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Multiple Mode Model of Tokamak Transport

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Theoretical models for radial transport of energy and particles in tokamaks due to drift waves, rippling modes, and resistive ballooning modes have been combined in a predictive transport code. The resulting unified model has been used to simulate low confinement mode (L-mode) energy confinement scalings. Dependence of global energy confinement on electron density for the resulting model is also described.

1. Introduction

A major goal of controlled fusion research is to obtain a theoretical description of plasma transport across the toroidal magnetic flux surfaces in tokamaks. Computational models which could predict the evolution of flux-surface-averaged plasma parameters in new experiments would be particularly useful. A number of previous computational studies of turbulent plasma transport have concentrated individually on various features of the drift-wave [1,2] or resistive ballooning modes [3]. These simulations have been successful in reproducing some features of low-confinement (L-mode) plasmas. However, computational models based on drift-wave theories alone are reportedly inadequate to reproduce scaling of global energy confinement with toroidal plasma current [4]. A model containing fluxes due to resistive ballooning modes reproduced some data from the Impurity Study Experiment (ISX-B) [3] but was not subsequently shown to reproduce results from other tokamaks.

In the present study, we use linear combinations of theoretical transport fluxes due to drift waves, resistive ballooning, and rippling modes, added to a fixed level of neoclassical transport. Such models are used to study the scaling of global energy confinement with various plasma parameters in L-mode plasmas. The original motivation for our simulations is based on comments in papers by T. Hahm, P. Diamond, and colleagues [5,6]. The rationale for the transport formulas used and a qualitative discussion of the expected results is given elsewhere [7]. An approximate analytic integration and the motivation for one of the levels of rippling mode fluxes used here was presented by Sheffield [8].

2. Transport Model

To the usual neoclassical fluxes [9–11], we added a linear combination of estimates of drift-wave, rippling mode, and resistive ballooning effects [4,6,7,12–18].

$$Q_{i,e} = c_1 Q_{i,e}^{DR} + c_2 Q_{i,e}^{RM} + c_3 Q_{i,e}^{RB} \tag{1}$$

for ion (i) and electron energy fluxes and $\Gamma_a = c_1 \Gamma_a^{DR} + c_2 \Gamma_a^{RM}$ for the flux of each hydrogen isotope, a.

For drift waves, the approximation $\Gamma_a^{DR} = c_1 D^{DR} n_a / L_n$ was used for flux-surface-averaged quasilinear radial particle fluxes. Here

$$D^{DR} = \frac{1+\beta'/\beta'_{c1}}{1+(\beta'/\beta'_{c1})^3}(1-\frac{f_{ith}}{.95+\nu_{e*}})\hat{D}_{te} \tag{2}$$

with $\beta' = -d\beta/dr$ and $\beta'_{c1} = \hat{s}/(1.7q^2R_0)$. The corresponding heat fluxes are

$$Q_e^{DR} = (\frac{5}{2}-\frac{3}{2}f_{ith})\frac{1+\beta'/\beta'_{c1}}{1+(\beta'/\beta'_{c1})^3}\hat{D}_{te}\frac{n_eT_e}{L_{T_e}} \tag{3}$$

$$Q_i^{DR} = \frac{5}{2}(\hat{D}_{te}+f_{ith}\hat{D}_i)\frac{1+\beta'/\beta'_{c1}}{1+(\beta'/\beta'_{c1})^3}\frac{n_iT_i}{L_{T_i}} \tag{4}$$

For completeness, the small anomalous electron→ion energy exchange

$$\Delta^{DR} = c_1(0.89-0.54\eta_i-0.6\beta'/\beta'_{c1})D^{DR}\frac{n_eT_e}{L_n^2} \tag{5}$$

was also included [14,19]. In these formulas we use the notation adopted by Ross et al. [15] from the work of Dominguez and Waltz [4], with

$$\hat{D}_{te} = \epsilon^{1/2}\frac{\omega_e^*}{k_\perp^2}\left[1,\frac{\omega_e^*}{\nu_{eff}}\right]_{min} \tag{6}$$

$$\hat{D}_i = \frac{\omega_e^*}{k_\perp^2}\left(\frac{2T_i}{T_e}\frac{L_n}{L_{T_i}}\frac{L_n}{R_0}\right)^{1/2} \tag{7}$$

Here $f_{ith} = \{1+\exp[-6(\eta_i-\eta_i^{th})]\}^{-1}$, $\eta_i^{th} = 1$ for $L_n/R_0 \leq 0.2$ and $\eta_i^{th} = (0.5+2.5L_n/R_0)$ for $L_n/R_0 > 0.2$.

The rippling mode fluxes are $\Gamma_a^{RM} = D_{\nabla\eta}n_a/L_n$, $Q_e^{RM} = D_{\nabla\eta}n_eT_e/L_n$, and $Q_i^{RM} = D_{\nabla\eta}n_iT_i/L_n$ with

$$D_{\nabla\eta} = \left(\frac{E_oL_s}{B_oL_\sigma}\right)^{4/3}\left(\frac{r^2L_s^2Z_{imp}^2\nu_{ii}}{25v_i^2}\right)^{1/3} \tag{8}$$

The resistive ballooning theory used affects only electron energy fluxes:

$$Q_e^{RB} = \Lambda_S^2\,\chi_{e,res.ball}\frac{n_eT_e}{L_{T_e}} \tag{9}$$

where

$$\chi_{e,res.ball} = \frac{3v_e\eta}{2\mu_o(2q)^{1/2}v_A}\left(\frac{\beta_\theta\epsilon^2 L_s}{L_p}\right)^{3/2} \tag{10}$$

and

$$\Lambda_S = \frac{4}{3\pi}\ln(\beta^{-1/2}R_0 v_A\mu_o/\eta) \tag{11}$$

from Diamond and Carreras [17,18].

Except for the leading coefficients (c_1, c_2, and c_3), the symbols in these expressions are defined in Table 1. Here r is the midplane half-width of a flux surface, R_0 is the major radius, $\epsilon = r/R_0$, B_0 is the toroidal magnetic field, $Z_{imp} = 6$, and E_0 and q are the local toroidal electric field and safety factor computed from the time evolution of the poloidal and toroidal fluxes. The fundamental physical constants in these formulas are $\mu_o = 4\pi \times 10^{-7}$, $\epsilon_o = 8.8542 \times 10^{-12}$, $c = (\mu_o\epsilon_o)^{-1/2}$, $e = 1.6022 \times 10^{-19}$, $m_e = 9.1095 \times 10^{-31}$, $m_p = 1.6726 \times 10^{-27}$, and $k_b = 1000e$. (In this paper we use SI units except that temperatures are in keV and heat fluxes are in keV·m^{-2}s^{-1}.)

For numerical convenience, the scale lengths in the above formulas are limited to a physically reasonable minimum: $|L_X| \geq \rho_{\theta i}$ (for $X = n$, T_e, T_i, or p). The shear is limited to $\hat{s} < r/\rho_{\theta i}$ when (and only when) using it for computing the above turbulent transport flux formulas. Also, the analytic approximation given above for the ideal ballooning limit, β'_{c1}, breaks down, for example, when $\hat{s} \tilde{<} -\sigma'$, where σ' is the radial derivative of the Shafranov shift [20]. As a result of these considerations, the shear is also limited to a minimum $0.5 < \hat{s}$ when (and only when) using it for computing the above turbulent transport flux formulas. This also helps keep the rippling mode fluxes from becoming too large in regions of very low shear.

The total transport flux formulas are thus defined when the leading coefficients c_1, c_2, and c_3 are given. Here we treat the *nominal* predictions of the theories, $c_1 = c_2 = c_3 = 1$, as rough estimates and allow some of these coefficients to vary over an order of magnitude range centered on 1.

3. Results

Here we report some quantitative simulation results which illustrate that the type of model described above can reproduce important features of neutral-beam-heated plasmas. The first results given here are L-mode global confinement scaling exponents $(\partial \ln \tau_E/\partial \ln X)$ where X is either the toroidal plasma current, I, the toroidal magnetic field, B, the neutral beam heating power, P, or the line average density, $\overline{n}_e$. These results were obtained using the approximation $(\partial \ln \tau_E/\partial \ln X) \sim [(\tau_1-\tau_2)(X_1+X_2)]/[(\tau_1+\tau_2)(X_1-X_2)]$ where τ_1 is the global thermal kinetic energy confinement time computed for a reference point $\{X_1\}$ =(3.75 $\times$ 10^5 Ampere, 2.2 Tesla, 2.9 $\times$ 10^6 Watt, 4.0 $\times$ 10^{19} m^{-3}), and τ_2 is computed for each value of X separately reduced by 20%. The remaining parameters, including the neutral beam configuration and the plasma current and density ramp forms, were set equal to the Axisymmetric Divertor Experiment (ASDEX) parameters given by Singer et al. [11] with the limiter-plasma boundary conditions given by Singer, Bateman, and Stotler [21].

The results are listed in Table 2 for a "nominal" model [with drift, rippling, and resistive ballooning coefficients, respectively $(c_1 = c_2 = c_3 = 1)$] and an "improved" model in which the coefficient of the drift contribution was reduced to 0.3 and the coefficient of the rippling contribution was increased to 3 (i.e., $c_1 = 0.3$, $c_2 = 3$, and $c_3 = 1$). The choice of $c_2 = 3$ rippling mode coefficient in the "improved" model was motivated by the studies of Sheffield [8]. The coefficient c_1 was then adjusted to give a reasonable fit to observed plasma profiles and L-mode confinement scalings inferred from fitting a large data base. The first two columns in Table 2 show the scaling exponents for current (I), magnetic field (B), auxiliary heating (P), and density ($\overline{n}_e$) from our simulations ("nominal" and "improved," respectively.) The other numbers listed in Table 2 are experimental scaling exponents deduced by Singer [22], Kaye and Goldston("K-G" [23]) and updated exponents obtained by Kaye using a larger data base [24]. (The confinement scalings from Kaye [24] used the "all" of the data base which was available and a two-step, "complex" method of computing confinement scalings for each device and then averaging the confinement scalings. The scaling exponents obtained from other methods of reducing the same data were very similar to the resulting "Kaye-All-Complex" exponents shown in Table 2. The global energy confinement time computed for the reference discharge from this scaling was 0.026 seconds, compared to 0.028 seconds for the simulation with the "improved" transport model.)

It is apparent from Table 2 that the L-mode scalings from the "improved" model are compatible with those inferred from experiment within the variation of the results obtained by analyzing different data bases. The figures in bold type show a good correspondence of the best model analyzed so far with the confinement scaling derived from the most complete data base.

Without further adjustment of the transport fluxes, the "improved" theory-based model just described was also used to simulate ohmically heated plasmas. A curve showing simulated confinement times as a function of line average density is compared to experimental data points in Fig. 1. The simulations used to produce the curve in Fig. 1 are identical to the ohmic phase of the discharge using the "improved" model described above, except that the plasma current was changed from 0.375 MA to the 0.4 MA used for the experimental data given above [25]. Although the magnitude of the transport coefficients has not been adjusted to match the ohmic confinement data, the model evidently predicts an initial rise and eventual saturation of confinement with increasing line average density.

4. Conclusions

The results shown here indicate that theoretical transport models based on local plasma parameters can be used to describe important qualitative features of plasma transport across closed flux surfaces in tokamaks. Such results had not previously been successfully obtained in computational transport simulations using fluxes for individual modes. Since theory predicts that all of these modes may be simultaneously important somewhere in a given plasma, it is not surprising that each mode would not work adequately alone in predictive simulations. The "improved" model described above also gives reasonably accurate electron temperature and density profile shapes both for the limiter plasmas simulated here and for the high confinement in divertor discharges when models of the shear [7] and the evolution of the boundary temperature [21] are included. This suggests that a systematic survey would be worthwhile to determine the ranges of unknown parameters in these models allowed by existing experimental data. A systematic statistical methodology for conducting such a survey has been worked out in detail and described elsewhere [26]. An estimate of the computational requirements suggests that it would be practical to vary the three adjustable parameters in the present model (c_1, c_2, and c_3) when treating a data base consisting of tens of discharges.

However, it should be kept in mind that, for example, the quasilinear saturation levels for transport due to drift waves would in reality be expected to be a slowly varying function of relevant dimensionless plasma parameters; i.e., $c_1 = c_1(q, \nu_e^*, \rho_i/L_p, \ldots)$. Even allowing only simple power law variations for such dependencies would introduce a large number of additional free parameters. There are also additional theoretical uncertainties in the present formulation of drift-wave and other turbulent transport models. Treating a large number of adjustable parameters would either require a much more efficient computational model or the use of some simplified description of the model's response to variation of the adjustable parameters.

Another difficulty is that both the theory and the available data base evolve faster than an aggressive experimental simulation program can be carried out. For this reason, we have frozen the theory at a relatively simple level and used only a very rough description of the available data in the present work. Despite all of these difficulties, we believe the results presented here illustrate a useful starting point for calibrating improving theoretical tokamak plasma transport models against an expanding empirical data base.

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References

[1] M. H. Redi, W. M. Tang, P. C. Efthimion, D. R. Mikkelsen, and G. L. Schmidt, "Transport Simulations of TFTR Using Microinstability Based Profile Consistent Models for Electron and Ion Thermal Transport," Nucl. Fusion **27** (1987) 2001.

[2] D. W. Ross, W. H. Miner, Jr., P. M. Valanju, and J. C. Wiley, "Transport Simulation with Theoretically Based Models," Bull. Am. Phys. Soc. **33** (1988) 2028.

[3] B. A. Carreras, P. H. Diamond, M. Murakami, J. L. Dunlap, J. D. Bell, H. R. Hicks, et al., Phys. Rev. Lett. **50** (1983) 503.

[4] R. Dominguez and R. E. Waltz, Nucl. Fusion **27** (1987) 65.

[5] P. Diamond, University of Texas Institute for Fusion Studies (private communication, 1987).

[6] T. S. Hahm, P. H. Diamond, P. W. Terry, L. Garcia, and B. Carreras, Phys. Fluids **30** (1987) 1452 .

[7] C. E. Singer, "Theoretical Particle and Energy Flux Formulas for Tokamaks," Comments Plasma Phys. Controlled Fusion **11** (1988) 165.

[8] J. Sheffield, "Tokamak Transport in the Presence of Multiple Mechanisms," Sherwood Controlled Fusion Theory Conference, Gatlinburg, TN, April 18–28, Abstract 1C35 (1988).

[9] C. S. Chang and F. L. Hinton, Phys. Fluids **29** (1986) 3314.

[10] C. E. Singer, D. E. Post, D. R. Mikkelsen, M. H. Redi, A. McKenney *et al.*, Computer Phys. Communications **49** (1988) 275.

[11] C. E. Singer, M. H. Redi, D. A. Boyd, A. J. Cavallo, B. Grek, et al., Nuclear Fusion **25** (1985) 1555.

[12] W. Tang, G. Rewoldt, C. Cheng, and M. Chance, Nucl. Fusion **25** (1985) 151.

[13] W. Tang, G. Rewoldt, and L. Chen, Phys. Fluids **29** (1986) 3715.

[14] G. Rewoldt, W. M. Tang, and R. J. Hastie, Phys. Fluids **30** (1987) 807.

[15] D. W. Ross, P. H. Diamond, J. F. Drake, F. L. Hinton, F. W. Perkins, W. M. Tang, R. E. Waltz, and S. J. Zweben, "Thermal and Particle Transport for Ignition Studies," DOE/ET-53193-7 and University of Texas Fusion Research Center Report FRCR # 295 (1987).

[16] B. A. Carreras, P. H. Diamond, M. Murakami, J. L. Dunlap, J. D. Bell, H. R. Hicks, J. A. Holmes, E. A. Lazarus, V. K. Paré, P. Similon, C. E. Thomas, and R. M. Wieland, Phys. Rev. Lett. **50** (1983) 503.

[17] P. H. Diamond and B. A. Carreras, Comments Plasma Phys. Controlled Fusion **10** (1987) 279.

[18] B. A. Carreras, L. Garcia, and P. H. Diamond, Oak Ridge National Laboratory Report ORNL/TM-10150 (1980).

[19] W. Horton, "Drift Wave Turbulence and Anomalous Transport," *Handbook of Plasma Physics*, Eds. M. N. Rosenbluth and D. Z. Sagdeev, Vol. **2**, Basic Plasma Physics II (Elsevier, NY, 1984).

[20] W. H. Choe and J. P. Freidberg, Phys. Fluids **29** (1986) 1768.

[21] C. E. Singer, G. Bateman, and D. P. Stotler, "Boundary Conditions for OH, L, and H-Mode Simulations," Princeton Plasma Physics Laboratory Report PPPL-2527 (1988).

[22] C. E. Singer, J. Fusion Energy **1** (1983) 231.

[23] S. M. Kaye and R. J. Goldston, Nucl. Fusion **25** (1985) 65.

[24] S. M. Kaye, ITER International Tokamak Reactor Internal Report, (May, 1988).

[25] K. Lackner, O. Gruber, and K. Grassie, "Different Confinement Regimes in Tokamaks," in *Theory of Fusion Plasmas* eds. A. Bodeson, E. Sindoni, and F. Troyon, Società Italian di Fisica (1988) p. 377.

[26] C. E. Singer and T. Djemil, "Maximum Likelihood Estimators for Tokamak Confinement Models" University of Illinois at Urbana-Champaign Fusion Studies Laboratory Rep. FSL-242 (1988).

Table 1. Formulas, mostly from Ross *et al.*

Symbol	Name (units)	Formula
ω_{ci}	ion cyclotron freq. (s^{-1})	$eB_o/(m_p A_i)$
β	beta	$(2\mu_o k_b/B_o^2)(n_e T_e + n_i T_i)$
ω_{pe}	plasma frequency (s^{-1})	$[n_e e^2/(m_e \epsilon_o)]^{1/2}$
v_e	elect. therm. vel. (m/s)	$(2k_b T_e/m_e)^{1/2}$
v_i	ion therm. vel. (m/s)	$(2k_b T_i/m_p A_i)^{1/2}$
c_s	sound speed (m/s)	$[k_b T_e/(m_p A_i)]^{1/2}$
v_A	Alfvén speed (m/s)	$B_o/(\mu_o n_e m_p A_i)^{1/2}$
β_θ	poloidal beta	$\beta(q/\epsilon)^2 = 4.027 \times 10^{-22}(n_e T_e + n_i T_i)B_o^{-2}\epsilon^{-2}q^2$
$\ln(\lambda)$	Coulomb logarithm	$37.8 - \ln(n_e^{1/2}T_e^{-1})$
ν_{ei}	electron coll. freq. (s^{-1})	$4(2\pi)^{1/2}n_e(\ln\lambda)e^4/[3(4\pi\epsilon_o)^2 m_e^{1/2}(k_b T_e)^{3/2}]$
ν_{ii}	ion coll. freq. (s^{-1})	$4\pi^{1/2}n_e(\ln\lambda)e^4/[3(4\pi\epsilon_o)^2(m_p A_i)^{1/2}(k_b T_i)^{3/2}]$
η	Spitzer res. (Ohm-m)	$\nu_{ei}/(2\epsilon_o\omega_{pe}^2)$
ν_{eff}	effective coll. freq. (s^{-1})	ν_{ei}/ϵ
ν_e^*	electron collisionality	$\nu_{ei} q R_o/(\epsilon^{3/2} v_e)$
L_n	density scale length (m)	$-n_e/(\partial n_e/\partial r)$
L_{T_j}	T_e; T_i scale lengths (m)	$-T_e/(\partial T_e/\partial r)$; $-T_i/(\partial T_i/\partial r)$
η_j		L_n/L_{T_j}; $j = i, e$
L_p	press. scale length (m)	$-\beta/(\partial\beta/\partial r) \equiv \beta/\beta'$
L_σ	η^{-1} scale length (m)	$L_{T_e}/1.5$
$\hat{s}$	shear	$(r/q)(\partial q/\partial r)$
L_s	shear length (m)	$R_o q/\hat{s}$
ρ_i	ion gyroradius (m)	$= v_i/\omega_{ci}$
$\rho_{\theta i}$	poloidal gyroradius (m)	$= \rho_i q/\epsilon$
ρ_s		$= c_s/\omega_{ci}$
$k_\perp$	wave number (m^{-1})	$\approx 0.3/\rho_s$
ω_e^*	diamagnetic freq. (s^{-1})	$k_\perp \rho_s c_s/L_n$

Table 2. L-Mode Confinement Scaling Exponents

Parameter	Simulations		Data Fits		
	Nominal	**Improved**	Singer	K-G	**Kaye**
I	0.7	**0.8**	1.1	1.2	**0.85**
B	0.6	**0.5**	-0.1	-0.1	**0.3**
P	-0.5	**-0.6**	-0.5	-0.6	**-0.5**
$\bar{n}_e$	0.3	**0.2**	0.1	0.3	**0.1**

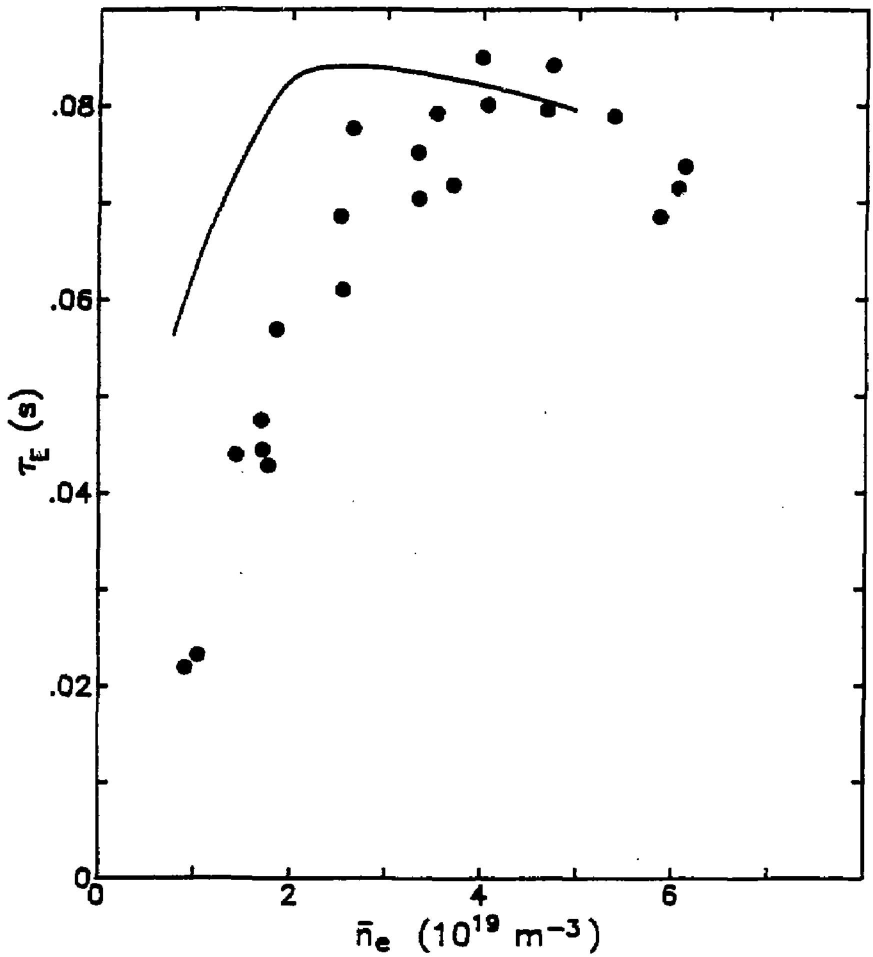

Fig. 1. Global energy confinement time for 'improved" model described in the text (with $c_1 = 0.3$, $c_2 = 3$, and $c_3 = 1$; solid curve) vs. experimental data from ASDEX.

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