A NEW VERSION OF THE MULTI-MODE TRANSPORT MODEL

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Abstract

A new version of the Multi-Mode transport model, designated MMM98, has been developed in an effort to improve its theoretical foundation. For transport near the edge of the plasma, a new model has been constructed based on 3-D nonlinear simulations of drift Alfvén mode turbulence by Bruce Scott [1]. Improvements have been made to the Weiland model for Ion Temperature Gradient and Trapped Electron Modes using eigenfunctions extended along magnetic field lines for a better approximation of finite beta effects. Without any adjustment to the coefficients, the new Multi-Mode model predicts the experimentally measured temperature and density profiles in simulations of TFTR discharges.

1. Introduction

The Multi-Mode transport model is a combination of theory-based transport models used to predict the temperature and density profiles in tokamaks. The version of the Multi-Mode model which was held fixed since 1995 (referred to as MMM95) [2] predicted experimentally measured profiles with an average rms deviation less than 15% for L-mode (low confinement mode) and H-mode (high confinement mode) discharges from TFTR, DIII-D, and JET [3,4]. That MMM95 model also correctly predicted the experimentally observed scalings of the confinement in systematic scans over plasma current, density, heating power, and normalized gyroradius [5]. Finally, simulations with the MMM95 model predict that ITER should ignite, even with L-mode boundary conditions [6].

The motivation for changing the Multi-Mode model is to incorporate newly available theoretically derived transport models, which have an improved theoretical basis compared to their predecessors, thereby eliminating the need for empirically adjusted factors in the overall model. By improving the theoretical foundation of the Multi-Mode model, we expect to improve our understanding of transport, increase the range of applicability of the model, and make more reliable projections for future tokamaks.

2. New Multi-Mode Transport Model — MMM98

An important new contribution to the Multi-Mode transport model is the drift Alfvén model based on 3-D nonlinear turbulence simulations carried out by Bruce Scott [1] which predict transport near the plasma edge. This model was constructed from more than 30 turbulence simulations, which were used to compute the ion heat flux, electron heat flux, and hydrogenic ion flux, as functions of plasma parameters. In these systematic scans, each of the following dimensionless parameters was varied independently: $\beta_e \equiv 2\mu_0 n_e T_e / B^2$; magnetic q; normalized pressure gradient $g_p = -R\nabla p_e / p_e$, (where R = major radius and $p_e = n_e T_e$ = electron thermal pressure); collisionality $\hat{\nu} = (\text{collision fequency}) R/(g_p c_s)$, (where $c_s = \sqrt{2T_e/M_i}$ is the sound speed); the ratio of the gradients $\eta = (T\nabla n)/(n\nabla T)$; and plasma elongation κ. The effects of T_i/T_e, magnetic shear, and externally-driven flow shear have yet to be included.

The resulting drift-Alfvén transport model has the form:

$$\text{Heat Flux} \propto n_e T_e c_s (\rho_s/R)^2 g_p^4 \, q^2 \, e^{-3.12\kappa} f_1(\beta_e) f_2(\eta) f_3(\hat{\nu})$$

where $\rho_s = \sqrt{2T_e M_i}/(eB)$. The factor $f_1(\beta_e)$ increases with β_e as shown in Figure 1. The factor $f_2(\eta)$ increases with η, but the form is different for each of the fluxes. In the current model, the factor $f_3(\hat{\nu})$ is taken to be independent of collisionality. The common point for each scan was: $q = 3.3$, $g_p q = 200$, $\hat{\nu} = 0.3$, $\beta_e (q g_p)^2 = 10$.

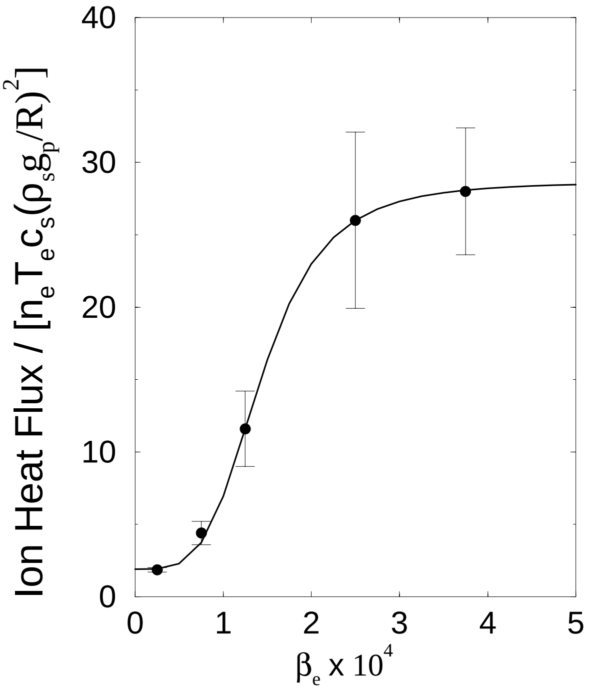

Fig. 1. Ion heat flux as a function of β_e driven by drift-Alfvén mode turbulence as computed in 3-D nonlinear turbulence simulations (points with error bars) and fitted by an analytic expression (solid curve).

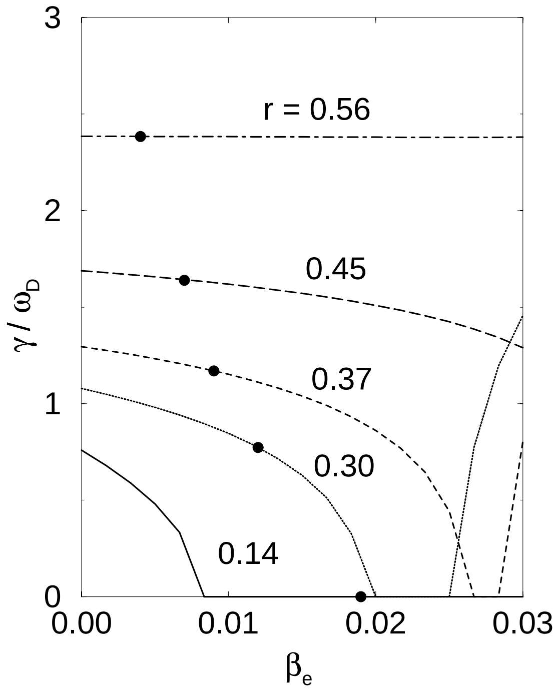

Fig. 2. Growth rate as a function of β_e for the ITG mode computed with the new Weiland model at different radii in DIII-D 81499. Points mark the β_e values measured at the different radii in the experiment.

This drift-Alfvén transport model exhibits gyro-Bohm scaling. The scaling with pressure gradient to the fourth power and with magnetic q^2 causes the transport to decrease rapidly from the edge to the core of the plasma. There is also a very strong scaling with plasma elongation and there is an order of magnitude increase in transport as $\beta_e (q g_p)^2$ is increased from 1 to 10.

The second important change to the Multi-Mode model is a new version of the Weiland model for ITG and TEM modes, with eigenfunctions extended along the field lines. In this new Weiland model, the linearized fluid equations [2] are written as a second order differential equation along the field lines. The extent of the eigenfunctions along the field lines is estimated from the asymptotic form of the solution (*i.e.*, in the limit of large poloidal angle). A variational method is then used to produce algebraic equations which are then used to compute the growth rate and frequency of the modes as well as quasilinear estimates of the transport fluxes.

As shown in Figure 2, the growth rate (and resulting transport) decreases with increasing β_e and then abruptly increases when the pressure gradient exceeds the local ideal MHD ballooning mode limit. The decrease with β_e is particularly dramatic in the low magnetic shear regions near the magnetic axis, as shown in the lower curves in Figure 2. As the plasma elongation is increased these curves are stretched to higher values of β_e.

The kinetic ballooning mode model that was present in MMM95 has been removed from MMM98. Work is in progress using the FULL kinetic stability code [7] to develop an improved model for kinetic balloning mode transport. Also, work is in progress to include flow shear effects and to improve the neoclassical transport model.

3. Simulation Results

Simulations have been carried out using the new MMM98 and the old MMM95 Multi-Mode models in the BALDUR transport code for the six TFTR L-mode discharges described in reference [8], representing scans in current, density, and heating power, as well as a selection of other discharges including the TFTR supershot 73265 described in reference [2] and the DIII-D H-mode 81499 shown in reference [4]. In almost all these simulations, the agreement between the simulated profiles and experimental data is at least as good with MMM98, where there are no empirical factors, as with MMM95.

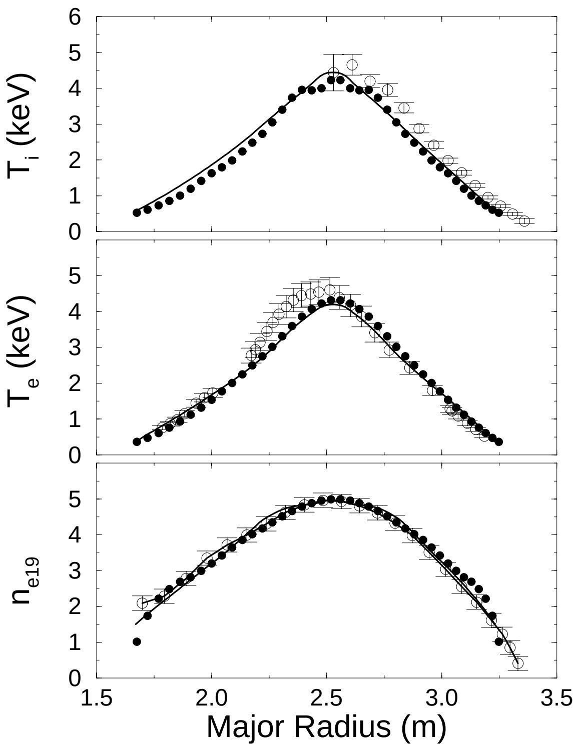

Fig. 3. Profiles as a function of major radius for TFTR 62270 at 4.03 sec. Simulated profiles using MMM98 (solid curves) are compared with measured experimental data (open circles with error bars) and with TRANSP-analysed experimental data (dots).

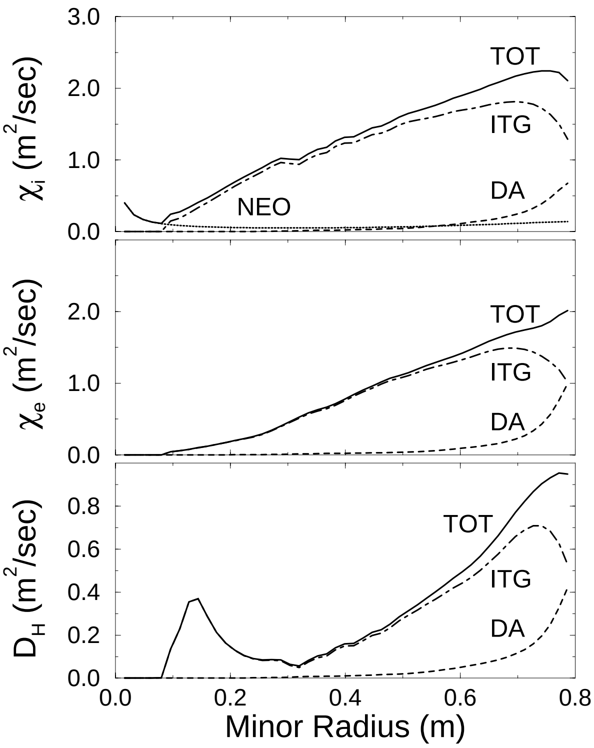

Fig. 4. Effective diffusivity profiles as a function of minor radius from the MMM98 simulation of TFTR 62270 at 4.03 sec. In each panel, the total effective diffusity (labeled TOT) is the sum of the Weiland model (ITG), drift-Alfvén model (DA) and neoclassical transport (NEO).

Figure 3 shows an example of the comparison between simulated profiles and experimental data from the low density L-mode TFTR discharge 62270 during neutral beam injection heating. The plasma parameters for this discharge can be found in reference [8]. Figure 4 shows the corresponding total effective diffusivities (curves labeled TOT) computed in the BALDUR simulation, as well as the individual contributions from the Weiland model (labeled ITG), drift-Alfvén model (labeled DA), and neoclassical transport (labeled NEO). In this simulation, the Weiland model dominates over most of the plasma, while the drift-Alfvén model contributes about half the transport at the edge of the simulation (at $r/a = 0.975$). Neoclassical transport fills in the central 10% for ion heat and particle transport (the latter is not shown in Figure 4).

The only simulation that did not fit the experimental data well is instructive. When the low current L-mode TFTR 45966 (described in reference [8]) was simulated with the current version of MMM98, the edge density gradient was too flat and the edge temperature gradients were too steep. This combination of gradients was outside the range of data used to construct the drift-Alfvén model, and the choice of extrapolation in developing the model produced a large particle transport relative to thermal transport. This indicates that it is necessary to extend this model with additional turbulence simulations.

4. Conclusions

The new drift-Alfvén transport model, based on 3-D nonlinear simulations of turbulence near the plasma edge, togther with the new Weiland model, with improved approximations for finite β and magnetic shear effects, are combined with neoclassical transport to produce a Multi-Mode Model (MMM98) with a better theoretical foundation. The predictive transport simulations using MMM98 are generally found to agree well with experimental data.

Acknowledgement

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References

[1] Bruce Scott: Plasma Phys. Control. Fusion **39**, 1635–1668 (1997).

[2] Glenn Bateman, Arnold H. Kritz, Jon E. Kinsey, Aaron J. Redd, and Jan Weiland: Phys. Plasmas **5**, 1793–1799 (1998).

[3] J. E. Kinsey, R.E. Waltz, and D.P. Schissel: in *European Physical Society Meeting*, Berchtesgaten, Germany June 1997, European Physical Society, Petit-Lancy.

[4] G. Bateman, J.E. Kinsey, A.H. Kritz, A.J. Redd, and J. Weiland: in *Proceedings of the Sixteenth IAEA Fusion Energy Conference,* Montréal, Canada, 7–11 October, Vienna, 1996, IAEA, Vol. 2, pp. 559–565.

[5] J.E. Kinsey and G. Bateman: Phys. Plasmas **3**, 3344–3357 (1996).

[6] G. Bateman, A.H. Kritz, J.E. Kinsey, and A.J. Redd: Phys. Plasmas **5**, 2355–2362 (1998).

[7] G. Rewoldt, L.L. Lao, W.M. Tang: Phys. Plasmas **3**, 4074 (1996).

[8] Jon E. Kinsey, Glenn Bateman, Arnold H. Kritz, Aaron J. Redd: Phys. Plasmas **3**, 561–570 (1996).