DriftWave-Based Modeling of Poloidal Spin-up Precursor and Step-wise Expansion of Transport Barriers* **IF**

G.M. Staebler[1], J.E. Kinsey[2], P. Zhu[3], G. Bateman[2], W. Horton[3], A. H. Kritz[2], T. Onjun[2], A. Pankin[2], and R.E. Waltz[1]

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

[2]Lehigh University, Bethlehem, Pennsylvania 18015

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

The rich phenomenology of internal transport barriers observed in tokamaks includes a poloidal spin-up precursor for balanced injection and step-wise expansion of the barrier for unbalanced neutral beam injection. Drift wave based predictive transport models are shown to reproduce these features in simulations. Two models (GLF23 and Multi-Mode) are used on different transport code platforms. Both include the suppression of ion temperature gradient modes as the E×B velocity shear approaches the computed maximum linear growth rate. Simulations of discharges with internal transport barriers from the DIII–D, JET and TFTR tokamaks are compared.

The theory-based GLF23 and Multi-Mode transport models includes the drift wave instabilities that are most important to tokamak transport: ion temperature gradient (ITG) modes, and trapped electron modes (TEM). The GLF23 model is fit to gyro-kinetic linear growth rates and to non-linear 3-D gyro-fluid simulations of these modes. No fitting parameters are taken from experimental data. The Multi-Mode model (MMM95) includes the Weiland fluid model for the ITG and TEM modes. Both models have been shown to reasonably reproduce the scaling of a large database of tokamak discharges. Nonlinear simulations of ITG turbulence have shown that the ion thermal transport reduces with increasing E×B velocity shear until the turbulence is quenched when the E×B shear rate exceeds the maximum linear growth rate of the ITG modes. The suppression of transport due to E×B shear has been included in both of the theory based models. This allows the models to be used to simulate the evolution of internal transport barrier regimes with suppressed thermal transport. Three experimental discharges from three different tokamaks will be used to illustrate the modeling of internal transport barrier evolution.

For balanced neutral beam injection, the poloidal velocity of carbon ions has been measured on the TFTR tokamak to greatly increase in a narrow layer as shown in Fig. 1. This poloidal spin-up occurs prior to the growth in the pressure gradient. An analytic model is used to show that the poloidal momentum balance equation admits solutions similar to this poloidal spin-up precursor. These solutions develop a localized monopolar jet [1] of E×B flow as shown in Fig. 2. The localization is caused by the presence of the neoclassical damping of poloidal velocity. The inclusion of the poloidal viscous stress due to turbulence is essential for the existence of the precursor. The jet grows up faster than the gradients of the pressure and density profiles. As the pressure gradient increases the jet shrinks and disappears. These features are also seen in the experiments. Jets are predicted to be unlikely

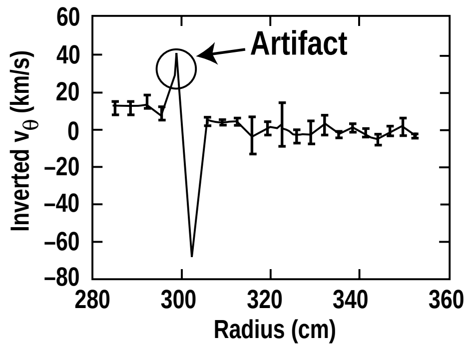

Fig. 1. Poloidal velocity of carbon ions from a TFTR enhanced reverse shear discharge.

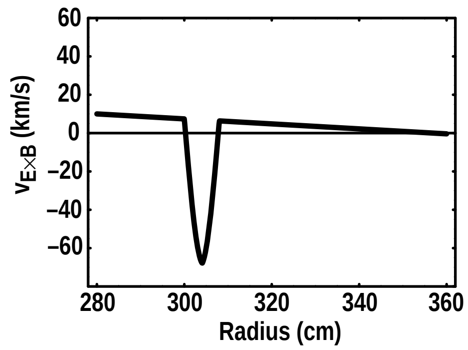

Fig. 2. E×B velocity versus major radius for a jet solution.

*Work supported by U.S. Department of Energy under Grant No. DE-FG03-95ER54309 and by U.S. DOE contract DE-FG02-92ER5414.

in discharges with large toroidal momentum sources and indeed no poloidal spin-up precursors have been seen in such cases. The theory predicts the existence of a parallel velocity component of the jet. Numerical simulations of the time evolution are planned.

Predictive Multi-Mode simulations have been used to reproduce the onset and time evolution of internal transport barriers in high performance JET and DIII–D discharges [2]. The simulations follow the transition from Ohmic to L–mode, to the formation of an internal transport barrier, to the transition to H–mode (implemented as a time-dependent boundary condition in these simulations), and then to the subsequent motion of the internal transport barrier. The time evolution of the ion temperature profile for a JET discharge is shown in Fig. 3. The density is also evolved but the toroidal rotation is taken from the data. Internal transport barriers are characterized by wider spacing between adjacent curves (steeper gradients). It can be seen that an internal transport barrier forms near the magnetic axis (close to top curve) and then moves closer to the edge of the plasma (lower curves) in both the simulation (left) and experiment (right) in Fig. 3.

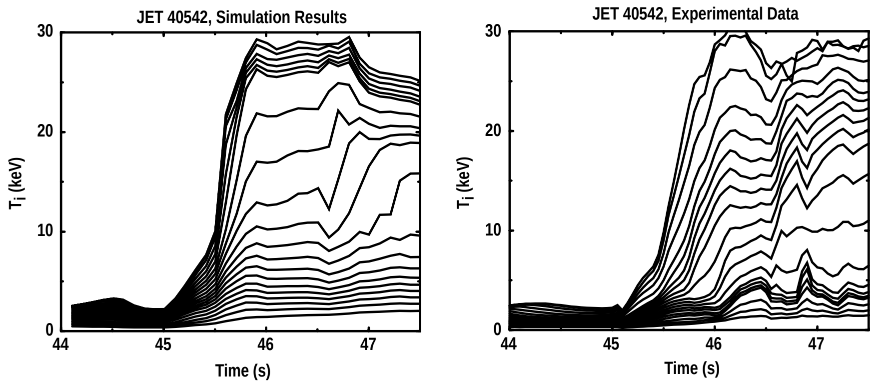

Fig. 3. Ion temperature as function of time at equally spaced intervals in normalized minor radius in simulation (left) and experiment (right) for JET optimized shear discharge #40542.

For co-injected neutral beam heating, solutions of the GLF23 model are shown to well reproduce the evolution of a DIII–D discharge with a step-wise expanding transport barrier as shown in Fig. 4. The step-wise behavior is due to the competition between the toroidal rotation and the diamagnetic contributions to the E×B velocity shear[3]. The toroidal rotation is evolved along with the temperatures. The density is taken from the data. The E×B velocity shear rate passes through zero at the leading edge of the barrier which frustrates the continuous expansion resulting in bursts of barrier propagation. This result agrees with the detailed measurements of the E×B velocity in similar discharges, including the precursor dips in toroidal velocity seen in Fig. 4(b). The dips in toroidal velocity correlate in time and space with the passing of the E×B velocity shear through zero.

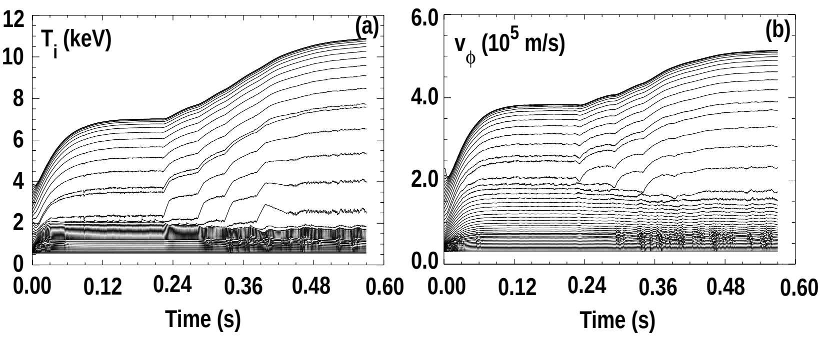

Fig. 4. GLF23 transport modeling of a DIII–D negative central shear discharge showing step-wise internal barrier expansion. Time histories of (a) ion temperature and (b) toroidal velocity at various radii.

[1] STAEBLER, G.M., “Jets in Tokamaks: A Theoretical Study,” to be published in Phys. Rev. Lett.

[2] ZHU, P., *et al*, "Predictive transport simulations of internal transport barriers using the Multi-Mode model", to be published in Phys. Plasmas.

[3] KINSEY, J.E., *et al*., “Dynamic Modeling of Step-Wise Internal Transport Barrier Formation in DIII–D NCS Discharges,” submitted to Phys. Rev. Lett.