JOINT INSTITUTE FOR FUSION THEORY

NEWSLETTER

September 1986 No. 9

Joint Institute for Fusion Theory

The Institute for Fusion Studies (IFS) at the University of Texas at Austin and the International Center for Fusion Theory (ICFT) in Nagoya work together to form the Joint Institute for Fusion Theory (JIFT). The primary purpose of JIFT is to foster the progress of scientific research by providing a planned set of exchange visits, workshops, and computational projects that involve United States and Japanese theoretical plasma physicists working on problems associated with the development of fusion systems.

The JIFT Steering Committee members are:

Prof. Y. Ichikawa - Director of ICFT, Nagoya

Prof. K. Nishikawa - Hiroshima University

Dr. W.L. Sadowski, Chief, Fusion Theory and Computer Services, U.S. Dept. of Energy

Prof. M.N. Rosenbluth - Director of IFS, University of Texas at Austin

Prof. J.M. Dawson - University of California at Los Angeles

JIFT activities are coordinated in the U.S. and Japan by two committees. The Japanese Management Committee consists of T. Kamimura (IPP)--Chairman, T. Sato (HIFT), T. Takeda (JAERI), and M. Wakatani (Kyoto). The U.S. Management Committee is at the IFS and consists of W. Horton--Chairman, J-N. Leboeuf, T. Tajima, and J.W. Van Dam.

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Exchange Scientists for 1986 to 1987

Dr. Gregory Rewoldt, PPPL, Visiting Scientist to Kyoto University and IPP Nagoya
September 7 - December 27, 1986
Stellarator Expansion MHD Analysis of Equilibrium and Stability

Dr. Ronald Waltz, GAT, Visiting Professor to IPP Nagoya
July 15 - November 20, 1986
Anomalous Transport

Prof. Herbert L. Berk, IFS, Visiting Scientist to IPP Nagoya
May 13 - June 20, 1986
Bumpy Torus, Trapped Particle Modes, and Hot Electron Physics Stability

Prof. T. Hatori, IPP Nagoya, Visiting Professor to Dartmouth and IFS
September 15, 1986 - January 15, 1987
Theory of Chaotic and Turbulent Phenomena in Plasmas

Prof. Hiromu Momota, IPP Nagoya, Visiting Scientist to IFS
January 1 - ~~April~~ March 30, 1987
Stabilization of FRC Plasmas by Energetic Particle Beams

Workshops for 1986 to 1987

Japan to US:

(1) *MHD Stability of Strongly Shaped Cross Section Tokamak*
Organizers: D. Sigmar and T. Amano
Location: GA Technologies
Date: January 19-23, 1987

(2) *Anomalous Transport*
Organizers: R. Waltz and M. Wakatani
Location: GA Technologies
Date: 1987

Workshops for 1986 to 1987 - *cont'd.*

US to Japan:

(1) *Advanced Plasma Modeling*
Organizers: T. Kamimura and J. Dawson
Location: IPP Nagoya
Date: March, 1987

(2) *MHD Relaxation Processes*
Organizers: T. Sato and H. Strauss
Location: Hiroshima
Date: 1987

Joint Computational Projects for 1986 to 1987

JIFT Joint Computational Projects involve collaboration by the participants through the MFENET-IPPNET computer link, as well as a visit of approximately one month's duration by one US scientist to Japan and vice versa.

(1) *Long-Time-Scale/Large-Space-Scale Implicit Methods for Particle Simulations*
Organizers: T. Kamimura, T. Tajima, and J-N. Leboeuf
Location: IPP Nagoya and IFS Texas

(2) *RF Heating and Current Drive*
Organizers: V. Decyk and H. Abe
Location: Kyoto University and UCLA

(3) *3D MHD Studies by BETA Code*
Organizers: M. Wakatani and F. Bauer
Location: Kyoto University and NYU

Reports from 1986 Workshops

3D MHD Simulation

Organizers: B. Carreras and T. Sato
Location: ORNL
Date March 3-7, 1986

Five Japanese scientists and six US scientists participated in this small workshop. The Japanese delegation consisted of T. Sato (HIFT), T. Takeda (JAERI), I. Kawakami (Nihon University), M. Wakatani (Kyoto University), and T. Hayashi (HIFT). There were some technical discussions and a few informal presentations; however, the primary purpose of this workshop was to prepare a report summarizing the activities on 3D MHD studies at the four US-Japan workshops held on this subject during the last five years.

This series of four workshops has covered a broad range of issues concerning macroscopic equilibrium and the linear and nonlinear stability properties of magnetically confined plasmas in many configurations (including tokamak, stellarator, RFP, spheromak, mirror, bumpy torus, compact torus, and FRC). During the period of these workshops, 3D MHD studies evolved rapidly due to three factors. The first has been the enhancement of computational facilities in both Japan and the US. New, powerful computers (CRAY I, XMP, II, FACOM VP100 and VP200) became available to fusion researchers, and their use was facilitated through continuous development of the computer networks (USMFE and IPP Nagoya) and through the user-oriented attitude of the people managing them. Recently, computer linkage between the two networks has been achieved. Second, the development of efficient and reliable numerical techniques and methods of calculation for 3D nonlinear computations has steadily continued. The third factor has been the related progress in the development of analytical models to understand and complement the numerical calculations, which has permitted effective use of the numerical results.

The report then highlights a number of major computational achievements during this five year period:

"(1) *Tokamak*: MHD simulations have led to a good understanding of the macroscopic behavior of tokamaks. Computations are able to reproduce events such as internal sawteeth and major disruptions. Various scenarios have been put forth for the major disruption such as nonlinear mode coupling, surface deformation, and contact of islands with limiters. Internal disruptions of various sorts, such as complete relaxation, partial relaxation, and continuous oscillations have been produced in the simulations. The simulations have explored ways to avoid major disruption by seeing what effects shaping, finite beta, and aspect ratio would have on these events. In addition to the disruptions, simulations have been able to reproduce diagnostic measurements such as soft x-ray and Mirnov loop measurements.

"(2) *Stellarator*: New numerical tools have been developed. They have allowed the investigation of equilibrium and stability beta limits for intrinsically 3-D configurations. The controversy on the role of shear versus magnetic well has been resolved in favor of shear, because with shear, a magnetic well is always obtained and one has the benefit of both. The theoretical developments have permitted the design of new experiments based on MHD optimization. Stable access to the second stability regime in a controlled way will be possible in some of these experiments.

"(3) *Reversed Field Pinch*: In 1981, understanding of the dynamics of the RFP was limited to two-dimensional, single helicity calculations. Subsequently, three-dimensional algorithms were developed to study relevant long wave length, low frequency motions. These algorithms were necessarily more complex than those developed previously for tokamaks due to the nature of the RFP magnetoplasma system. Recently these codes have yielded an understanding of the phenomena of plasma relaxation, self-reversal, profile sustainment, flux generation, and dynamo action. Experimental observations such as sawtooth oscillations have also been explained. Present

applications include the simulation of F-Θ pumping, a possible method for low frequency current drive. Studies of high frequency, short wavelength turbulence, and its implications for anomalous transport, are also underway.

"(4) *Spheromak*: The following areas of spheromak research have been addressed with 3-D MHD simulations: the injection of helicity using an induction scheme, the gun-injection of helicity, spheromak merging, the destructive evolution of the tilting spheromak, the stabilization of the tilt mode through an analysis of wall position, central conductors, external coils, vessel shape, line-tying, and rotation, and the resistive evolution of both the decaying and sustained phases of the gun-injected spheromak."

The report also summarized the main benefits that have been derived from the US-Japan workshops, viz., channeling communications on recent results and developments in 3D MHD studies, building complementary approaches to 3D calculations to avoid duplication of effort, and facilitating fruitful contact and collaborations between researchers in both countries.

Finally, the report suggests future directions for continued work in this area: (1) a shift from feasibility considerations to an increase in extraction of physics information and detailed comparison with experiment; (2) an assessment of the different approaches in 3D MHD calculations--i.e., as computer capabilities change, so will the optimal approach to a problem; and (3) a continuation of improvement in numerical techniques with the goal of faster and more reliable 3D calculations. The report concludes by stating that "the US-Japan cooperation and workshops in 3D MHD studies can play an important role in these future developments. In relation to the first point, the complementarity of experimental facilities and 3D MHD computational capabilities in both countries makes exchanges of information advisable. As groups in Japan and the US have followed different approaches to the 3D calculations, future workshops will be valuable for the assessments of these approaches. Finally, as indicated before, the character of these meetings have been conducive to the exchange of detailed information. This is very difficult to do in meetings having a broader scope. The US-Japan Workshops on 3D MHD studies have been the only regular specialized meetings on this topic. The discussions of the new numerical techniques tried by the different groups involved in this area of research have been and can continue to be very stimulating." Its recommendation is that these workshops continue to be held biannually.

Statistical Plasma Physics

Organizers: R. Littlejohn and T. Hatori
Location: IPP Nagoya
Date: February 17-21, 1986

Talks by twenty-one Japanese scientists and five US participants were presented at this workshop. The US delegation consisted of R. Littlejohn (UC Berkeley), J. Meiss (IFS), W. Horton (IFS), D. Dubin (UC San Diego), and J. Krommes (PPPL). The Japanese contingent included theorists in statistical mechanics from Nagoya, Hiroshima, Tokyo, and Kyoto, as well as fusion theorists from the JAERI and Heliotron projects. The purpose of this conference was to bring together Japanese and US scientists with common interests in the areas of plasma transport and confinement, nonequilibrium statistical mechanics, and applications of dynamical system theory to transport processes in plasmas.

There were several main themes to the conference, all relatively recent in development:

(1) Clump theory, its limits of applicability, and relevance to transport and diffusion.
(2) New ideas in WKB theory, such as phase space concepts and their application to wave packet evolution.
(3) Mean field theories, renormalization group, and coherent anomalies, as applied to the asymptotic behavior of cooperative systems.
(4) Selective relaxation and applications to time asymptotic behavior of plasmas.
(5) Self-organization processes in 3D MHD.

(6) Transport in Hamiltonian systems due to breakdown of KAM tori.
(7) Long-time correlation in Hamiltonian systems, such as Z-wave systems applied to drift wave turbulence.
(8) Intermittency, symbolic dynamics, and models of 1/f noise.

The invited papers will be published by the Institute of Plasma Physics, Nagoya.

Reports from 1985 to 1986 Exchange Scientists

Russell M. Kulsrud

Visiting Professor to IPP Nagoya and Kyoto University
September 1 - December 31, 1985

Prof. Kulsrud, from Princeton Plasma Physics Laboratory, spent one month based at IPP Nagoya. Here he worked on reversed field pinches, the Taylor invariant, polarized nuclei, and stellarators. He also gave a series of six lectures on magnetic reconnection and stellarator transport, which were published as a report (IPPJ-762).

The rest of his time was spent at the Heliotron Laboratory of Kyoto University, where he collaborated with M. Wakatani and K. Itoh. Here he worked on tearing modes, reconnection, polarization, stellarator transport, and wave trapping and amplification by alpha particles in tokamak reactors. In particular, he worked with Itoh on determining the importance of ripple transport for the confinement of energy and particles in Heliotron-type stellarators. Previously, a detailed comparison with transport in the Heliotron experiment had shown that the predicted transport was larger than that observed. A possible reason for this discrepancy was now found as follows. Theoretically a radial electric field is necessary to establish equality of electron and ion particle transport; this electric field was found to be directed outward so as to hold electrons back. Inclusion of this electric field modified the theoretical prediction of the rate of energy transport for electrons and brought the results in line with experimental measurements. In fact, the ripple transport was so nearly equal to measured values that the anomalous transport in Heliotron E may be inconsequential. This agreement indicated the distinct possibility of ripple transport, and experimental measurements to confirm this were planned. An estimate of electron ripple transport rates in the proposed next Heliotron machine indicated rapid losses, which would affect whether such a device could be heated.

Prof. Kulsrud also visited JAERI, Tsukuba University, ILE Osaka, Hiroshima University, and Kyushu University and participated in a meeting on muon catalyzed fusion in Tokyo.

Hitoshi Hojo

Visiting Scientist to LLNL, Wisconsin, MIT, and IFS Texas
September 30, 1985 - March 29, 1986

Dr. Hojo, from the Faculty of Science of Hiroshima University, spent his first four months visiting the mirror theory group at Livermore, where he continued his studies on the stabilization of mirror-confined plasmas by means of radio-frequency applied electric fields. Thereafter he visited the Phaedrus group at Wisconsin for two weeks, the Tara group at MIT for three weeks, and the IFS for four weeks.

Tetsuo Kamimura

Visiting Scientist to LLNL and IFS Texas
March 10 - April 2, 1986

Prof. Kamimura, from the Institute of Plasma Physics at Nagoya University, has been involved in a long-standing JIFT collaboration project with the IFS to develop an implicit particle code to simulate electromagnetic plasma phenomena. During his recent visit to the IFS, he worked with J-N. Leboeuf, E. Montalvo, and T. Tajima and with D.C. Barnes (SAIC-Austin) to write a paper on this subject, which was submitted for publication. He also collaborated with W. Horton, J. Shutkeker, and T. Tajima on implicit electrostatic simulations of the Kelvin-Helmholtz instability.

Hiromu Momota

Visiting Professor to IFS Texas
November 15, 1985 - March 15, 1986

Prof. Momota, from the Institute of Plasma Physics at Nagoya University, visited the IFS for four months, during which time he collaborated with H. Berk and T. Tajima in a study of equilibria for field-reversed configurations, with application to an advanced fuel fusion reactor. This work considered the use of fusion products as current carriers, in order to create a hollow magnetic field profile and thus inhibit synchrotron radiation. Several self-consistent distributions, including the effect of finite Larmor radii, were examined, and a semi-analytic solution for classical transport was derived. Results from this work were reported at the 1986 Sherwood Meeting. After returning to Nagoya, Prof. Momota has been investigating the stability of such FRC equilibria.

Other News...

As was reported in the August, 1985, issue of this Newsletter, the JIFT Steering Committee had agreed that after approximately five years of continued collaboration on a topic, a summary report based on self-evaluation of that activity should be published. In particular, it had requested that the organizers of the workshop series on 3D MHD studies and on statistical plasma physics, respectively, prepare such reports during the 1985-86 period.

The former, entitled ***US-Japan 3D MHD Workshops: Report on the Activities of the Last Five Years*** and authored by B. Carreras (ORNL) and T. Sato (HIFT), was the major focus of discussion at the recent JIFT Workshop on 3D MHD Simulation. The contents of this report have been summarized earlier in this Newsletter issue in a report concerning this workshop.

The latter subject was described in a report entitled ***Five-Year Progress Report and Review of the US-Japan Workshop Series on Nonlinear Dynamics and Statistical Physics: 1980-1985***, which was written by W. Horton (IFS) and Y. Ichikawa (IPP). Prof. Ichikawa visited the IFS in February, 1986, to compile this report. The report begins with an overview of the scientific background of developments in nonlinear mathematics, integrable field equations, and neutral fluid turbulence that motivated the planning of JIFT theory exchange workshops in these areas. Six workshops have been held, the first in March of 1981 and the most recent in February of 1986 (described earlier in this Newsletter). The report then describes the purpose and organization of the US-Japan workshops and reviews the progress of new developments that were considered at these meetings. The new developments are classified under the headings of: (a) self-similar structure of dynamics, renormalization group theory, and

universal numbers; (b) coherent structures, solitons, vortical flows, and clumps and holes; and (c) Hamiltonian structure of plasma field equations. The report finishes with a section on conclusions and recommendations, which is quoted in its entirety here:

"In the preceding sections, we have surveyed the critical subjects discussed in the five-year series of workshops on statistical plasma physics. It would be worthwhile to recall here that the perturbed structure of the magnetic surface was studied by Rosenbluth, Sagdeev, Taylor, and Zaslavskii (1966) in the scheme of a kinetic equation approach in the early stage of plasma fusion research. Now, after the lapse of two decades, the subject of the statistical motion comes back as a central issue with a new look of a nonlinear dynamics problem. During the past twenty-five years, the celebrated Vlasov equation served as the principal tool for plasma physicists to handle the statistical properties of a nearly collisionless plasmas. During these years, statistical mechanics itself was making much progress with the introduction of new concepts such as the onset of stochasticity, period doubling, chaos and other nonlinear phenomena. One of the principal aims of the present workshop series is to expose the central, difficult problems in fusion plasma research to the broader view of theoretical physicists. The purpose of this exposure is to inspire or challenge scientific interests in these core problems of plasma research and at the same time to modernize the theoretical tools of plasma physicists by having intense exchanges on specific plasma problems in the context of the wider point of view of general theoretical physics. We are convinced that the present five-year series of workshops has achieved this aim to a large degree.

"Referring to the practical results for fusion research, we must recognize the rather limited nature of the classical mathematical tools that have been available to plasma physicists in order to understand properties of high temperature plasmas. One of the responsibilities of the theoretical groups in plasma physics is to enrich the mathematical notions and calculational tools so that plasma physicists can use them to disentangle the complex phenomena of nuclear fusion. In this regard the workshops have played a key role in stimulating the development of new mathematical descriptions of the nonlinear collective dynamics of plasmas. In the preceding section we have summarized in some detail the areas where progress at the workshops has been perhaps most exciting to the theoretical plasma physicists. We should point out, however, that each workshop has works presented from the area of fusion plasmas concerning more applied and practical problems. For example, at the 1986 Nagoya workshop, works on the evolution from computer simulations of 3D MHD current carrying plasma, on collisional drift waves in a cylindrical model of a stellarator and the ripple induced losses of alpha particles in a proposed fusion reactor design were presented. These practical problems work with the fundamental problems to keep in clear focus the essential questions in the magnetic fusion program.

"In the problem of radio frequency heating and current drive, the results of stochasticity were developed early using the methods of area perserving maps which proved to be a valuable new method. Now further studies on this problem are carried out in a rf heating US-Japan workshop series organized within the JIFT program.

"In conclusion, we wish to propose a new workshop series on statistical plasma physics, with the particular emphasis on exploring the universal structure of nonlinear dynamical systems, the non-ideal soliton behavior with account of the interaction with particles, waves and dissipative effects, and the structure of the turbulent fluctuations including such effects as vortices in the dynamics of the relevent confinement plasma systems."

[Editor's note: The complete texts of these two reports are available upon request.]