In principle, it is possible to scale up the geometrical parameters of Ignitor, which is the only experiment proposed and designed to reach ignition, but within a narrow range if the ability to maintain this goal is preserved with reasonable margins against the onset of macroscopic instabilities in plasmas with the high central pressures that are needed. Another important asset to be preserved is the strength of ohmic heating to the extent that the produced plasmas can attain ignition even in the case of failure of the auxiliary heating system, that is, by ohmic heating alone. We note that the only system demonstrated to be capable of heating high density plasmas is Ion Cyclotron Resonance Heating and that the reliability of this kind of system has been problematic. The Columbus experiment [1] is proposed as a parallel US project to the Ignitor program [2, 3] that is being carried out in Italy and is geometrically self similar to Ignitor the (linear) dimensions being increased by the factor 25/22.

The most important parameter to preserve is the value of the mean poloidal field defined as $\bar{B}_p \equiv I_p/(5\sqrt{ab})$, where I_p is the toroidal plasma current, in megampere, and a and b are the minor radii of the plasma cross section. We take $\bar{B}_p$ 3.4T as the target value that is close to that chosen for Ignitor. A list of the main design parameters is given in the following Table.

Parameter	Columbus	Ignitor
Major radius R_0	1.50 m	1.32 m
Minor radii a b	0.535 m 0.98 m	0.47 m 0.86 m
Aspect ratio A	2.8	2.8
Elongation κ	1.83	1.83
Triangularity δ	0.4	0.4
Vacuum Toroidal Field B_T at $R = R_0$	$\lesssim$ 12.6 T	$\lesssim$ 13T
Toroidal Current I_p	$\lesssim$ 12.2 MA	$\lesssim$ 11 MA
Poloidal Current I_θ	$\lesssim$ 10 MA	$\lesssim$ 9 MA
Paramagnetic Field Produced by I_θ	1.4 T	1.4 T
Mean Poloidal Field $\bar{B}_p$ $I_p/(5\sqrt{ab})$	3.4 T	3.4 T
Confinement Strength S $\bar{B}_p I_p$	$\lesssim$ 41.5 MN/m	$\lesssim$ 38 MN/m
Toroidal Current Density $<J_\Phi>$ $I_p/(\pi ab)$	$\lesssim$ 7.4 MA/m^2	$\lesssim$ 9.3 MA/m^2
Maximum Poloidal Field B_{pM} $(R< R_0)$	$\lesssim$ 6.5 T	$\lesssim$ 6.5 T
Edge Magnetic Safety Factor q_ψ	3.6 @ I_p 12.2 MA	3.6 @ I_p 11 MA
Magnetic Flux Swing	$\lesssim$ 37.5 Vs	$\lesssim$ 33 Vs
Plasma Volume V_0	14.5 m^3	10 m^3
Plasma Surface S_0	44 m^2	34 m^2

The plasma current I_p 12.2MA is close to that which the ITER-Feat concept would have for the same value of the safety factor $q_{95}(\psi)$ 3.6 in spite of the large difference in the total magnetic energy associated with the two machines. The current densities in the toroidal magnet and the plasma for Columbus are about 85% lower than those for Ignitor. Therefore the machine characteristic times related to the ohmic heating of the magnet are longer by a factor of about 1.4, relative to Ignitor. As in the case of Ingitor and ITER-Feat, designed not to reach ignition but $Q = 10$ with a lower safety factor $q_{95}(\psi)$ 3, the plasma current redistribution time and the duration of the plasma burning state are comparable.

*Sponsored in part by the U.S. Department of Energy

[1] B. Coppi and M. Salvetti, Massachusetts Institute of Technology, R.L.E., Report PTP-02/06 (December 2002)

[2] B. Coppi et al., Massachusetts Institute of Technology, R.L.E., Report PTP-02/05 (December 2002)

[3] B. Coppi, A. Airoldi, F. Bombarda, et al., *Nucl. Fusion* **41**, 1253 (2001)

2C14

Simulations of Pellet Injection in Tokamaks using AMR

R. Samtaney[1], S. Jardin[1], P. Colella[2], D. Martin[2]

[1] Princeton Plasma Physics Laboratory
Princeton University, Princeton, NJ 08543
[2]Lawrence Berkeley National Laboratory
Berkeley, CA 94720

Abstract

Injecting small pellets of frozen hydrogen is a proven method of fueling tokamaks. Experimentally it is known that the density distribution, after the pellet ablates upon encountering the high temperatures in a tokamak, is not consistent with the distribution inferred from assuming that the ablated material remains on flux surfaces where ablation occurred. The subsequent redistribution of mass is due to MHD processes. In this poster, we will report on the progress made toward simulating the pellet injection process using an Adaptive Mesh Refinement (AMR) technique. AMR is essential to provide the resolution required to simulate realistic pellet sizes relative to device dimensions (typical ratios are $O(10^{-3})$). The mathematical model is the single-fluid resistive MHD equations with source terms in the continuity equation along with a pellet ablation rate model given by Parks[1]. Further, we use a source term in the momentum equations to mimic toroidal effects in a Cartesian geometry. The numerical method used is a explicit 8-wave upwinding formulation [2], coupled with a projection method to enforce the solenoidal property of the magnetic field. The Chombo[3] framework is used for AMR. Preliminary results show that AMR is essential for well-resolved simulations of pellet injection.

This work was supported by USDOE Contract no. DE-AC020-76-CH03073. This research used resources of the National Energy Research Scientific Computing Center, which is supported by the Office of Science of the U.S. Department of Energy under Contract No. DE-AC03-76SF00098.

[1] P. B. Parks and R. J. Turnbull, Phys. Fluids, vol. 21, pp:1735, 1978.
[2] Powell et al. Journal of computational physics, vol. 154, pp:284-309, 1999
[3] http://seesar.lbl.gov/ANAG/chombo

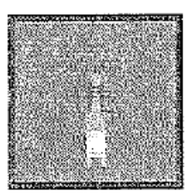


Figure 1: Density image of a pellet propagating in a uniform magnetic field. Note the increased density trailing behind the pellet. The black boxes are the AMR mesh boundaries.

2C15

OPTIMAL CONTROL OF TOKAMAK RESISTIVE WALL MODES IN PRESENCE OF NOISE

A. K. Sen, M. Nagashima, and R. W. Longman
Columbia University

Abstract

A scheme of optimal control based on ìstateî feedback for th e resistive wall modes in tokamaks is described. The important effects of ever present MHD noises which have been neglected in the past, are included in the stochastic formulation of the basic equations. The optimality of the system is obtained both in terms of minimization of the stabilized fluctuation levels of the modes and the control energy. It is found that the stabilized fluctuation level and control signal level are of the order of the noise level of the system in the steady state.

2C16

Role of Bumpy Fields on Single Particle Orbit of near Quasi-Helically Symmetric Stellarators*

J. Seol and C. C. Hegna
Department of Engineering Physics University of Wisconsin
Madison, WI 53706-1609

We investigate the role of symmetry breaking effect on single particle orbit in near helically symmetric stellarators. In particular, the effect of a mirror term is included in the analysis of trapped particle orbits. By means of the longitudinal adiabatic invariant along the banana orbit, solutions of the banana drift equation can be evaluated. From these solutions, we find that all trapped particle orbits are determined by circular traces where B_{min} is constant in the plasma cross section. These particle orbits reside on these surfaces regardless of pitch angle and are determined by initial position and the B_{min} contour. Trapped particles are confined as long as the particles' circular trace does not intersect the plasma-vacuum boundary. We also will investigate transition properties between the trapped particle banana drift orbits. These transitions occur when the magnetic well along the trace is sufficiently shallow. Progress towards a quantitative estimate of these transitions will be described.

*Research Supported by U.S. DoE under grant no.DE-F02-99ER54546

2C17

Comparing Envelope and Full-Fluid Models of Intense Laser-Plasma Interactions

B. A. Shadwick,[1,2] C. B. Schroeder,[1] G. M. Tarkenton,[2] and E. H. Esarey[1]

[1]Center for Beam Physics, Lawrence Berkeley National Lab, Berkeley, CA 94720, USA
[2]Institute for Advanced Physics, 10875 US Hwy. 285, Suite 199 Conifer, C0 80433, USA

Abstract

Full-fluid models (wherein the only approximation is the assumption of hydrodynamics) can be computationally intensive in the parameter regimes relevant to advanced accelerator concepts, thus there is interest in evaluating the physics content of less intensive models. Recently we have begun exploration of a variety of envelope models to compliment our full-fluid models. We present detailed comparisons of the predictions of these models for the case of long propagation of a resonant laser pulse in a channel. This configuration is important as it is the primary candidate for a multi-GeV accelerator stage and is the subject of active experimental investigation by a number of groups. Accurate handling of the laser propagation over long distances (order of a thousand plasma oscillations) is essential to assessing the performance of a putative accelerator module. We examine the differences in physics content of these models in regard to laser energy transport and generation of plasma waves as well as various numerical considerations such as resolution, convergence, dissipation, dispersion and computational resource requirements. We also examine the role of the wave action adiabatic invariant and the consequences of the numerical handling of this invariant in the different models.

2C18

Island Rotation with Island-Induced Viscosity in Tokamaks

K. C. Shaing
Engineering Physics Department
University of Wisconsin
Madison, WI 53706

Abstract

Island rotation is an important part of the island dynamics in tokamaks. In an island rotation theory, momentum equation is used to determine the current density perpendicular to the magnetic surface. The Braginskii viscosity is employed in the momentum equation for such a purpose in most of the recent theories. The radial electric field profile is also determined using Braginskii viscosity. Here, we develop a theory for the island rotation using island-induced viscosity. In the vicinity of a magnetic island in tokamaks, the toroidal symmetry is broken due to the variation of the toroidal magnetic field strength over the distorted island magnetic surface. This symmetry breaking effect leads to a non-vanishing toroidal component of the viscosity. The radial electric field profile function can be determined from the island magnetic surface averaged toroidal component of the momentum equation. The time dependent terms in this equation describe the rate of change of the plasma momentum and the electromagnetic field momentum of the rotating island. At the steady state, it describes the ambipolarity across the island magnetic surface. Once the electric field profile function is determined, the perpendicular current density is calculated from the un-averaged version of the toroidal momentum equation. Island rotation frequency is then calculated from the *sine* component of the Ampere's law. To complete the description of the island dynamics with island-induced viscosity, we also calculate island width from the *cosine* component of the Ampere's law.

This work was supported by US Department of Energy under grant No. DE-FG02-01ER54619 with the University of Wisconsin.

2C19

Effect of Hot Ions with Large Orbits on MHD Spectrum in Tokamaks

S.E.Sharapov[1] and A.B.Mikhailovskii[2]

[1]*Euratom/UKAEA Fusion Association, Culham Science Centre, Abingdon, Oxfordshire, UK*

[2]*Institute for Nuclear Fusion, RRC Kurchatov Institute, Moscow, Russia*

Abstract

Hot ions with orbit widths much larger than the scale length of MHD perturbations can non-perturbatively affect the Alfvén spectrum and induce an Alfvén Cascade eigenmode in tokamak plasma with a reversed magnetic shear [1]. Though the hot ions do not experience, on average, the E **B** drift due to the MHD perturbation, the plasma electrons compensating the charge of the hot ions do interact with the MHD perturbation and this interaction depends on parameters of the hot ions. An MHD-type model is developed for effect of hot ions with very large orbits, and this model is incorporated in the MISHKA code as an extension of the ideal MHD model with ion drift effects [2]. The effect of hot ions on both stable (waves) and on unstable (instabilities) parts of the MHD spectrum is assessed for two examples; the Alfvén Cascades in a shear-reversal equilibrium, and for $n = 1$ ideal MHD kink mode.

This work was partly supported by the UK Department of Trade and Industry and Euratom

[1] H.L.Berk et al., Phys. Rev. Lett. **87** (2001) 185002

[2] G.T.A.Huysmans et al., Physics of Plasmas **8** (2001) 4292

2C21

Distributed Technologies for Nuclear Fusion Data

S. G. Shasharina[1], R. Eger[1], J. R. Cary[1], T. W. Fredian[2], D. Alexander[1]

[1]Tech-X Corporation, 5541 Central Ave, Suite 135, Boulder, CO 80301, USA
[2]MIT Plasma Science and Fusion Center, 167 Albany Street · Cambridge, MA 02139 USA

Abstract

Simulations in the nuclear fusion community are generating large data sets at remote sites. Visualization and analysis of these data sets is then difficult, as downloading it to local computers can take hours over even the fastest network connections. Problems such as these are what Grid technologies,[1] in particular the Globus Toolkit, are addressing. Until now nuclear fusion has been using non-Grid and domain-specific solutions for distributed data storage, acquisition and analysis. In the described work, we will compare performance, flexibility and ease of use of Globus and MDSplus,[2] as data transfer mechanisms, and HDF5[3] and MDSplus, as data formats. As a first step, we have done performance tests of data transfer in two models: one using the Globus Toolkit (GridFTP transfer of HDF5 files), another using MDSplus (mdsip transfer of equivalent MDSplus SIGNALS). To make these tests possible, an HDF5-to-MDSplus importer was developed. The preliminary tests on a 100Base-T Local Area Network show that one-stream GridFTP is 2-2.5 times faster than MDSplus, when large data sets are being transferred. When the size of the data is relatively small (<4.5 MB) MDSplus is more efficient. Tests with partial extraction and transferring of data indicated that MDSplus is more efficient in data extraction than the other scenario, which had a significant overhead associated with the Globus Resource Allocation Manager (GRAM), which we used for HDF5 dataset extraction. Similar to our LAN results, preliminary Wide Area Network transfer tests show that the GridFTP becomes more efficient for larger files (>45MB). We will present the tests results and discuss our recommendations for implementation of fusion data grids, which will hopefully combine the benefits of all the technologies: MDSplus, Grids and HDF5.

The work was supported by a DOE/SBIR grant DE-FG03-02ER83555.

1 I. Foster, C. Kesselman, S. Tuecke, *The Anatomy of the Grid: Enabling Scalable Virtual Organizations*, International J. Supercomputer Applications, 15(3), 2001.

2 T. Fredian and J. Stillerman, *MDSplus Remote Collaboration Support* – Internet and the World Wide Web, Fusion Engineering and Design 43, (1999).

3 http://hdf.ncsa.uiuc.edu/HDF5/.

2C22

Periodic orbits in muonic hydrogen atoms exposed to both circularly-polarized laser light and a uniform magnetic field

C. Smith and S. Johnston

The Oklahoma School of Science and Mathematics
Oklahoma City, OK 73104

Abstract

The underlying motivation for this work has been a search for a viable stripping mechanism to ameliorate the critical sticking problem in muon-catalyzed fusion schemes, i.e., the problem of muon capture by the fusion alpha particle. The present paper considers a classical muonic hydrogen atom and the motion of the muon in the combined fields of the atomic nucleus, a strong circularly-polarized laser, and a coaxial magnetic field. Quantum mechanical treatments of atomic hydrogen in strong circularly-polarized laser fields [1] provide clear evidence that the resulting quantum waveforms are due to localization of the electron onto nonlinear *classical* structures. Accordingly, our model is classical.

Two exact circular orbits, phase-locked to the laser polarization, exist in this combination of fields. Underlying these orbits is a rotating potential energy function, analogous to the rotating saddle-shaped potential responsible for the stability of ion motion in a Paul trap [2]. The uniform magnetic field introduces a new dimension in parameter space and interesting resonance effects. An analysis of the stability properties of the orbits will be presented. The optimum conditions for muon *instability* and escape will also be discussed.

[1] H. Klar, Z. Phys. D **11**, 45 (1989); I. Bialynicki-Birula, M. Kalinski, and J.H. Eberly, Phys. Rev. Lett. **73**, 1777 (1994); W. Chism, D.-I. Choi, and L.E. Reichl, Phys. Rev. **A61**, 054702 (2000).

[2] W. Paul, Rev. Mod. Phys. **62**, 3 (1990).

Presented at the 2003 International Sherwood Fusion Theory Conference, Corpus Christi, Texas, April 28-30, 2003.

2C23

Developments in the peeling-ballooning model of ELMs and pedestal constraints*

P.B. Snyder,[1] H.R. Wilson,[2] and X.Q. Xu[3]

[1]General Atomics, P.O. Box 85608, San Diego, California 92186-5608.

[2]EURATOM/UKAEA Fusion Association, Abingdon, Oxon OX14 3DB, United Kingdom.

[3] Lawrence Livermore National Laboratory, Livermore, California 94550.

Maximizing the pedestal height while maintaining acceptable edge localized modes (ELMs) is a key issue for optimizing tokamak performance. We present a model for ELMs and pedestal constraints based upon theoretical analysis of edge MHD instabilities which can limit the pedestal height and drive ELMs. Sharp pedestal pressure gradients drive large bootstrap currents which play a complex dual role in the stability physics, on the one hand driving peeling modes, while on the other hand opening second stability access to high n ballooning modes. Low n modes are stabilized by line bending and coupling to the conducting wall, while high n modes are stabilized by second stability access and FLR effects; consequently the dominant modes are often intermediate-n coupled "peeling-ballooning" modes, driven both by current and the pressure gradient. A highly efficient MHD code, ELITE,[1,2] is used to study these modes, and calculate quantitative stability constraints on the pedestal, including direct constraints on the pedestal height. A model of various ELM types is presented, and quantitatively compared to data from multiple tokamaks. A number of observations agree with predictions, including ELM onset times, ELM depth, localization to the outer midplane, and variation in pedestal height with discharge shape and density.[2,3]

Recent progress will be presented in three areas: 1) systematic characterization of peeling-ballooning constraints on the pedestal and comparison with observed trends, 2) inclusion of compression and toroidal rotation shear effects, 3) nonlinear simulations of peeling-ballooning modes with the electromagnetic reduced-Braginskii BOUT code.[4]

[1]H.R. Wilson *et al.*, Phys Plasmas **9**, 1277 (2002).
[2]P.B. Snyder *et al.*, Phys Plasmas **9**, 2037 (2002).
[3]P.B. Snyder *et al.*, IAEA 2002, submitted to Nucl Fusion.
[4]X.Q. Xu *et al.*, New Journal of Physics **4**, 53 (2002).

*Supported by U.S. Department of Energy Contract Nos. DE-FG03-95ER54309 and W-7405-ENG-48.

2C24

Use of Nonsymmetric Algebraic Operators in a Semi-Implicit MHD Advance*

C. R. Sovinec and H. Tian

Department of Engineering Physics, University of Wisconsin-Madison
Madison, WI 53706

Abstract

Semi-implicit numerical methods for hyperbolic PDEs are typically formulated with implicit coupling that is represented by symmetric- or Hermitian-positive-definite matrices in the time-advance equations. Having positive and wavenumber-dependent eigenvalues, the operators provide numerical stability for oscillatory behavior at arbitrarily large time-step by introducing unphysical dispersion.[1] This is useful for solving stiff systems, like resistive MHD in application to macroscopic behavior in fusion devices, where magnetic tearing behavior is orders of magnitude slower than the propagation of compressional waves. Here, the numerical dispersion allows computations with time-steps that are large in comparison to wave propagation times, and the accuracy of the computed slow behavior depends on how well the semi-implicit operator represents the modes of the MHD system.[1,2]

Effects that are not described by symmetric operators fall outside the strength of traditional semi-implicit methods. Advection due to fluid flow is the most important example for single-fluid MHD (see Ref. 3), but the Hall term in an extended-MHD description is also more easily described through nonsymmetric operators in a numerical algorithm. In addition, formulating the MHD advance in terms of a single nonsymmetric system for flow velocity, magnetic field, and pressure may provide better accuracy with finite element spatial representation than the traditional symmetric system for flow alone, because a 'mixed' discretization can separate shear and compressional behavior to a greater extent.[4]

Here, the use of nonsymmetric operators for semi-implicit MHD algorithms is explored through numerical analysis and implementation in the NIMROD code[5] (http://nimrodteam.org). A recently updated coupling to the AZTEC parallel linear system library (www.cs.sandia.gov/CRF/aztec1.html) has made it possible to use nonsymmetric systems in NIMROD, and their application is tested for advection, the Hall term, and the MHD advance. We also report on the performance of symmetric system solution methods in the AZTEC library, when applied to NIMROD computations, and compare with the native solver performance.

[1]D. D. Schnack, D. C. Barnes, Z. Mikić, et al., J. Comput. Phys. **70**, 330 (1987).
[2]K. Lerbinger and J. F. Luciani, J. Comput. Phys. **97**, 444 (1991).
[3]R. Lionello, Z. Mikić, and J. A. Linker, J. Comput. Phys. **152**, 346 (1999).
[4]R. Gruber and J. Rappaz, *Finite Element Methods in Linear Ideal Magnetohydrodynamics*, (Springer-Verlag, 1985).
[5]A. H. Glasser, C. R. Sovinec, R. A. Nebel, et al., Plasma Phys. Control. Fusion **41**, A747 (1999).

*This work is supported by the U.S. Dept. of Energy through the Scientific Discovery through Advanced Computation (SCIDAC) initiative and by Sandia National Laboratory.

2C25

PHYSICS ISSUES OF COMPACT QUASI-POLOIDAL STELLARATORS

D.A. Spong[1], S.P. Hirshman[1], D.J. Strickler[1], J.F. Lyon[1], L.A. Berry[1], A.S. Ware[2], E. Barcikowski[2], G.Y. Fu[3], D. Mikkelsen[3], D.A. Monticello[3], R. Sanchez[4], D. Westerly[2]

[1]Oak Ridge National Laboratory, P.O. Box 2009, Oak Ridge, TN 37831-8073

[2]Department of Physics and Astronomy, University of Montana, Missoula, MT, 59812

[3]Princeton Plasma Physics Laboratory, P.O. Box 451, Princeton, NJ 08502

[4]Universidad Carlos III de Madrid, Madrid, Spain

Quasi-poloidal (QP) stellarator symmetry has recently allowed the design of very low aspect ratio ($R_0/\langle a\rangle = 2.5$-$3$) two field period (racetrack-shaped) hybrid devices that generate their rotational transform from a combination of internal plasma currents and external shaping. The equilibria of compact QP plasmas involve strong poloidal/toroidal couplings due to the need to minimize the 1/R terms in the magnetic field spectrum, which constitute "undesirable ripple" in this context. Significant improvements have been made in 3-D equilibrium solvers allowing not only routine calculation of strongly coupled QP equilibria, but comprehensive optimization of these systems for good confinement, bootstrap current consistency, stability and coil-engineering properties. It has also been possible to form configurations having very little change in the flux surface shape with increasing plasma β and reduced resonant magnetic island width. Neoclassical transport in QP stellarators has been minimized so as to be negligible in comparison to the expected anomalous levels. Recent improvements in the neoclassical transport theory of 3-D systems have allowed calculation of the full transport matrix (diffusion of particles and heat, viscosity, and bootstrap current) for multiple helicity $|B|$, arbitrary electric fields and collisionalities, and including momentum–conserving corrections. QP systems possess an anisotropy in their viscous damping coefficients (poloidal viscosity < toroidal viscosity) that is opposite to that of tokamaks. This feature is expected to help maintain sheared radial electric fields driven by cross-field transport and may facilitate access to enhanced confinement regimes. The stability analysis of QP devices indicates first ballooning stability boundaries exist at $\langle\beta\rangle = 2$–2.5% and kink/vertical stability boundaries at $\langle\beta\rangle = 4$–5%. Many QP systems also have second stable regimes; for example, a class of devices with low vacuum transform has been studied that are second stable up to $\langle\beta\rangle \approx 15\%$. A favorable synergism exists between the finite β effects on the equilibrium and confinement of such systems, allowing not only relatively constant bootstrap current levels with increasing β, but also improved QP-symmetry and energetic particle confinement. MHD Alfvén gap modes have been analyzed in these systems, indicating a denser spectrum than tokamaks with helical couplings that are unique to 3-D devices. By varying the coil currents in proposed QP systems, substantial flexibility has been demonstrated theoretically with respect to neoclassical confinement, MHD stability, and magnetic island widths. This flexibility coupled with the unique magnetic structure of these systems will contribute to our basic understanding of plasma transport, MHD phenomena and confinement. The physics issues of these devices will be discussed along with new challenges in the theory and modeling of such compact 3-D systems.

Work supported by U.S. Department of Energy under Contract DE-AC05-00OR22725 with UT-Battelle, LLC.

2C26

Development of a Robust Class of Quasi-Poloidal Compact Stellarator Configurations

D. J. Strickler[1], S. P. Hirshman[1], D. A. Spong[1], L. A. Berry[1], M. J. Cole[1], J. F. Lyon[1], B. E. Nelson[1], A. S. Ware[2], D. E. Williamson[1]

[1]Oak Ridge National Laboratory, P.O.Box 2009,Oak Ridge, TN 37831-8073

[2]Department of Physics and Astronomy, University of Montana, Missoula, MT 59812

A compact quasi-poloidally symmetric stellarator plasma and coil configuration is described that has desirable plasma properties and a large volume bounded by good magnetic flux surfaces for both vacuum and 2% beta. The configuration is robust insofar as variations of the plasma beta and consequent bootstrap current leave the bounding flux surface nearly intact, minimizing the need for active positional control. This configuration was developed using a new computational method targeting good vacuum flux surfaces, as a measure of robustness, in the design of magnetic coils. The recently combined[1] stellarator plasma and coil design codes STELLOPT and COILOPT are used to vary coil geometry and plasma profiles to optimize free-boundary 3-D equilibria with respect to neoclassical transport, infinite-n ballooning stability, and coil engineering parameters (e.g., coil-plasma and coil-coil separation, minimum coil radius of curvature), while simultaneously minimizing the term $\chi_B = \omega_B |\mathbf{B}\cdot\mathbf{n}|/|\mathbf{B}|$ in the STELLOPT objective function. Here, $\mathbf{n}$ is the normal to the full-pressure plasma boundary and $\mathbf{B}$ is the *vaccum* magnetic field due to the coils. This vacuum field constraint, together with recent changes in the coil model, has resulted in an improved plasma and coil configuration for the Quasi-Poloidal Stellarator (QPS). In particular, the plasma volume enclosed by good vacuum magnetic surfaces is equal to, or greater than, that of the full-beta plasma with only insignificant islands. This implies a preservation of aspect ratio as beta is increased, an important feature in QPS since experiments that focus on neoclassical transport will take place at low beta. Coil design features include 1) a reconfiguration of the modular coils in QPS, reducing the number of coils from 16 to 10, and the number of coil winding forms from 4 to 3, and 2) improved engineering feasibility, due to increased coil separation and minimum coil radius of curvature.

1. D. J. Strickler, L. A. Berry, S. P. Hirshman, et al., "Integrated Plasma and Coil Optimization for Compact Stellarators," 19th IAEA Fusion Energy Conference, Lyon, France (October, 2002).

Work supported by U.S. Department of Energy under Contract DE-AC05-00OR22725 with UT-Battelle,LLC.

2C27

Coherent Ion Energization by Electrostatic Waves

D. J. Strozzi, A. K. Ram, and A. Bers
Plasma Science and Fusion Center, Massachusetts Institute of Technology, Cambridge, Massachusetts 02139

The possibility of coherent, in contrast to chaotic, ion acceleration by multiple electrostatic waves, with both discrete and continuous frequency spectra, is presented. Two electrostatic waves, e.g., lower-hybrid waves, propagating perpendicularly[1] or obliquely[2] to an ambient magnetic field $\vec{B}_0$ can coherently energize ions when their Doppler-shifted frequencies differ by a multiple of the ion cyclotron frequency: $\omega_1 - \omega_2 - (k_{1\|} - k_{2\|})v_\| = N\omega_{ci}$. Using the Lie perturbation technique we find that the coherent energization of ions is described by a Hamiltonian that is second-order in the wave amplitudes.

The energization of ions has no lower bound in ion energy and occurs for any angle of wave propagation with respect to $\vec{B}_0$ provided $k_{1\|} \approx k_{2\|}$. The change in gyroradius is linear in the wave frequencies and independent of wave amplitude. The period of coherent motion is inversely proportional to the square of the wave amplitudes and is proportional to ω^4 ($\omega \sim \omega_1 \sim \omega_2$). Furthermore, the deviation from resonance $\Delta\omega = \omega_1 - \omega_2 - N\omega_{ci}$ for which coherent acceleration occurs scales like ω^{-4}, while the range in $\Delta k_\| = k_{1\|} - k_{2\|}$ for coherent motion scales like ω^{-3}. For lower-frequency waves coherent ion acceleration is faster and less sensitive to wave parameters. This process of coherent energization could account for the observed energization of ionospheric ions transverse to the geomagnetic field [3], and is being studied in a laboratory experiment [4].

In the natural space environment, the electric fields are observed as a broadband frequency spectrum. If the frequency spectrum extends over at least $2\omega_{ci}$, a narrow frequency band of the spectrum matches a similar band separated in frequency by ω_{ci}. This could lead to the resonant interactions that produce coherent acceleration as in the case of two plane waves. We will present consequences of the finite bandwidth on the dynamics of ions interacting with such fields.

This work was supported by DOE Contract DE-FG02-91ER-54109, DOE/NSF Contract DE-FG02-99ER-54555 and NSF Contract ATM-0114462.

---

[1]D. Bénisti, A. K. Ram and A. Bers, *Phys. Plasmas* 5(9):3224-3232 (1998)

[2]D. J. Strozzi, A. K. Ram and A. Bers, submitted to *Phys. Plasmas*

[3]A. K. Ram, A. Bers and D. Bénisti, *J. Geophys. Res.*, 103(A5): 9431-9440 (1998)

[4]R. Spektor and E. Y. Choueiri, presented at *2001 IEPC Meeting*

2C28

Effects of fast particles on internal modes in reversed field pinches

V. A. Svidzinski, S. C. Prager
Department of Physics, University of Wisconsin-Madison
Madison WI 53706

Abstract

Fast ion population in tokamaks is found to have a significant influence on the dynamics of global plasma modes. In a normal mode analysis of plasma oscillations the fast particles are described by drift kinetic equation in which the perturbed electric and magnetic fields are evaluated at the position of the particle's guiding center. In this treatment the effects due to spatial variation of perturbed fields within the gyroradius are not considered. In reversed field pinches (RFP) the magnetic field is an order of magnitude smaller than in tokamaks. The Larmor radius of neutral beam injected particles in the 20 KeV energy range in RFPs is a substantial portion of the minor radius. The perpendicular wave length of global plasma modes is comparable to the Larmor radius of fast particles; thus the finite Larmor radius effects mentioned above can be important. In this study we concentrate on these effects only. We apply a simple constitutive relation without drift contributions for the fast particle dielectric response obtained from the linearized Vlasov equation. We consider cylindrical RFP equilibrium and use the resistive MHD model for the description of the plasma bulk. The changes to the internal modes due to the fast particles with large gyroradius are estimated. Analysis shows that the changes are sizable and that fast particles can either stabilize or destabilize plasma within the considered model. The effect depends on the radial distribution of fast particle density.

2C29

Edge plasma simulations for Large Helical Device with UEDGE

A. Takayama[1], A. Yu. Pigarov[2], S. I. Krasheninnikov[2], Y. Tomita[1], and T. D. Rognlien[3]

[1]*National Institute for Fusion Science, 322-6 Oroshi-cho, Toki 509-5292, Japan*
[2]*University of California San Diego, La Jolla, CA 92093, USA*
[3]*Lawrence Livermore National Laboratory, Livermore, CA 94551, USA*

Abstract

Magnetic configuration at the edge of a stellarator is very complex and contains a mixture of closed flux surfaces and stochastic field lines. At present, there is no complete plasma transport code that fully accounts for all of the features of this highly complex case. Moreover, it is even not very clear what kind of set of transport equations can be used for these purposes. At the same time, it is feasible that due to a strong anomalous cross-field plasma transport and convective plasma flows, a rather detailed features of stellarator magnetic topology do not matter much for averaged plasma parameters. Therefore, it is worth to try a simple approach to the modeling of stellarator edge plasma based on "averaging" of edge plasma parameters along the magnetic axis and introducing effective two-dimensional flux surfaces. In this sense, we substitute the stellarator edge with that what can be called stellarator-equivalent tokamak edge.

In the report, we apply this approach to edge plasma modeling for Large Helical Device. The LHD stellarator-equivalent tokamak is simulated with 2D multi-fluid transport code UEDGE. We consider the possible ways of construction of effective magnetic flux surface configuration that represent major features of LHD edge region as well as the usage of this configuration in UEDGE. We discuss the cross-field transport model adequate to ergodic edge plasma. We report preliminary results of UEDGE modeling and their comparison with experimental data for typical LHD shot.

2C30
Plasma potential of an electrostatically driven plasma

X. Z. Tang and Z. H. Wang
Los Alamos National Laboratory, Los Alamos, NM 87545

A. H. Boozer
Columbia University, New York, NY 10027

For a magnetized plasma, externally imposed electrostatic bias can induce both plasma current and plasma flow. The plasma current is driven by the parallel electric field along a magnetic field line and the magnitude of the current density is proportional to the Lundquist number. The parallel electric field, in a steady state plasma, is just the electrostatic potential drop along the magnetic field line. In a transient plasma, there is an additional inductive electric field piece corresponding to movement of the field line in the lab frame and relative slippage between the poloidal and toroidal flux linkage. The plasma flow in an electrostatically driven plasma is predominantly $\mathbf{E} \times \mathbf{B}/B^2$ with an ignorable correction inversely proportional to the Lundquist number. At steady state, the electric field is purely electrostatic, $\mathbf{E} = -\nabla\Phi$. The plasma potential Φ is central for the plasma current and flow drive by external voltage biasing.

Recent experiments have been devised to make use of both the current drive and flow drive capabilities of external voltage biasing. The Co-axial Helicity Injection (CHI) experiments on HIT-II and NSTX target electrostatic current drive as means for toroidal plasma startup and current sustainment. The Flowing Magnetized Plasma (FMP) experiment at LANL also employs a co-axial setup but emphasizes electrostatically driven plasma rotation. The sheared $\mathbf{B} \times \nabla\Phi/B^2$ plasma rotation simulates astrophysical accretion for studying magnetic rotational instability and dynamos.

The co-axial setup of voltage biasing insures that the external electrostatic drive conserves the toroidal magnetic flux inside the discharge chamber. A critical advantage is the ready accessibility of steady state operation. For CHI discharges, the plasma potential is directly responsible for parallel current drive, so force balance dictates the plasma potential. By that, we mean, for example, how far away the plasma potential is different from the vacuum potential. In fact, if the plasma inertia is ignored, the plasma potential is completely given by the Grad-Shafranov model and parallel resistive Ohm's law, hence the name Grad-Shafranov potential. The subtle physics of a small plasma inertia on modifying the plasma potential from the Grad-Shafranov potential will be clarified by both analytical calculation and numerical computation.

The ideal of the FMP experiment is to completely avoid plasma potential drop within a magnetic surface. Indeed, for a uniform vertical magnetic field, the vacuum potential ($\ln r$) and the associated Couette flow ($v_\varphi \propto r^{-1}$) are self-consistent solutions to the MHD equations. The experimental obstacle is the uncertainty regarding the accessibility of these solutions in a realistic discharge. In other words, the vacuum potential might not be an attractor for the plasma potential if one follows the plasma dynamics. We will present 2D and 3D numerical simulations that clarify the subtleties involved.

This work was supported by U.S. Department of Energy OFES and LANL internal LDRD funds.

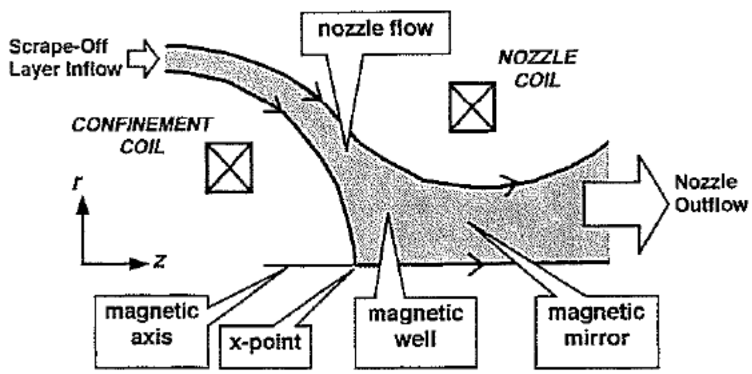
2C31

Plasma Flow Control in a Magnetic Nozzle for Electric Propulsion and Fusion Scrape-Off Layer Applications*

Alfonso G. Tarditi[1] and Loren C. Steinhauer[2]

[1]Advanced Space Propulsion Laboratory, NASA Johnson Space Center, Houston, TX (USA)
[2]University of Washington, Redmond Plasma Physics Laboratory, Seattle, WA (USA)

The control of the plasma flow in a magnetic nozzle configuration has application to both space plasma propulsion and to the design of the scrape-off layer (SOL) region in fusion devices. A conceptual flow-control scheme is derived, for example, by merging a field-reversed configuration (FRC) confinement topology with a magnetic nozzle, as illustrated in the figure below. The confinement coil can be thought as one of the two mirror coils of an FRC. The structure is characterized by an x-point on the axis, which creates a magnetic well region, while the nozzle coil generates another mirror downstream, now external to the SOL flow. The nozzle is annular at the source end with a spindle-like channel at the exit. The combination of magnetic well and mirror may allow control of both the flow rate and exit jet speed. In some ways the flow resembles that in the fluid-dynamics Laval nozzle in which the flow rate is regulated by a sonic "choking" condition at the nozzle throat (that in this case corresponds to the magnetic mirror).



Effects peculiar to this magnetic topology can be exploited to control the flow: when the mean free-path is comparable to the magnetic well length then the overall flow rate can be strongly throttled. Furthermore, a conducting end plate in the SOL region (for example, on the opposite side of the nozzle) causes a shorting of the magnetic field lines. The current drawn on the plate sets a j B rotation of the plasma in the duct along the azimuthal direction: this centrifugal effect can also regulate the overall flow.
This configuration is being modeled both analytically, by a double-adiabatic flow model, and numerically, by a fluid simulation with the *NIMROD* code. Details of the model developments and preliminary simulation results are presented.

* *Work supported by NASA (AGT) and by USDOE Grant DE-FG03-98ER54480 (LCS)*

2C32

Nonlinear covariant kinetic theory of magnetoplasmas

M.Tessarotto

Department of Mathematical Sciences, University of Trieste, Trieste, Italy

A.Beklemishev

Budker Institute of Nuclear Physics Novosibirsk, Russia

Recently, an increasing interest in astrophysical as well as laboratory plasmas has been manifested in reference to the existence of relativistic flows, related in turn to the production of intense electric fields in magnetized systems [1]. Such phenomena require their description in the framework of a consistent relativistic kinetic theory, rather than on relativistic MHD equations, subject to specific closure conditions. Single-particle relativistic gyrokinetic theory appears therefore a basic prerequisite for a consistent formulation of relativistic theories. The purpose of this work is to extend the relativistic single-particle guiding-center theory developed by Boghosian [2], Pozzo *et al.* [3] and Beklemishev *et al.* [4] to include both effects due to strong quasi-stationary EM fields as well as the nonlinear treatment of possible EM perturbations characterized by small wavelengths which may naturally arise in such systems. For this purpose, a closed set of relativistic gyrokinetic equations, consisting of the collisionless relativistic kinetic equation, expressed in hybrid gyrokinetic variables (*here denoted as hybrid relativistic gyrokinetic Vlasov equation*) and the averaged Maxwell's equations, is derived for an arbitrary four-dimensional coordinate system. The guiding-center dynamics of charged particles and the gyrokinetic transformation are obtained accurate through second order of the ratio of the Larmor radius to the equilibrium scale length. The wave-terms with arbitrary wavelength ($k\rho \sim 1$) are described in the second order (nonlinear) approximation with respect to the amplitude of the wave. The same approximations are used in the derivation of the gyrophase-averaged Maxwell's equations. The derivation is based on the perturbative Lagrangian approach with a fully relativistic, four-dimensional covariant formulation expressed in terms of arbitrary *hybrid* (i.e., generally non-canonical) variables, which allows relativistic drift velocities as well as consistent description of gravitation. Our results improve on existing limitations of the relativistic gyrokinetic theory [2] and extend the earlier formulation of Beklemishev *et al.* [4] in three aspects: the parallel electric field is not necessarily small; there is no limitation on the parallel wavelength of perturbations; second order (nonlinear) contributions are explicitly calculated.

Acknowledgements

Work supported by MIUR (Italian Ministry of University and Research) through the Research Program "Programma Cofin 2002: Metodi matematici delle teorie cinetiche" and the Consortium for Magnetofluid Dynamics, University of Trieste, Italy.

References

1 - J. N. Mohanty and K. C. Baral, Phys. Plasmas **3**, 804 (1996) and references therein.

2 - B.M.Boghosian, *Covariant Lagrangian methods of relativistic plasma theory*, (PhD thesis, University of California, Davis, 1987)

3 - M.Pozzo and M.Tessarotto, Phys. Plasmas **5**,2232 (1998).

4 - A.Beklemishev and M.Tessarotto, Phys. Plasmas **6**, 4487 (1999).

2C33

Nonlinear MHD Stability and Dynamical Accessibility

Jean-Luc Thiffeault

Department of Mathematics, Imperial College London, SW7 2AZ, United Kingdom

P. J. Morrison

Department of Physics and Institute for Fusion Studies,
University of Texas at Austin, Austin, TX 78712-1060

Abstract

We obtain sufficient conditions for the stability of equilibria for two- and three-dimensional MHD, and generalizations of MHD, by using dynamical accessibility. The use of dynamical accessibility ensures that the physical perturbations preserve the natural constraints on the system imposed by the Hamiltonian structure.[1] Our procedure is a generalization of the work of Newcomb,[2] Frieman and Rotenberg,[3] and Arnold,[4] among others, who make use of Lagrangian displacements. Comparisons between various approaches are made.

[1] Morrison, P. J., Rev. Mod. Phys. 70, 467 (1998)
[2] Newcomb, W. A., Nuclear Fusion: Supplement, part 2, 451 (1962)
[3] Frieman, E. A., and M. Rotenberg, Rev. Mod. Phys. 32, 898 (1960)
[4] Arnold, V. I., J. de Mecanique, 5, 29 (1966)

This work was supported in part by the U.S. Department of Energy Contract No. DE-FG03-96ER--54346.

Presented at the Sherwood Meeting, Corpus Christi, TX, March 2003.

2C34

Simulation of intermittent beam ion loss in a TFTR experiment

Y. Todo

Theory and Computer Simulation Center,

NATIONAL Institute for Fusion Science, Toki 509-5292, Japan

H. L. Berk and B. N. Breizman

Institute for Fusion Studies,University of Texas at Austin, Austin, Texas 78712

Recurrent bursts of toroidicity-induced Alfvén eigenmodes (TAE) are studied using a self-consistent simulation model. Bursts of beam ion losses observed in the neutral beam injection experiment at the Tokamak Fusion Test Reactor [K. L. Wong *et al.*, Phys. Rev. Lett. **66**, 1874 (1991)] are reproduced using experimental parameters. It is found that synchronized TAE bursts take place at regular time intervals of 2.9 ms, which is close to the experimental value of 2.2 ms. The stored beam energy saturates at about 40% of that of the classical slowing down distribution. The stored beam energy drop associated with each burst has a modulation depth of 10% which is also close to the inferred experimental value of 7%. Surface of section plots demonstrate that both the resonance overlap of different eigenmodes and the dissapearance of KAM surfaces in phase space due to overlap of higher-order islands created by a single eigenmode lead to particle loss. Only co-injected beam ions build up to a significant stored energy even though their distribution is flattened in the plasma center. However, they are not directly lost as their orbits extend beyond the outer plasma edge when the core plasma leans on a high field side limiter. The saturation amplitude is larger than would appear to be compatible with experiment. Physical arguments are presented for why the stored energetic particle response observed in the simulation is still plausible.

This work was partly supported by the U.S. Department of Energy Contract No. DE-FG03-96ER-54346

2C35

Ideal MHD ballooning modes and stability boundaries of near helically symmetric stellarators

R. Torasso, E. Hameiri, H.R. Strauss,
Courant Institute of Mathematical Sciences, New York University
New York, NY 10012

C.C. Hegna
University of Wisconsin, Madison, WI 53706

S.R. Hudson
Princeton Plasma Physics Laboratory, Princeton, NJ 08543

Abstract

A method for generating a set of three-dimensional MHD equilibria has been developed which allows for variations in the plasma profiles in the vicinity of a magnetic surface associated with an existing equilibrium.[1] Two free profile functions, in particular the variation of pressure and rotational transform gradients, appear in parameterizing the new class of equilibria. In this work, we examine the effect of profile variations on the ideal MHD ballooning stability properties of a near helically symmetric configuration. Marginal stability boundaries are denoted by constructing generalized $s-\alpha$ curves, where s and α are dimensionless measures of the rotational transform and pressure gradient, respectively. In particular, we apply this technique to magnetic configurations available to the HSX stellarator. A result of these studies is that in contrast to axisymmetric configurations, we find no evidence of a second stability regime of operation for the HSX stellarator. Moreover, the ballooning eigenvalues are highly field line dependent indicating that the most unstable ballooning modes will be highly localized on a given magnetic surface.

The analysis is based on the numerical solution of the ballooning equation, where the boundary conditions are taken to be the vanishing of the eigenfunctions after a finite number of field period revolutions around the major axis of the torus. We analytically explore how to determine the length of the field period revolutions.

[1] C.C. Hegna and N. Nakajima, *Phys. Plasmas* 5, 1336 (1998).

Work supported by U.S. Department of Energy Grant Nos. DE-FG02-99ER54546 AND DE-FG02-86ER53223.

2C36

Random Attractors and ELMs

Eugene R. Tracy[1], John M. Finn[2], Wei Yang[1], and Bill Cooke[1]

[1] College of William and Mary

[2] Los Alamos National Laboratory

Abstract

It is important to be able to distinguish between different low dimensional models for Type I ELMs in order to predict scaling to larger devices and to design a system to control the ELMs. Here we consider the possibility that the ELM dynamics is influenced by fluctuations in the core of the tokamak, which might be modelled as noise. Typically, in doing nonlinear time series analysis, the first step is to determine whether the time series is from a linear stochastic system or from a nonlinear deterministic system. Motivated by the ELM issues, we have constructed a second order nonlinear system with noise in which the noise contributes in a fundamental way. Specifically, the deterministic system amplifies the effects of the noise so that the system can occupy a region of its state space far from any attractor of the underlying deterministic system, and this *random attractor* behaves much like a chaotic deterministic attractor. This type of behavior appears not to have been observed in previous nonlinear dynamical studies. We plan to develop methods of nonlinear time series analysis to distinguish this type of behavior from that of a deterministic system, because the methods of control will be fundamentally different for the two cases. For the system we have studied, there is a range of parameters for which the dynamics consists of a series of large localized bursts separated by quiescent time intervals, and both the burst amplitudes and intervals appear to be chaotic, similar to ELMs in tokamaks. We have found that there is a strong nonlinear correlation between the burst amplitudes and the succeeding time intervals, but the time intervals are decorrelated from the succeeding burst amplitudes. This is a possible signature for this type of noise amplified behavior. We will show experimental results from a nonlinear circuit having some of these characteristics.

2C37

Nonlinear Resistive MHD Analysis of the Turbulent Dynamo and Pressure-Driven Transport in the Reversed-Field Pinch*

Leaf Turner and Alan H. Glasser
Theoretical Division, Los Alamos National Laboratory, Los Alamos, NM 87545

For systems with only one invariant, *e.g.* energy, there are known statistical closure schemes which lead to manageable expressions for evolution of the turbulent spectrum. For ideal MHD, there can be two or more invariants, including also magnetic helicity and cross helicity. These complicate the task of finding such a closure scheme.[1]

We describe a new approach to the study of the turbulent dynamo and pressure-driven transport in a cylindrical-model reversed-field pinch (RFP). We expand the nonlinear resistive MHD equations, using the eigenfunctions of the linearized equations as basis functions. This yields a high-order nonlinear system of ordinary differential equations (ODEs) for the time-dependent amplitudes $\alpha_i(t)$ of the basis functions,

$$\sum_{j=0}^{n} M_{i,j}\left(\dot{\alpha}_j - \gamma_j \alpha_j\right) = \sum_{j,k=0}^{n} c_{i,j,k}\alpha_j\alpha_k \tag{1}$$

where the γ_j are linear growth rates; the $M_{i,j}$ are components of a 2nd-rank mass matrix; and the $c_{i,j,k}$ are components of a 3rd-rank coupling matrix. $\mathbf{M}$ and $\mathbf{c}$ are expressed as quadratures over quadratic and cubic products of the linear eigenfunctions. Numerical computation using matched asymptotic expansions for the linear eigenfunctions for a given instantaneous cylindrical equilibrium permits fast and accurate evaluation of these quantities for arbitrarily high values of the Lundquist number S. Numerical integration of Eq. (1) permits the study of dynamical saturation mechanisms much more efficiently than the commonly used approach of multidimensional simulation codes like DEBS and NIMROD. Statistical closure schemes for describing the saturated spectrum can be developed and tested against this direct numerical simulation. The reaction of the saturated spectrum on the slowly-evolving cylindrical equilibrium is used to make predictions about the evolution of field reversal and the level of turbulent transport.

* Work supported by U.S. Department of Energy

[1] L. Turner, "Cross-correlations in nonlinear dynamics," LA-UR 02-7833 (submitted for publication).

2C38

Modeling of effects of magnetic perturbation on the quality of flux surfaces in SSPX spheromak

M.V. Umansky, R.H. Bulmer, D.N. Hill, W.M. Nevins, D.D. Ryutov, S. Woodruff

Lawrence Livermore National Laboratory
Livermore, CA 94551 USA

Abstract

We present results showing the effect of magnetic fluctuations on the quality of flux surfaces in realistic spheromak geometries. In the SSPX spheromak at LLNL, the thermal diffusivity can at times be higher than the Bohm value [1]. This may be due to degradation of magnetic flux surfaces by magnetic fluctuations when islands produced on mode-rational surfaces overlap. Few systematic studies of the effect of magnetic perturbations on the quality of flux surfaces exist. Most recently, NIMROD simulations have shown that large amplitude n=1 modes can produce completely stochastic magnetic field lines in strongly driven spheromaks [2]. However, in the SSPX experiment, low edge-field fluctuation amplitudes (dB/B < 1%) and strongly peaked pressure profiles with Te being a flux function [1] are commonly observed. Therefore, a study relating magnetic fluctuations to the quality of flux surfaces and global energy confinement is timely.

We analyze the effect of magnetic field fluctuations on the quality of confinement in SSPX spheromak plasmas by analyzing a perturbed magnetic field. The unperturbed magnetic field is calculated from MHD equilibrium code CORSICA [3], and a perturbation model is added to it. The perturbation is set analytically as a set of Fourier harmonics, and its poloidal and toroidal structure is constrained by available data on edge magnetic field fluctuations.

Using numerical magnetic line integration we construct Poincare maps for the perturbed field. Magnetic perturbation causes formation of islands, and as the amplitude of the perturbation is turned up, the islands overlap and stochastic regions are observed. We estimate the effective heat transport induced by the presence of stochastic magnetic field and compare our calculations with the scaling of peak electron temperature and global energy confinement time as a function of the amplitude of the magnetic fluctuations.

[1] H.S. McLean et al., Phys. Rev. Lett. 88 125004 (2002)
[2] C.R. Sovinec et al., Phys. Plasmas 8, 475 (2001)
[3] E.B. Hooper et al., Nucl. Fusion 39, 863 (1999)

Work performed for U.S. DOE by UC LLNL under contract W-7405-Eng-48.

2C39

Quantum Lattice Gas Representation for Vector Solitons

George Vahala[1] , Linda Vahala[2] , Jeffrey Yepez[3]

[1] Department of Physics, William & Mary, Williamsburg, VA 23187
[2] Department of Electrical & Computer Engineering, Old Dominion University, Norfolk, VA 23529
[3] Air Force Research Laboratory, Hanscom AFB, MA 01731

Abstract

The study of solitons has impacted such diverse fields as plasma physics, neuclear/particle physics, molecular biology, geology, meteorology, oceanography, astrophysics, cosmology, semi-conductor physics and even to the study of protein systems and neurophysiology

There is much interest in developing algorithms for quantum computers - computers that (theoretically) can yield exponential speed-up over classical computers because of their ability to utilize quantum superposition of states. The classical binary bit is now replaced by a qubit as the basic building block. By ingenious methods, it is believed possible to sustain phase coherence over millions of globally entangled qubits for sufficiently long time intervals so that classically intractable problems (e.g., the factoring of large composite numbers, or the simulation of large many-body quantum systems) can be solved. These types of quantum computers can be designated as Type-I and have yet to be built. However, it is much simpler to develop quantum computers that only require qubit entanglement over short ranges and for short times. Thus these quantum computers would involve large parallel arrays of small quantum computers, with each quantum computing node embodying only a small set of qubits, and a classical communication network connecting the nodes. This quantum architecture has been designated as a Type-II quantum computer. While exponential speed-up is now restricted to those steps involving quantum entanglement, this is an excellent and ideal stepping stone to the future Type-I computer. Moreover, Type-II macroscopic scale computers exist (e.g., using liquid-state NMR technology) and implemented to solve some simple quantum algorithms (e.g., the solution of the diffusion equation).

We determine quantum lattice gas representations for NLS and KdV that are unconditionally stable and ideal for implementation (and parallelization) on a hybrid quantum-classical computer as well as on a classical computer. In particular results will be shown for both the integrable (cubic) NLS as well as the non-integrable NLS which yields soliton turbulence. Vector solitons of the Manakov type will also be considered.

2C40

Shielding of Resonant Magnetic Perturbations in the Long Mean-free-path Regime

F. L. Waelbroeck
Institute for Fusion Studies, University of Texas

The resonant response of a plasma in a layer where the wavefront is parallel to the magnetic field is of interest in many contexts. In axisymmetric systems, it influences the dynamics of wall modes,[1] the interaction between the various internal modes, and the effect of externally imposed perturbations such as feedback corrections and error fields.[2] In helical systems, the resonant response governs the extent to which flux surfaces are destroyed by magnetic islands.

In a static plasma resonant perturbations give rise, through magnetic reconnection, to islands of widths proportional to the square root of the transverse displacement at a large distance from the island. Magnetic reconnection is strongly inhibited, however, in the presence of even modest levels of plasma motion.[3] The primary effect of the perturbations is then to exert a braking force on the plasma. When the perturbation exceeds a threshold amplitude, the plasma is abruptly stopped and reconnection proceeds to saturation.

Although both existing and planned fusion experiments operate in the long mean-free-path regime, previous calculations of the braking force and mode penetration threshold, both analytic and numerical, have used a low beta Magnetohydrodynamics (MHD) model in slab geometry. In principle, however, the validity of this model is restricted to the collisional regime. In order to improve the reliability of extrapolations to burning plasma experiments, we have investigated the effect of long electron mean free path on the resonant response of a plasma to magnetic perturbations. We find that the scaling with machine size of the threshold for mode penetration in Ohmic discharges for the long mean-free-path model ($\Psi_{\rm pen} \sim R_0^{-1.76}$) is almost identical to that obtained with short mean-free-path MHD ($\Psi_{\rm pen} \sim R_0^{-1.71}$). The nature of the force exerted on a moving plasma by a resonant perturbation is qualitatively altered, however, by both drift and long mean-free-path effects. The force is found to have three minima, each of which is a possible locus for discontinuous transitions in plasma velocity. Between these minima are two points where the force exerted by the perturbation vanishes. These points describe locked states where shielding is ineffective and a magnetic island will grow. They correspond to rotation velocities such that either the electrons or the ions are at rest in the frame of the perturbation. The ion root, however, is unstable. The model thus predicts that during the growth of low-density locked modes the plasma will rotate so as to bring the electrons to rest in the frame of the perturbation.

Acknowledgements This work was funded by the U.S. Department of Energy Contract No. DE-FG03-96ER-54346.

References

[1] A. Garofalo, R. J. La Haye, and J. Scoville, Nucl. Fusion **42**, 1335 (2002).
[2] R. J. La Haye and J. Scoville, Nucl. Fusion **32**, 2119 (1992).
[3] R. Fitzpatrick, Nuclear Fusion **33**, 1049 (1993).

2C41

Progress on full radius gyrokinetic turbulence simulations and prospects for treating transport time scales with GYRO*

R.E. Waltz, J. Candy, and F.L.Hinton

General Atomics, P.O. Box 85608, San Diego, California 92186-5608

Abstract

GYRO is a physically comprehensive continuum global gyrokinetic code for simulating turbulent transport in tokamaks. Beyond the now standard ion-temperature-gradient (ITG) mode turbulence, the code includes trapped and passing electrons with pitch angle collisions, electromagnetic finite-β perturbations, real geometry from Miller local equilibrium, E B and parallel flow shears. It operates at finite (but small) $\rho_* = \rho_i/a$ and treats general profile shear stabilization in a WKB-like approximation. Tremendous progress has been made since the project began in 1999. At the 2002 Sherwood meeting, we reported comprehensive simulations of Bohm-scaled DIII-D L-mode ρ_*-scaled discharges which compared within a factor 2 of experimental transport levels. These simulations were limited to 80 ρ_i radial slices (one-third the minor radius), $\mu = \sqrt{m_i/m_e} = 20$, and required five 24-hour restarts on 128 processors of the NERSC IBM SP (seaborg.nersc.gov). Timesteps were limited to about 1/10th the nonlinear ITG adiabatic-electron timestep. Since then, a better data distribution scheme has allowed processor scaling beyond 512 processors, with a full global electromagnetic simulation now achievable in a single 24-hour run. As we moved to larger radial slices and larger μ, the 4th-order Runge-Kutta method was plagued by numerical difficulties connected with extremely fast "electrostatic" Alfvén modes. This caused the development of weak n=0 "radial box" instabilities. A new 3rd order implicit-explicit Runge-Kutta method splits off the stiff linear parallel electron motion for implicit treatment, stepping over the troublesome modes, and allowing near full radius 240 ρ_i DIII-D runs with physical $\mu = 60$ (deuterium) at significantly larger time steps. The DIII-D L-mode simulations are now closer to experimental levels. We will shortly add $\delta B_{\parallel}$ perturbations for NSTX high-β simulations, and implement a better formulation of the parallel shear Kelvin-Helmhotz drive at finite Mach number. We believe that the timestep is presently limited by the explicit nonlinear magnetic flutter term. Nevertheless, with full radius operation, we have started to assess prospects for treating "turbulence on transport time scales". Gyrokinetic codes are too expensive to run longer than a few percent of the transport confinement time. However, given the stiff nature of core transport, it is more accurate to predict profiles given experimental flows. An interaction with an outer" transport code time scale loop, which adjusts the profiles, to the given sources should make this possible.

*Work supported by the U.S. Department of Energy under Grant No. DE-FG03-95ER54309 and the SciDAC Plasma Microturbulence Project.

2C42

δf Simulation of Collisionless Tearing Modes

W. Wan, Y. Chen and S. E. Parker
University of Colorado, Boulder, CO 80309

The evolution of the collisionless tearing mode is studied using a three-dimensional particle-in-cell simulation model that uses the δf-method with the split-weight scheme to enhance the time step, and a novel algorithm to accurately solve the Ampere's equation for experimentally relevant β values, $\beta \frac{m_i}{m_e} \gg 1$.[1] We compare the cases of gyrokinetic electrons with drift-kinetic electrons. The gyrokinetic electron simulation is interesting because kinetic theory shows that during reconnection, the half width of the induced current could be well below the ion Larmor radius and the effect of finite electron Larmor radius could be significant. Linear simulation results will be benchmarked with eigenmode analysis for the case of fixed ions and drift kinetic electrons. The nonlinear dynamics of small-scale magnetic islands will be studied using the δf scheme and the results will be compared with previous studies using the full-f PIC simulation method[2].

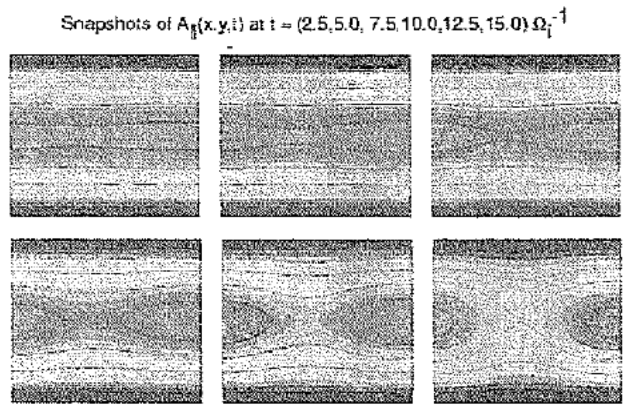


Figure 1: Island growth due to a tearing mode with $k_y \rho_i = 1$, $k_\| = 0$, $\beta = 6\%$, obtained from the split-weight δf code.

[1] Y. Chen and S. E. Parker, submitted to J. Comp. Phys.
[2] R. D. Sydora, Phys. Plasmas 8, 1929 (2001)

2C43

Stellarator Optimization: A Comparison of Genetic, Differential Evolution, and Levenberg-Marquadt Optimization Algorithms

S. Wang,[1] A. S. Ware,[1] S. P. Hirshman,[2] D. A. Spong[2]

[1]Department of Physics and Astronomy, University of Montana, Missoula, MT 59812-1080
[2]Oak Ridge National Laboratory, P.O. Box 2009, Oak Ridge, TN 37831-8070

Abstract

The efficiency and effectiveness of stellarator optimization methods has improved greatly in recent years. A number of different optimization algorithms have been applied to stellarator optimization including both steepest descent and evolutionary optimization algorithms. In this work, we present a comparison of three different algorithms applied to the optimization of three-dimensional equilibria: (1) a Levenberg-Marquadt routine (LM), (2) a genetic algorithm (GA), and (3) a differential evolution algorithm (DE). LM is a nonlinear least squares method while GA and DE are both evolutionary algorithms. The speed and efficiency of numerical codes used to obtain equilibrium, stability, and transport properties of three-dimensional plasmas has been sufficiently enhanced so that global (in parameter space) optimization methods are now feasible. In principle, the primary advantage of the evolutionary algorithms is that they perform a global parameter space search while the steepest descent methods (such as LM) perform a local parameter space search for the optimal configuration. We present results which indicate the evolutionary algorithms are more sensitive to the user input than the LM method and that they are also constrained in stellarator optimization by the fact that equilibria do not exist for a large range of parameter space. Finally, we present initial work towards the development of a breeding optimization algorithm: a global genetic algorithm which uses a local LM optimizer to refine a generation. The goal of the breeding algorithm is to take advantage of the global parameter space search of the evolutionary algorithm while maintaining the efficiency of the LM method.

2C44

Neoclassical Transport Calculation for ST Plasma

W.X. Wang, W. M. Tang, F. L. Hinton[1], L. E. Zakharov and R. B. White

Princeton Plasma Physics Laboratory, P.O. Box 451
Princeton, NJ 08543
[1] *General Atomics, San Diego*

Abstract

In assessing the confinement properties of toroidal plasmas, it is important to accurately calculate the neoclassical dynamics, which set the irreducible minimum level of transport in such systems. While much attention is paid to turbulent transport studies, there remain significant unresolved neoclassical issues – especially in spherical torus experiments such as NSTX. In the NSTX plasmas, typical features which violate basic assumptions of most theories include low aspect ratio, large orbit size, large trapped particle fraction (up to ~100%), large toroidal rotation with strong shear, etc. When these effects are properly taken into account, together with self-consistent calculation of the equilibrium electric field, it is obviously of interest to assess the possible strong impact on ion thermal transport and the bootstrap current. In the present investigation, the neoclassical physics of ST plasmas is systematically studied using a generalized particle-in-cell (PIC) 3-dimensional code, which employs the delta-f method to solve the drift kinetic equations together with the Poisson equation governing the ambipolar electric field in general toroidal geometry. The main physical and numerical features of the code include:

- full global geometry effects
- dynamics of the self-consistent electric field in both the radial and poloidal directions
- finite orbit effects (nonlocal transport) which may have a significant influence on neoclassical transport near the magnetic axis and in the region of large plasma gradients
- systematic treatment of plasma rotations
- ions and electrons at present, multi-species (energetic particles and impurities) to be developed
- accurate Lagrangian equations recently developed for guiding-center motion calculations
- a coordinate system with approximately equal arc length, which allows a uniform grid in the poloidal direction and a better representation of numerical equilibria for high beta, strongly shaped plasmas

The present code has first been carefully benchmarked in the large aspect ratio circular geometry limit with neoclassical theory and with existing codes, such as FORTEC-E. General geometry simulations are then used to assess plasma transport due to collisional relaxation in an ST plasma, such as NSTX. This includes evaluation of the ion thermal flux, radial electric field dynamics and structure, poloidal flow, angular momentum transport, and bootstrap current.

Work supported by U.S. DOE.

2C45

Ideal MHD Stability of the Quasi-Poloidal Stellarator

A. S. Ware,[1] E. Barcikowski,[1] L. A. Berry,[2] G. Y. Fu,[3] S. P. Hirshman,[2] J. F. Lyon,[2] R. Sanchez,[4] D. A. Spong,[2] D. J. Strickler[2]

[1]Department of Physics and Astronomy, University of Montana, Missoula, MT 59812-1080
[2]Oak Ridge National Laboratory, P.O. Box 2009, Oak Ridge, TN 37831-8070
[3]Princeton Plasma Physics Laboratory, P.O. Box 451, Princeton, NJ 08502
[4]Universidad Carlos III de Madrid, Madrid, Spain

Abstract

This work examines the MHD stability prosperities of the Quasi-Poloidal Stellarator[1] (QPS). The proposed QPS device is a stellarator with very low plasma aspect ratio ($R/a \sim 2.7$, roughly 1/2 to 1/4 that of existing stellarators). The dominant feature of the magnetic spectrum of QPS is quasi-poloidal symmetry: $\partial|B|/\partial\theta \approx 0$ in flux coordinates. As part of its mission, QPS will explore the physics of MHD stability in a quasi-poloidal symmetric device. QPS has been designed to run with a bootstrap aligned current profile (a total current of ~40 kA at $\langle\beta\rangle = 2\%$). The design of QPS optimized for infinite-n ballooning stability at $\langle\beta\rangle = 2\%$. The testing and optimization for ballooning stability was performed using the COBRA code.[2] The latest reference configuration has exceeded this goal with an infinite-n ballooning stability limit of $\langle\beta\rangle > 2\%$ for a simple pressure profile, $p = p_0(1-s)^2$ (where s is the normalized toroidal flux) and $\langle\beta\rangle > 2.3\%$ for optimized pressure profiles. More recently, QPS plasmas have been tested for finite-n ballooning mode stability (up to $n = 19$) using the Terpsichore MHD stability code.[3] As expected, the β limits for finite-n ballooning modes are higher than for infinite-n: $\langle\beta\rangle > 2.5\%$ for the simple pressure profile and even higher for optimized pressure profiles. Results on the impact of plasma shape variation with β on finite-n ballooning stability will be presented. The Terpsichore code has also been used to examine kink and vertical mode stability. While QPS has been designed including bootstrap current in the equilibrium, the magnitude of the bootstrap current is 1/3-1/5 that in an equivalent axisymmetric device. The reduced bootstrap current results in improved stability to kink and vertical modes. The reference QPS design is stable to vertical modes for $\langle\beta\rangle > 5\%$ and is stable to kink modes for $\langle\beta\rangle > 4\%$.

[1]J. F. Lyon, et al., "Physics and Engineering Design of a Very-Low-Aspect-Ratio Quasi-Poloidal Stellarator", in preparation for Nucl. Fusion, (2003).
[2]R. Sanchez, et al., J. Comp. Physics **161**, 576 (2000).
[3]D. V. Anderson, et al., Scient. Comp. Supercomputer II, 159 (1990).

2C46

A non-dissipative closure model for mirror instability in a collisionless plasma

T.-H.Watanabe[1], H.Sugama[1], W.Horton[2], and V.H.Wong[2]

[1]National Institute for Fusion Science/The Graduate University for Advanced Studies, Toki, Gifu 509-5292 Japan
[2]Institute for Fusion Studies, The University of Texas at Austin, Austin, Texas 78712

The ideal magnetohydrodynamic (MHD) equations describing macroscopic behaviors of collisionless plasmas are completed by considering the moment-closure problem. It is well known that the CGL (Chew-Goldberger-Low) model, where the parallel heat flux is presumed to be zero, predicts a lower criterion of temperature anisotropy for the mirror instability than that of linear analysis of the Vlasov equation (by a factor of 6). The difference of the criteria is important not only as a fundamental problem in plasma physics but also as one of key factors determining temperature anisotropy in the Earth's magnetosheath. In order to resolve the problem in the CGL model, Kulsrud proposed a set of kinetic and fluid equations where two components of the pressure tensor $(p_\perp, p_\parallel)$ are directly given by second-order moments of a drift kinetic equation [1]. In the Kulsrud's approach, the fluid and kinetic equations are derived by $(1/e)$-ordering and gyrophase averaging of the Vlasov equation, and are coupled with each other to be solved. Here, it is called "kinetic MHD equations".

It has been desired to find a closure model for the kinetic MHD equations, since they are too complicated to be applied to numerical simulations although the derivation is strict and valid. Snyder and his co-authors have applied the 4+2 and/or 3+1 Landau-fluid models to closing the moment hierarchy [2]. It is, however, known that a dissipative closure relation such as the Landau-fluid model does not preserve the time-reversibility of linearly unstable modes. Thus, according to the idea of the non-dissipative closure model for the ion temperature gradient mode turbulence [3,4], we consider a closure relation between the heat flux $(q_{\perp 1}, q_{\parallel 1})$, the pressure $(p_{\perp 1}, p_{\parallel 1})$ and the parallel flow $U_\parallel$ with real-valued coefficients which are determined so as to reproduce the two conditions; the relation between $(q_{\perp 1}, q_{\parallel 1})$ and $(p_{\perp 1}, p_{\parallel 1})$ given by the kinetic MHD equations and the linear dispersion relation (where the subscript 1 denotes fluctuations). Applying the closure model to $(q_{\perp 1}, q_{\parallel 1})$ in equations for $(p_{\perp 1}, p_{\parallel 1})$ given by taking second-order moments of the kinetic equation, we have found a set of fluid equations which preserve the time-reversibility for unstable modes and give the same dispersion relation as that from the kinetic analysis.

[1] R.M.Kulsrud, *Handbook of Plasma Physics*, **1**, Chapt.1.4 (1983).
[2] P.B.Snyder, G.W.Hammett, and W.Dorland, Phys. Plasmas, **4**, 3974 (1997).
[3] H.Sugama, T.-H.Watanabe, and W.Horton, Phys. Plasmas, **8**, 2617 (2001).
[4] H.Sugama, T.-H.Watanabe, and W.Horton, Phys. Plasmas, **10**, 726 (2003).

2C47

Hall current effects in dynamic magnetic reconnection solutions

P. G. Watson[1], I. J. D. Craig[2], J. Heerikhuisen[2]

[1] Center for Magnetic Reconnection Studies, Institute for Fusion Studies, University of Texas at Austin, Austin, TX 78712

[2] Department of Mathematics, University of Waikato, New Zealand

Abstract

The impact of Hall current contributions on flow driven planar magnetic merging solutions is investigated using both analytical and numerical approaches. The Hall current is important if the dimensionless Hall parameter (or normalized ion skin depth) satisfies $d_i > \eta$, where η is the inverse Lundquist number for the plasma. Analysis of a simplified 1D current sheet model shows that the Hall current initially manifests itself by inducing a non-reconnecting perpendicular "separator" component in the magnetic field. Only when the stronger condition $d_i^2 > \eta$ is satisfied does the Hall current affect the reconnecting planar field. These analytic predictions are tested by performing a series of numerical experiments in periodic geometry, using the full system of planar MHD equations. These results confirm that the nature of the merging changes dramatically when the Hall coupling satisfies $d_i^2 > \eta$. In line with the analytic treatment, the coupling provided by the Hall term leads to the emergence of multiple current layers that can enhance the global Ohmic dissipation at the expense of the reconnection rate. However, the details of the dissipation depend critically on the symmetries of the simulation, and when the merging is "head-on" (i.e., comprises four-fold symmetry) the reconnection rate can be enhanced. The 2D simulations also show that strong Hall currents eventually lead to the destruction of the typical quasi-one-dimensional current sheets found in the standard MHD model.

This work was supported by the U.S. Dept. of Energy Contract No. DE-FC02-01ER-54652 under the auspices of the program for Scientific Discovery through Advanced Computing

2C48

Second Ballooning Stability Access in the Quasi-Poloidal Stellarator

D. Westerly,[1] A. S. Ware,[1] L. A. Berry,[2] S. P. Hirshman,[2] J. F. Lyon,[2] R. Sanchez,[3] D. A. Spong,[2] D. J. Strickler[2]

[1]Department of Physics and Astronomy, University of Montana, Missoula, MT 59812-1080
[2]Oak Ridge National Laboratory, P.O. Box 2009, Oak Ridge, TN 37831-8070
[3]Universidad Carlos III de Madrid, Madrid, Spain

Abstract

Access to second ballooning stable regions in the Quasi-Poloidal Stellarator[1] (QPS) is investigated. The proposed QPS device is a very-low-aspect ratio (A = 2.7) stellarator with a $|B|$ spectrum which exhibits quasi-poloidal symmetry. The QPS experiment will test the concept of quasi-poloidal symmetry as a pathway for obtaining adequate neoclassical confinement at very-low aspect ratio and in addition will explore the physics of MHD stability and anomalous transport in a quasi-poloidal symmetric device. QPS has been designed to run with a bootstrap aligned current profile (a total current of $\leq$ 40 kA) at $\langle\beta\rangle \leq 2\%$. However, similarities in the magnetic spectrum of QPS and that of very high-β, quasi-poloidally-symmetric, hybrid stellarator configurations[2] have led us to investigate the existence of second ballooning stable regimes in QPS at higher β values. The computational work on high-β plasmas in quasi-poloidally symmetric stellarator hybrids investigated non-axisymmetirc plasma equilibria with tokamak rotational transform profiles that displayed regions of second stability for $5\% < \langle\beta\rangle < 20\%$. This is in contrast to recent theoretical work by Hegna and Hudson that has suggested that regions of second ballooing stability do not exist for three-dimensional magnetic equilibria.[3] In this work, a reference QPS coil set is used to generate high-β ($\langle\beta\rangle > 5\%$) free-boundary equilibria. Variation of the external coil currents, plasma pressure profile, and plasma current profile is used to optimize for ballooning stability at high-β. Equilibria with large second ballooning stable regions have been obtained at $\langle\beta\rangle \sim 6\%$. The role of the plasma current profile in accessing second stability will be discussed. Overlap (or lack thereof) between regions of weak magnetic shear and bad curvature is explored and the effect of degrading quasi-poloidal symmetry on this region of overlap is investigated. Finally, the link between qps and second stability access in three-dimensional equilibria is investigated.

[1]J. F. Lyon, et al., "Physics and Engineering Design of a Very-Low-Aspect-Ratio Quasi-Poloidal Stellarator", in preparation for Nucl. Fusion, (2003).
[2]A. S. Ware, et al., Phys. Rev. Lett. **89**, 125003 (2002).
[3]C. C. Hegna and S. R. Hudson, Phys. Plasmas **9**, 2014 (2002).

2C49

Bootstrap Currrent Simulation

Roscoe White

Leonid Zakharov

Princeton Plasma Physics Lab, PO Box 451, Princeton NJ 08543, USA

Numerical simulations of bootstrap current are carried out for tokamak configurations, for low and high energy particles. Bootstrap current is important because it is relied on to supply a large fraction of the total current in many projected tokamak ignition devices. Advances in computing capacity have made it possible to simulate the bootstrap current due to full Maxwellian distributions as well as to examine a larger range of collision frequencies than previously possible. Recently there have been a number of theoretical papers predicting anomalously large bootstrap current as a natural phenomenon occuring at the magnetic axis. We examine this prediction in detail, and the nature of the bootstrap contribution in the vicinity of the magnetic axis as a function of particle energy. Special burning plasma scenarios are also discussed.

References

[1] A. A. Galeev and R. Z. Sagdeev, Sov. Phys. JETP **26**, 233 (1968)
[2] B. B. Kadomtsev and V. D. Shafranov, Plasma Phys. Controlled Nucl. Fusion Res. **2**, 479 (1971)
[3] R. J. Bickerton, J. W. Connor, and J. B. Taylor, Nature Phys. Sci. **229**, 110 (1971)
[4] V. D. Pustovitov, JETP Lett. 54, 313 (1991)
[5] H. R. Wilson, Nucl. Fusion **32**,257 (1992)
[6] Y. Wu and R. B. White, Phys Fluids **5** 3291 (1993)
[7] M. Sasinowski and A. Boozer, Phys Plasmas **2** 613 (1995)
[8] Yang Chen and Roscoe White, Phys Plasmas **4** 3591 (1997)
[9] V. Ya. Goloborod'ko, Ya. I. Kolesnichenko, and V. A. Yavorsky, Nucl. Fusion **23**, 399 (1983)
[10] K. C. Shaing, R. D. Hazeltine, and M. C. Zarnstorff, Phys. of Plasmas **4**, 1375 (1997).
[11] S. Wang, Phys. of Plasmas **5**, 3319 (1998).
[12] K. C. Shaing, Phys. of Plasmas **7**, 5081 (2000).
[13] Yu. V. Gott and E. I. Yurchenko, Plasma Physics Reports **28**, 382 (2002).
[14] A. H. Boozer and G. Kuo-Petravic, Phys Fluids **24**, 851 (1981)

2C50

MHD-like plasma equations for hybrid-particle simulations*

H. Vernon Wong

Institute for Fusion Studies, University of Texas at Austin,
Austin, Texas 78712

Abstract

In particle simulations of electromagnetic plasma perturbations, the perturbed fields are frequently expressed in terms of the potentials $\delta\phi$, $\delta\mathbf{A}_{\|}$, and the parallel perturbed magnetic field $\delta B_{\|}$. The perturbed potential $\delta A_{\|}$ describes the Magnetohydromagnetic (MHD) plasma response. Ideal MHD plasma behaviour can however be adequately described by fluid equations and it is undesireable to reproduce fluid-like phenomena using numerical simulation. Furthermore, Ampere's law for $\delta A_{\|}$ involves the perturbed parallel component of the plasma current which in turn requires the computation of the first moment of the parallel particle velocity component. Thus to reproduce ideal MHD, the parallel particle trajectory must be determined accurately enough to reflect the fact that the particles and field lines tend to move together. An alternative choice is $\delta\phi$ and $\delta\mathbf{A}_{\perp}$ or equivalently $\xi = (\mathbf{b}\times\mathbf{A})/B$, with $\mathbf{A}_{\|} = 0$. The two sets of perturbed fields are related by a gauge transformation. The vector ξ is essentially the magnetic field line displacement and $\nabla_{\perp}\cdot\xi$ describes the field line compression. Plasma kinetic equations are derived for arbitrary perturbed pototentials $\delta\phi, \delta A_{\|}, \delta A_{\perp}$, and Maxwell's equations are formulated so as to require the evaluation of the plasma pressure rather than the plasma current. Gauge invariant linearised equations are obtained, and in the case where the chosen gauge is $\delta A_{\|} = 0$, they reduce to the conventional linearised MHD fluid equations. Kinetic effects are included by integrating the kinetic drift (or gyrokinetic) equation to calculate that part of the perturbed plasma pressure which depends on the details of the particle guiding center motion. Nonlinearities can be included by adding nonlinear terms quadratic in the field amplitudes. The suitability of these equations as the basis of a hybrid-simulation code is being explored.

*This work was supported by the U.S. Dept. of Energy Contract No. DE-FG03-96ER-54346

2C51

Full Wave Simulations of ICRF Mode Conversion and Lower Hybrid Propagation in Toroidal Geometry.*

J. C. Wright[1], P. T. Bonoli[1], M. Brambilla[2], and E. D'Azevedo[3]

[1]MIT Plasma Science and Fusion Center
Cambridge, MA

[2]Max-Planck Institute for Plasma Physics
Garching, Germany

[3] Oak Ridge National Laboratory
Oak Ridge, TN

ABSTRACT

The increased availability of massively parallel processing (MPP) systems has lead to the improved accessibility of some Full Wave (FW) phenomena and some new regimes as well. FW studies of mode conversion (MC) processes in toroidal plasmas have required prohibitive amount of computer resources in the past. The TORIC code solves the linear fourth order reduced wave equation for the ion cyclotron range of frequencies (ICRF) - in toroidal geometry using a Fourier representation for the poloidal dimension and finite elements in the flux dimension. It has been parallelized to access the increased available computer processing and memory of MPP computers. Mode conversion scenarios may now be done routinely in a few hours of elapsed time with only 32 processors – even large problems can be done with more processors. We present examples of fully converged studies of MC on Asdex-Upgrade and Alcator C-Mod. The new capabilities of the code extend beyond what is required for ICRF MC and permit studies of the very small wavelengths of lower hybrid (LH) waves. We will show preliminary results of FWLH calculations in C-Mod geometry. Some discussion of LH physics issues from a FW perspective, such as focusing, diffraction, and spectral broadening will also be given.

*Work supported by SciDAC and USDOE Contract No. DE-FC02-01ER54648.

2C52

Action Principle Derivation of Generalized Magnetofluid Models

Alexander Wurm* and P.J. Morrison
Institute for Fusion Studies and Department of Physics
The University of Texas at Austin
Austin, TX 78712

Abstract

As it is well-known, ideal MHD possesses an action principle formulation when it is expressed in terms of Lagrangian (or material) variables.[1] Starting with a general magnetofluid Lagrangian, we derive action principles for both MHD approximations and generalizations that contain more complete versions of Ohm's law.

[1] W.A. Newcomb, Nuclear Fusion: 1962 Suppl. Part 2, p. 451

* Supported by an appointment to the U.S. Department of Energy Fusion Energy Postdoctoral Research Program administered by the Oak Ridge Institute for Science and Education.

2C53

Nonlinear Dynamics of the Firehose Instability in Magnetic Dipoles*

Bai-Yu Xu, W. Horton, H.V. Wong, C. Crabtree, J. Van Dam

Institute for Fusion Studies, University of Texas at Austin,
Austin, Texas 78712

Abstract

There is renewed interest in the nonlinear dynamics of the firehose instability in magnetic dipoles because these modes remain as one possible explanation for the onset of plasma flow events called bursty bulk flows. The events are widely observed in the geotail plasma where the plasma pressure exceeds the magnetic pressure. We have developed a nonlinear model and computer simulations of the firehose instability. The nonlinear model gives saturation due to nonlinear weakening of the magnetic curvature force from the pressure anisotropy for large field line distortions. In addition, kinetic theory effects related to the Hall MHD fluid description are required to limit the k_z for the fastest growth rate. A δf code is used to investigate the bounce averaging effects on the growth rate. The quasilinear isotropization of the pressure anisotropy is thought to be of secondary importance because there is a strong mechanism to support this anisotropy. As flux-tubes convect toward the center of the dipole their field lines will shorten. To conserve J as an adiabatic invariant requires an increase in the parallel pressure. A new nonlinear initial value fluid code is used to invetigate the instability and the nonlinear states for dipole geometries.

*This work was supported by the U.S. Dept. of Energy Contract No. DE-FG03-96ER-54346 and the National Science Foundation Grant ATM-9907637

2C54

Development of the kinetic adaptive MHD codes: AEGIS

L.-J. Zheng, M. Kotschenreuther

Institute for Fusion Studies, University of Texas at Austin, Austin, TX 78712

A. Turnbull

General Atomic, San Diego

Abstract

The principle object of current work is to develop a generalized MHD (AEGIS: Adaptive EiGenfunction Independent Solution) code with non conventional MHD effects included, such as plasma rotation, finite Larmor radius, wave-particle resonance, and energetic particle effects. These kinetic effects are often important in thin inertial layers, so a spatially adaptive solution procedure has been devised to be highly efficient on parallel architectures. Especially, it is intended to use the code to study the rotation effect on the ideal and resistive wall modes with the kinetic description of the compressibility term. With the parallel electric field and trapped particle effects included, the code can be also used to study the ST device. Our code follows some parts of philosophy of DCON by abandoning relaxation methods based on radial finite element expansion in favor of an efficient shooting procedure with adaptive gridding. The δW criterion is replaced by the shooting procedure and subsequent matrix eigenvalue problem. Since the technique of expanding a general solution into a summation of the independent solutions employed, the rank of the matrices involved is just a few hundreds. This eases the eigenvalue problem with non-ideal MHD effects. To include kinetic effects, the approach of solving for the distribution function as a local eigenvalue ω problem as in the GS2 code will be employed in the future. The ideal MHD version of the code: "AEGIS_mhd" has been developed. Benchmarking with existing major MHD codes: GATO, PEST, and DCON is in the progress. In constructing the vacuum code the following liquid metal wall is considered in collaboration with the APEX group in order to develop the liquid metal wall concept. Rotation effects will be included next, followed by FLR and full kinetc effects, noting that kinetic ion dissipation frequently determines MHD stability with FLR. The authors acknowledge various contributions for including the non-ideal MHD effects into the code from IFS theorists.

Tuesday Evening, April 29

19:00 to 21:00

Corpus Christi Ballroom C

Oral Session 2D

2D01

Zonal flow spectra and the reduction of collisionless trapped electron turbulence by nonlinear damping

P.W. Terry and R. Gatto
University of Wisconsin-Madison, Madison, Wisconsin 53706

Abstract

Close analogs with quasigeostrophic turbulence and rotating 3D fluid turbulence indicate that plasma zonal flows in drift-wave-type turbulence are the condensate of an inverse spectral energy transfer process in which the spatial structure of the zonal flow is an expression of the anisotropy of the zero frequency wave.[1] This principle allows calculation and assessment of key properties of the system. In quasigeostrophic turbulence it yields the zonal flow spectrum.[2] We use it to derive two additional results: an expression for the timescale required for excitation of zonal flows in an inverse cascade driven by stirring at small scale, and a demonstration that in such a spectrum there is no suppression of turbulence by zonal flow shearing, because the shear suppression criterion is nowhere satisfied in the spectrum. We apply this type of analysis to collisionless trapped electron mode (CTEM) turbulence, first noting that systems with multiple fields must be transformed to the eigenmode decomposition, the analog of the helical decomposition employed in rotating 3D turbulence. Like rotating 3D turbulence, both eigenmodes are excited, even though in CTEM, one eigenmode is damped for all wavenumbers. The excitation of the damped eigenmode introduces a significant amount of finite-amplitude-induced dissipation, which saturates zonal flows and is a significant saturation mechanism for the smaller scale turbulence. A closure calculation yields the relative magnitudes of all fields, while spectral variation is obtained from the appropriate balance of wave frequency and nonlinearity. The power spectra go as k_x^{-3} for both the electron density and the potential. We find that in an inertial range there is no suppression of turbulence by zonal flow shearing. In the wavenumber range of unstable modes, suppression is possible provided the scale separation between zonal modes and turbulent modes ($\Delta_{zf}/\Delta_{turb}$) does not exceed the inverse nonadiabaticity parameter δ^{-1} of the CTEM instability. However, the energy dissipation rate associated with the excitation of the damped eigenmode is much larger than the enhanced decorrelation associated with zonal flow shearing. The ratio goes as $\delta^{-3/2}(\Delta_{zf}/\Delta_{turb})^{5/2}$. This indicates that the order of magnitude reduction in fluctuation level observed when zonal flows are included in CTEM simulations is a result primarily of the dissipation associated with the damped eigenmode, and not zonal flow shearing. The important role played by the damped eigenmode in CTEM turbulence is discussed in connection with the observation of geodesic acoustic mode excitation in DIII-D and TEXT.

[1] P.W. Terry, R. Gatto, and D.A. Baver, Phys. Rev. Lett. **89**, 205001 (2002).
[2] A. Chekhlov *et al.*, Physica D **98D**, 321 (1996).
Work supported by USDOE.

2D02

Zonal flow dynamics and size-scaling of anomalous transport

Liu Chen

Department of Physics and Astronomy, University of California, Irvine CA 92697-4575, U.S.A.

Roscoe B. White

Princeton Plasma Physics Lab, PO Box 451, Princeton NJ 08543, USA

Fulvio Zonca

Associazione EURATOM-ENEA sulla Fusione, C.P. 65 – 00044 Frascati, Italy

The dependence of plasma confinement on the device size is obviously a very crucial issue in fusion energy research. Assuming drift waves are responsible for the anomalous transport, this size-scaling issue then can be reduced, in the simplest model, to the dependence of drift-wave fluctuation intensity on ρ_*. Here $\rho_* = \rho_i/L$ with ρ_i and L being, respectively, the ion Larmor radius and the plasma inhomogeneity scale length. Since in the $L \to \infty$ limit, the coherent 4-wave drift wave-zonal flow modulation interaction model of Chen, Lin and White [1] has captured the essential features observed in global gyrokinetic simulations, we are thus motivated to adopt , as a theoretical paradigm, the coherent 4-wave model including the finite L (i.e., finite ρ_*) plasma inhomogeneities. In this finite-ρ_* coherent 4-wave model, thus, not only the pump radial envelope will be localized leading to reduction in the modulational instability growth rate due to the finite interaction region; but more interestingly the damped pump and sidebands will disperse outward leading to radial spreading of the drift wave turbulence; qualitatively similar to that observed in recent simulations by Lin et al [2].

We have constructed a numerical model which displays these features. Thresholds, growth rates, and nonlinear saturation properties are studied as a function of scale length L. Results are compared to gyrokinetic simulations.

References

[1] Liu Chen, Zhihong Lin and Roscoe White, Phys. Plasmas **7**, 3129, (2000).

[2] Z. Lin, S. Ethier, T.S. Hahm and W.M. Tang, Phys. Rev. Lett. **88**, 195004, (2002).

#

2D03

Simulations of Electromagnetic Microtubulence with Kinetic Electrons[1]

Y. Chen and S. E. Parker[2]
University of Colorado, Boulder, CO 80309

A new numerical algorithm has recently been developed that allows for simulation of electromagnetic tokamak microturbulence with drift-kinetic electrons, experimental values of plasma β, and realistic mass ratios using gyrokinetic δf particle-in-cell (PIC) simulation methods[3]. PIC methods of this type have the computational advantage of resolving particle-wave resonance effects using only a three-dimensional spatial grid. Such simulations can use a very large number of particles ($10^8 - 10^9$) thereby providing a useful tool to determine if fine phase space resolution is needed for the microturbulence problem. The new algorithm solves a long-standing problem in gyrokinetic particle simulation when kinetic electrons and finite-β effects are introduced[4]. The problem is associated with the electron current of the zero-order distribution (Maxwellian in terms of parallel canonical momentum) which typically far exceeds the total perturbed current. It is solved here by evaluating this current using the same marker particles and the same particle shape as that used for the perturbed distribution to get near exact numerical cancellation. The simulation uses three-dimensional toroidal field-line-following flux-tube geometry and includes electron-ion collisional effects. Linear benchmarks show good agreement with continuum codes[5]. It is found that for H-mode parameters, the nonadiabatic effects of kinetic electrons increase linear growth rates of the Ion-Temperature-Gradient-Driven (ITG) modes, mainly due to trapped-electron drive. The ion heat transport is also increased from that obtained with adiabatic electrons. The ion heat transport decreases to below the adiabatic electron level when finite plasma β is included due to finite-β stabilization of the ITG modes. This may help explain why past H-mode results predicted transport levels much too high[6].

---

[1]work supported by the US Department of Energy SciDAC Plasma Microturbulence Project

[2]with Summit Framework collaborators: B. I. Cohen, A. M. Dimits, W. M. Nevins, D. Shumaker, LLNL; V.K. Decyk, J.N. Leboeuf, UCLA

[3]Y. Chen and S. E. Parker, submitted to J. Comput. Phys. 2002.

[4]J. Cummings, Ph.D thesis, Princeton University, 1994; Y. Chen and S. E. Parker, Phys. Plasmas 8, 2095 (2001)

[5]J. Candy and R. Waltz, General Atomics Rep. GA-A23876, to appear in J. Comput. Phys.; W. Dorland et. al, Proc. 18th Intnl. Conf. on Fus. Energy, IAEA, Sorrento, Italy, 2000

[6]A. M. Dimits, et al. Phys. Plasmas 7, 969 (2000)

2D04

Enhanced Neoclassical Polarization and its Equivalence to the Pinch Effect

Kim Molvig, Yong Xiao, Darin R. Ernst, Klaus Hallatschek
Plasma Science and Fusion Center, Massachusetts Institute of Technology, Cambridge, MA 02139

Abstract

The absence of collisionless damping of so-called zonal flows accounts for their prominance in the saturation of ion temperature gradient (ITG) turbulence in tokamaks. In fact, a tokamak responds to zonal flows with a reactive, neoclassical polarization current.[1] This neoclassical polarization response is *small*, of order $\varepsilon^{3/2}$ times the neoclassical factor, $\frac{\omega_{pi}^2}{\omega_{ci}^2}\frac{q^2}{\varepsilon^2}$, where ε is the inverse aspect ratio. Any increase in this polarization, which shields the zonal flow potential, could have significant adverse effects on tokamak transport. Even if the polarization response remains reactive, the zonal flows produced by ITG turbulence would be reduced and thereby raise the saturated turbulence level. A new effect which increases this neoclassical polarization by a factor of order ε^{-1} is presented in this paper. We show that this neoclassical polarization is equivalent to the pinch effect driven by the toroidal electric field. This equivalence orginates with the replacement of the time varying radial electric field by an inertial toroidal force, $F_\zeta = -m_i c/B_p\left(\partial E_r/\partial t\right)$, from which one can compute the radial currents in an exact, to order ε, replica of the pinch effect. This calculation is carried out using the Lagrangian formulation of neoclassical transport[2] so that we can clearly understand, recognize and separate the collisionless flows of Rosenbluth and Hinton[1] (RH) from potentially new collisional processes. The smallness of the RH polarization is attributed to a kinematic cancelation recognized some time ago for the Ware effect.[2] Although trapped particles drift inward radially under the influence of the toroidal electric field, the circulating particles actually drift out, collisionlessly, canceling the Ware pinch completely, to leading order in $\varepsilon^{1/2}$. This same cancelation occurs for the RH polarization, leaving just the small residual, $\mathcal{O}\left(\varepsilon^{3/2}\right)$. The new effect proposed here, which increases the neoclassical polarization, is identical to the process which produces the actual pinch in neoclassical theory – a collisional process on circulating particles whereby velocity and radial scattering (of mean orbits) are correlated. It is interesting that the net neoclassical polarization, including the new effect, behaves as though the trapped particles respond in the obvious way, $v_\zeta \sim cE_r/B_p$, with no circulating particle response, just like the neoclassical pinch can appear to be the Ware pinch for trapped particles, with no circulating particle response. The true microscopic physics is in fact quite different. Simulation work is in progress to verify these predictions using GS2[3] and neoclassical codes.

[1]M.N. Rosenbluth and F.L. Hinton, Phys. Rev. Lett. 80, 724 (1998).
[2]I.B. Bernstein and K. Molvig, Phys. Fluids, 26, 1488 (1983).
[3]W. Dorland, F. Jenko, M. Kotschenruther, B.N. Rogers, Phys. Rev. Lett. 85, 5579 (2000).

Wednesday Morning, April 30

8:30 to 9:30

Corpus Christi Ballroom C

Review Talk 3A

3A01

Scaling astrophysical hydrodynamics to high energy density laboratory experiments

D.D. Ryutov[+]

Lawrence Livermore National Laboratory, Livermore, CA 94551, USA

Abstract

A broad range of astrophysical phenomena can be adequately described by hydrodynamic (magnetohydrodynamic) equations. In particular, astrophysical jets, photoevaporated molecular clouds, and certain stages of supernova explosions fall into this category. As was demonstrated during the past few years, properly designed laboratory experiments can provide important insights into the processes involved (e.g., [1-4]). Not only do they make possible benchmarking of codes used for simulating astrophysical phenomena but, in a number of cases, allow studying issues which are still outside the realm of computer simulations.

We discuss several phenomena that can be adequately simulated in high-energy-density laboratory experiments. After having summarized observational data and outlined the scaling issues, we describe existing and suggest new experiments. We consider the following specific problems: dynamics of photoevaporated molecular clouds (star nurseries), with an emphasis on possible role of tangled magnetic fields; momentum transfer to a core (future neutron star) in a non-spherically symmetric supernova explosion; implosion of rotating stars; and generation of magnetized jets.

We also describe a proposed experiment that allows one to make direct evaluation of the role of small-scale turbulence in high-energy-density experiments of relevance to astrophysics.

Work performed under the auspices of the U.S. Department of Energy by University of California Lawrence Livermore National Laboratory under contract W-7405-Eng-48.

[+] In collaboration with B.A. Remington.

1. Remington B A, Drake R P, Takabe H, Arnett D 1999 *Science* **284** 1488; Remington B A, Drake R P, Takabe H, Arnett D 2000 *Phys. Plasmas* **7** 1641
2. Robey H F, Kane J O, Remington B A, Drake R P, Hurricane O A, Louis H, Wallace R J, Knauer J, Keiter P, Arnett D, Ryutov D D 2001 *Phys. Plasmas* **8** 2446.
3. Lebedev S V, Chittenden J P, Beg F N, Bland S N, Ciardi A, Ampleford D, Hughes S, Haines M G, Frank A, Blackman E G, Gardiner T 2002 *ApJ* **564** 113.
4. Ryutov D D, Drake R P, Kane J O, Liang E, Remington B A, and Wood-Vasey W M 1999, *ApJ* **518** 821; Ryutov D D, Drake R P, and Remington B A 2000 *ApJ - Supplement* **127** 465; Ryutov D D, Remington B A, Robey H F, Drake R P 2001 *Phys. Plasmas* **8** 1804.

Wednesday Morning, April 30

9:30 to 10:00

Corpus Christi Ballroom C

Oral Session 3B

3B01

Power deposition mechanism in helicon plasma sources

A. Arefiev and M. Panevsky

The University of Texas at Austin, Austin, TX 78712

Abstract

Despite the fact that helicon sources are routinely used for production of dense plasmas, the mechanism of power deposition into the plasma is yet to be clearly understood. Helicon sources produce plasma supposedly via helicon waves excited by an rf-antenna. It is crucial that these waves are strongly affected by the plasma density gradient. As a result, the eigenmodes in the discharge are drastically different from those in a homogeneous plasma [1]. We have performed a dedicated experiment to identify the eigenmodes and to examine their role in the power deposition. The Argon helicon plasma is created using a primary rf-generator, while an eigenmode is excited by a secondary low-power generator with variable frequency. Our data confirm the existence of an eigenmode with frequency just below the operational frequency. Measuring the power absorption by the plasma as a function of the antenna frequency for a fixed density profile, we observed a sharp absorption peak down shifted from the primary generator frequency representing an eigenmode excitation. We used a magnetic probe to measure the amplitude of the magnetic field perturbations at the primary frequency downstream from the antenna. Assuming that the eigenmode is a radially localized helicon mode [1], we have used the measured signal to calculate the wave energy density and the corresponding power absorption. This absorption accounts for only a fraction of the power deposited by the primary generator, which clearly indicates that the main part of the power is not deposited via helicon modes.

Motivated by this observation, we have investigated the possibility of power deposition via the excitation of electrostatic waves. The perturbed magnetic field is very small compared to the electric field in these waves, which may explain a low level of signal at the magnetic probe. These waves have a very short radial scale-length and can propagate in plasma even when their frequency is below the low-hybrid frequency, provided that there is a sufficient density gradient. We computed the total power deposited into a long plasma column by exciting electrostatic waves via a finite-length capacitive antenna. The resonantly absorbed power is independent of the dissipation mechanism and its value gives an upper estimate for the power deposition in the experiment. The electrostatic power deposition analysis is being combined with a particle balance analysis [2] to develop a self-consistent description of a helicon plasma source.

Research is supported in part by Johnson Space Center, NASA.

[1] B. N. Breizman and A. V. Arefiev, Phys. Rev. Lett. 84, 3863 (2000).
[2] B. N. Breizman and A. V. Arefiev, Phys. Plasmas 9, 1015 (2002).

Wednesday Morning, April 30

10:30 to 12:00

Corpus Christi Ballroom C

Oral Session 3C

LiWall tokamak regimes and our path to the fusion power reactor

L. E. Zakharov[1], S.Krasheninnikov[2], R. White[1], P.Parks[3]

[1] *Princeton Plasma Physics Laboratory, MS-27 P.O.Box 451, Princeton NJ 08543-0451,*
[2] *University of California, San Diego, Energy Research Center, La Jolla CA 92093,*
[3] *General Atomic, P.P.Box 85608, San Diego, CA, 92186-5608*

February 28, 2003

Since its first formulation in Dec.1998, the LiWall concept has made an outstanding progress is developing the new vision of the magnetic fusion power reactor, its regime, design and development path. It was shown, that a number of fundamental requirements for the power reactor, such as a stable, high-beta operation with a high density of the DT power (10 MW/m^3), high wall load (10 MW/m^2), efficient power extraction from the plasma (consistent with the plasma facing elements), efficient power conversion into electricity, tritium cycle and control, etc (which is still out of reach by the conventional approach), fits well the LiWall reactor concept.

Concerning the plasma regime, LiWall relies on a low recycling plasma edge and on a high-beta, wall stabilized plasma with the lithium coated surface in a contact with the high-temperature plasma edge. The resulting flat temperature profile eliminates the Troyon beta-limit and the thermo-conduction transport, thus, creating a unique situation, where the plasma control can be performed exclusively by the core plasma fueling.

The present talk addresses the consistency of the LiWall physics with the operational power reactor regime in both small scale (30 m^3) demonstration Ignited Spherical Tokamak (IST) device (0.5 GW of the DT power) and in a LiWall tokamak power reactor (R=6.4 m, a=1.6 m, 380 m^3 volume, 4 GW DT power). It is shown that the LiWall regime opens a wide parameter space for a reliably stable operation at high-beta with a 100 % (or overdriven) bootstrap current value (calculated by direct numerical simulations of the plasma particle trajectories).

Finally, the apparently unsolvable problem of core fueling, which is fundamental for an entire magnetic fusion, has been resolved in a beautiful way, consistent with the low recycling, high-temperature plasma of the LiWalls. This recent achievement removes the most prominent plasma physics objection against the low recycling LiWall regime. It puts the LiWall in the leading position as a magnetic fusion concept with a practical R&D path to an Ignited Spherical Tokamak demonstration experiment (possible in about 8-10 years), then IST based ignited Component Test Facility (12-15 years) and, finally, to the LiWall fusion power reactor (in 20-25 years).

3C03

Poloidally Localized Fueling Effects on Toroidal Flow and Radial Electric Field

T. Fülöp[(1)], P. Helander[(2)], P. J. Catto[(3)],
N. J. Conway[(2)], A. R. Field[(2)], and H. Meyer[(2)]

[(1)] Department of Electromagnetics, Chalmers University of Technology

[(2)] EURATOM/UKAEA Fusion Association, Culham Science Centre

[(3)] Plasma Science and Fusion Center, Massachusetts Institute of Technology

Abstract

Neutrals at the edge of tokamaks can affect confinement by altering the radial electric field and toroidal plasma flow velocity through charge-exchange and ionization interactions. We show that the flow and electric field are very sensitive to the poloidal location of the neutrals and the ion collisionality. These predictions are consistent with differences observed on MAST between measured toroidal flows for inboard and outboard gas puffing, and may also explain observations indicating that inboard puffing allows easier H mode access [1]. In a collisional plasma the neutral kinetics is treated first in the short mean-free path limit and then for arbitrary mean-free path [2] by employing a self-similar neutral distribution function obtained for special temperature and density profiles [3]. The resulting neutral distribution function is used to investigate neutral effects on the ion flow and electrostatic potential as the neutral mean-free path varies from being very short to being comparable to the scale length of plasma density and temperature. In addition to recovering short mean-free path results, we find that neutral effects on the flow and radial electric field depend sensitively on the poloidal location of the neutrals, especially in a spherical tokamak. In particular, we find that the radial electric field and outboard toroidal flow velocity in a collisional edge plasma tend to be larger if the atoms are concentrated on the inboard side rather than on the outboard side - consistent with the MAST results and suggesting that the flow shear introduced by the neutrals is suppressing edge turbulence and playing a role in forming the edge transport barrier. These results are then shown to be sensitive to plasma collisionality by considering banana regime ions and collisional neutrals. In this case, larger outboard toroidal flow and radial electric field are obtained for outboard puffing - suggesting that outboard puffing could suppress edge turbulence and generate an edge transport barrier in tokamaks with less collisional edges.

[1] P. G. Carolan, et al, 19th IAEA Fusion Energy Conference, Lyon, France 14-19 October 2002, paper IAEA-CN-94/EX/C2-6-6, submitted to Nucl. Fusion.

[2] T. Fülöp, P. Helander and P. J. Catto, Phys. Rev. Lett. 89, 225003 (2002).

[3] P. Helander and S. I. Krasheninnikov, Phys. Plasmas, 3, 226 (1995).

This work was funded by EURATOM under association contracts with Sweden and UK, by the UK Department of Trade and Industry, and by the US Department of Energy.

Author Index

Author Index

Author Index

Author Index

Author Index

Monday, April 28,

08:20. Welcome: Wendell Horton, Local Organizing Committee. Ballroom C, Omni Hotel, Bayfront Tower, Third Level

08:30. Review Talk 1A. New Frontiers in Controlling the Motion of Matter with Light: From Single Atoms to Neurons. *Mark Raizen*
Chair: Diego del-Castillo-Negrete

09:30. Oral Session 1B. Blob Stability and Transport in the SOL Plasma. *Dan D'Ippolito*
Chair: Diego del-Castillo-Negrete

10:00. Poster Session 1C.
Coffee Break during Poster Session

12:00. Lunch

Oral Session 1D. Chair: Carl R. Sovinec

13:30. The Three-Dimensional MHD Dynamics of ac Helicity Injection. *Fatima Ebrahimi*

14:00. Relaxation Current Drive in Spheromaks as a Forward Energy Cascade Requiring Sufficient Lundquist Number. *Valerie Izzo*

14:30. Stability Properties of Field-Reversed Configurations. *Elena Belova*

15:00. The Behavior of Current/Vortex Sheets in Extended MHD: A System-Scale Theory for Fast Reconnection? *Luis Chacon*

15:30. Poster Session 1E.
Coffee/Beverage Break during Poster Session

Tuesday, April 29

8:30. Review Talk 2A. The Earth Simulator and Its Impact on Science and Technology. *Tetsuya Sato*
Chair: Linda Sugiyama

9:30. Oral Session 2B. Linear Theory and Chaos: Breakthrough in the Description of Wave-Particle Interaction in Plasmas. *Dominique Escande*
Chair: Linda Sugiyama

10:00. Poster Session 2C.
Coffee Break during Poster Session

12:00. Lunch—Free Afternoon

17:30. Fajita Feast. Omni Hotel, Bayfront Tower, Third Level

Oral Session 2D. Chair: Ron Waltz

19:00. Zonal Flow Spectra and the Reduction of Collisionless Trapped Electron Turbulence by Nonlinear Damping. *Paul Terry*

19:30. Zonal Flow Dynamics and Size-Scaling of Anomalous Transport. *Liu Chen*

20:00. Simulations of Turbulence Transport with Kinetic Electrons and Electromagnetic Effects from the Summit Framework. *Yang Chen*

20:30. Enhanced Neoclassical Polarization and its Equivalence to the Pinch Effect. *Kim Molvig*

Wednesday, April 30

8:30. Review Talk 3A. Scaling Astrophysical Hydrodynamics to High Energy Density Laboratory Experiments. *Dmitri Ryutov*
Chair: Boris Breizman

9:30. Oral Session 3B. Power Deposition Mechanism in Helicon Plasma Sources.
Alexei Arefiev
Chair: Boris Breizman

10:00. Coffee Break

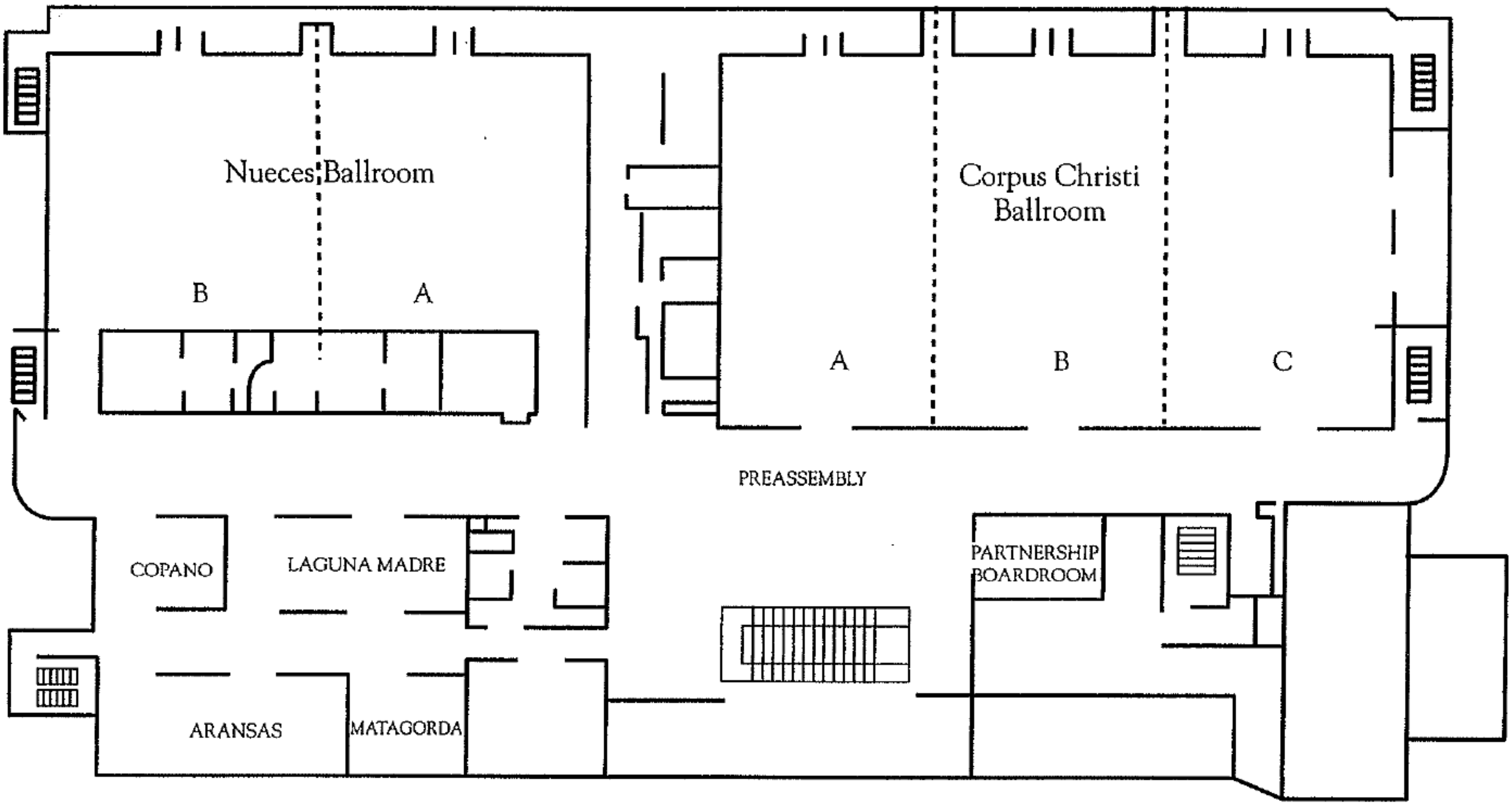
Oral Session 3C. Chair: Tom Rognlien

10:30. Delta-W Calculation of Magnetic Islands in Plasma Equilibria. *Allen Boozer*

11:00. LiWall Tokamak Regimes and Our Path to the Fusion Power Reactor. *Leonid Zakharov*

11:30. Poloidally Localized Fueling Effects on Toroidal Flow and Radial Electric Field.
Tunde Fülöp

THIRD FLOOR



Nueces Ballroom
B
A
Corpus Christi
Ballroom
A
B
C
PREASSEMBLY
COPANO
LAGUNA MADRE
PARTNERSHIP
BOARDROOM
ARANSAS
MATAGORDA