MEETING REPORT

SUMMARY OF THE IAEA TECHNICAL COMMITTEE MEETING ON ADVANCES IN SIMULATION AND MODELING THERMONUCLEAR PLASMAS, MONTREAL, CANADA, JUNE 15–17, 1992

This International Atomic Energy Agency (IAEA) Technical Committee Meeting was organized by R. A. Bolton and M. Shoucri of the Tokamak de Varennes in Varennes, Quebec, Canada. The aim of the meeting was to discuss recent advances in the simulation and modeling of plasmas. Although the emphasis was on new techniques and new codes, new physics results were also welcomed.

There were 42 participants at the meeting, and they presented 34 papers. These papers will be published by the IAEA in a technical document. A somewhat expanded version of this review will appear in *Nuclear Fusion*. At the meeting, the papers were very effectively organized by topic into six sessions. The topics were as follows: the numerical tokamak, turbulent transport, plasma equilibrium and stability, three-dimensional modeling, tokamak edge simulations, and potpourri. Each session, except the last one, was opened by either a review paper or a detailed description of some new work on the session topic. Although most results dealt with tokamak physics, other areas of plasma research (such as heavy-ion fusion and stellarators) were presented.

This summary is organized in the same way as the conference, that is, by the six topics mentioned earlier. As can be seen from the following discussion, most of the papers described new codes that use fairly standard techniques applied to difficult physics issues and the results from those codes.

The meeting opened with an overview of the Numerical Tokamak project, presented by J. M. Dawson [University of California–Los Angeles (UCLA)]. He pointed out that it is now realistic to consider simulating real tokamaks starting from fundamental physics models. The models proposed were gyrokinetic, gyrofluid, and fluid models of the tokamak plasmas. The hope is that these models could explain tokamak core transport. It was speculated that with factors of 200 over the Cray-II computer in speed, the Joint European Torus (JET) or the Tokamak Fusion Test Reactor (TFTR) could successfully be modeled. This increase in speed is expected in the next 5 yr. Most of this increase in speed will, of course, come from computers having a very large number of processors. D. Forslund [Los Alamos National Laboratory (LANL)] commented on these massively parallel computers and indicated that new tools would be needed to handle, transmit, store, and visualize the tremendous amount of data they would generate. Forslund was more pessimistic, however, on the speedup factor needed to realistically model a full tokamak. He estimated it would take a 100-teraflop machine, a factor of ~10 000 times faster than current machines, to model the tokamak and that such machines would be available in ~10 yr.

D. Boucher (JET) showed results from a new code that indicated we might not need such large computers to simulate the tokamak. His new code uses the Rebut-Lallia-Watkins model for the transport coefficients. Comparison of code output with JET and with PBX-M shots appeared to be very good. Especially impressive were the results for a JET shot that produced very low transport in a reversed shear region.

V. K. Decyk (UCLA) and co-workers have developed a suite of codes that can form the backbone of particle simulations such as gyrokinetic codes. The one- and two-dimensional versions of these codes will be available shortly, and work is progressing on three-dimensional versions. Decyk pointed out that codes must be 100% vectorized for machines like the CM-2 or they would perform very poorly. Even fully vectorized codes did not appear to be that encouraging to this reviewer; a full 64-k CM-2 could run these particle codes only at the speed of a four-2 processor Cray-2. This appears to be below the potential for the CM-2 quoted by Dawson as being a factor of 20 times faster than the Cray-2.

M. Ottaviani (JET) opened the session on turbulent transport with a critical review of direct simulations of turbulence through the last decade. He called into question the main result of these simulations, which is that the quasi-linear approximation is essentially correct. He argued convincingly that with the low resolution of these simulations, the only result that could be produced is that the transport is gyro-reduced Bohm. To modify this result, very high resolution is necessary to capture effects like dissipation.

The session on equilibrium and stability was opened by a review by W. Kerner (JET). He gave an in-depth review of equilibrium and stability, mostly of calculations that he and his co-workers have been doing over the last 10 yr. The list of accomplishment was most impressive. Equilibrium codes have been pushed on two fronts: accuracy and speed. Fast codes are needed for plasma control, and highly accurate codes are needed for stability calculations and, more recently, for determining profiles of critical quantities, such as the safety factor. Noting the recent controversy concerning the value of the safety factor on axis, they have used flux-loop measurements, pickup coil measurements, and one value of q from the motional Stark effect measurements as input to the equilibrium code to determine the current profile. This procedure has yielded a safety factor on axis of ~ 1. Most of the increase in accuracy has come from use of high-order finite element techniques applied to the Grad-Shafranov equation. Finite element methods also form the basis for their eigenvalue solvers for the stability analysis of resistive magnetohydrodynamics (MHD). The eigenvalue problem was recently extended to include applications where kinetic effects are important.

C. Z. Cheng (Princeton Plasma Physics Laboratory) described the NOVA-K code that he uses to deal with the effects of energetic particles on MHD modes. Cheng presented an application of NOVA-K to TFTR. By finding that toroidicity-induced shear Alfvén eigenmode (TAE) modes can be destabilized with very small pressure, alpha-particle beta of the order of 10^{-4}, he was able to show that TFTR could access unstable TAE modes in its upcoming deuterium-tritium runs.

The other two papers in this session were concerned with resistive MHD instabilities. A. Bondeson (Swiss Federal Institute of Technology) described his new code, MARS, a linear inability code with a novel tunable integration scheme for increasing the accuracy and decreasing the computational effort of calculations. This code also has a vacuum calculation that can treat arbitrarily shaped walls. Bondeson presented evidence that both the ideal and resistive internal kink modes are more unstable than previous theories suggested. G. Kurita (Japan Atomic Energy Research Institute) presented results from a simple helical code that suggest a novel way of stabilizing the tearing mode by rotating the field in alternate directions to avoid mode locking and phase matching that makes the usual feedback schemes difficult.

This author opened the next session with a review of three-dimensional MHD modeling codes. The review discussed the ways various codes have dealt with the problem of disparate time scales. The techniques reviewed included reduced equations codes, incompressible codes, and partially implicit and semi-implicit codes. Physics results from these codes were also discussed.

A new semi-implicit code, XTOR, was discussed by H. Baty (École Polytechnique). The XTOR code combines the advantages of the fully implicit linear code of Oak Ridge National Laboratory workers with the semi-implicit method. Because the linear operator is implicit, the code needs very little semi-implicit stabilization and, hence, does not suffer as great an accuracy problem as the usual semi-implicit schemes. Baty has applied the code to the question of the low value of the safety factor on axis and finds that with beta on axis as low as 1% and a safety factor ~ 0.8, the sawtooth causes so large a stochastic region that the pressure is expelled before the sawtooth completely reconnects. The central region is then returned to the origin and has the same value of safety factor as before the crash.

A review of progress in plasma edge simulation was given by B. Braams (Courant Institute). Braams described the most widely used schemes, which are fluid equations for the plasma and Monte Carlo models for the neutral species. An extensive discussion of the equations and the numerical problems associated with solving these problems was presented, as was a description of the various codes in use throughout the edge physics community. The issues dealt with included disparate time scales of the order of 10^4, nonlinear coefficients, a wide range of parameter values (for example, electron temperatures ranging over two orders of magnitude), and complicated source terms for the neutral gas.

H. D. Parcher [Next European Torus (NET)] showed applications of Braams' B2 code to International Thermonuclear Experimental Reactor (ITER) and NET divertor designs. From many runs with this code, he has inferred scaling laws for the electron temperature at the point of peak power load and the peak power per unit area to the divertor plate.

Three-dimensional Fokker-Plank codes have recently been developed that can produce meaningful results using modest amounts of computer time. M. R. O'Brien (Culham Laboratory) described two such codes: Bandit-3D and FPP-3D. Results from Bandit-3D show that inclusion of radial transport broadens significantly the current profile driven by electron cyclotron current drive (ECCD). This broadening is an important consideration when ECCD is to be used for suppression of tearing modes by local modification of the current profile. The FPP-2D code is unique in that it can treat fast particles whose orbits do not closely follow flux surfaces, such as ion cyclotron resonance heated minority ions. This code is under development, and no results from it were given. A detailed description of another Fokker-Plank code, CQL3D, was given by R. Harvey (General Atomics). The CQL3D code contains effects of multiple species, radiofrequency diffusion, synchrotron diffusion, neutral beam injection, noncircularity, and radial diffusion. In fact, the code lacks only a time-dependent evolution of the Ampére and Faraday laws to be a full transport code, and this extension is under way.

A. Friedman (Lawrence Livermore National Laboratory) presented an extensive description of simulation codes for heavy-ion fusion. He described a suite of ~ 30 codes that describe the physics from beginning to end of the ILSE facility. M. Shoucri (CCFM) presented studies of lower hybrid current drive. Using a model power deposition profile for the radio frequency and the Fisch formulas for the driven current, the TSC code is used to follow the two-dimensional evolution of the tokamak plasma. Various applications of this procedure were presented, such as understanding sawtooth stabilization and the possibility of recharging the transformer.

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