*34th EPS Conference on Plasma Phys. Warsaw, 2 - 6 July 2007 ECA Vol.**31F**, P-4.042 (2007)*

Controlling shear flow generation in a transport model

N. Daniels,[1] A. S. Ware,[1] B. Fetscher,[1] D. E. Newman,[2] C. Hidalgo,[3] and M. A. Pedrosa[3]

[1] *University of Montana, Missoula, Montana, USA*

[2] *University of Alaska - Fairbanks, Fairbanks, Alaska, USA*

[3] *CIEMAT, Madrid, Spain*

Abstract

A one-dimensional transport model is used to study edge poloidal shear flow generation during gas puffing experiments and hysteresis effects in the generation of this flow. Above a critical threshold the shear flow improves confinement by reducing turbulent transport. For subcritical flows (i.e., flows that do not trigger transition to a higher confinement regime), there is no true hysteresisin theflow. An apparent lag may be observed if the rateof ramping the particle source is rapid relative to transport time scales. Initial work on critical flows is also presented.

I. Introduction

The existence of a naturally occurring edge poloidal shear flow in toroidal confinement devices has long been known [1]. Recently, the shear flow was shown to be sensitive to the edge density [2]. In experiments on the TJ-II stellarator, Hidalgo *et al.* used gas puffing to control the edge density and made Langmuir probes measurements of the density, electrostatic potential fluctuations and turbulent particle fluxes. It was shown that a critical density threshold exists for the onset of the edge $\mathbf{E} \times \mathbf{B}$ poloidal shear flow. More recent studies involving ramping the gas puffing up and down indicate a possible hysteresis effect on the poloidal flows [3, 4].

Here, a transport code is used to investigate the link between changes in the edge particle source and generation of edge poloidal flow. As the particle source is ramped up, the following mechanism results in the generation of edge poloidal flow: (1) the edge density gradients increase as a direct result of the increased partilce source; (2) the the increased density gradient leads to an increasedinstability growth rate resulting in an increased fluctuation level; and (3) the larger fluctuation level results in an enhanced Reynolds stress flow drive, generating edge poloidal flow. For flows below a critical level, no transition is observed, and an apparent hysteresis in the development of the flow is only a function of the ramp time and disappears as the ramp time increases. Above a critical flow level, a transition takes place in which fluctuations are suppressed locally by increased $\mathbf{E} \times \mathbf{B}$ shearing. For critical flows, the barrier location can oscillate and the the exisitence of actual hysteresis is unclear.

II. The transport model

The details of the transport model [5] are described here with an emphasis on the evolution of density, poloidal flow, and fluctuation amplitude. Cylindrical geometry is used and all fields are flux-surface averaged. The evolution of the density is governed by

$$\frac{\partial n}{\partial t} = \frac{1}{r}\frac{\partial}{\partial r}\left(rD\frac{\partial n}{\partial r}\right) + S_{\rm gp} \tag{1}$$

where n is the flux-surface averaged, mean particle density (quasi-neutrality is assumed), r is the radial coordinate, $D = D_{\rm neo} + D_\varepsilon \varepsilon^2$ is the total particle diffusivity, $D_{\rm neo}$ and D_ε are constants, ε is the r.m.s., flux-surface averaged, fluctuation amplitude, and S_{gp} is an edge-localized particle source. The particle source has a Gaussian profile, $S_{\rm gp} = S_0(t)e^{-(r-a)^2/\delta_{\rm gp}^2}$, where S_0 is the amplitude of the particle source, $\delta_{\rm gp}$ ($\sim 0.30a$) is the radial width of the particle source.

The evolution of the fluctuations is given by

$$\frac{\partial \varepsilon}{\partial t} = \left\{\gamma(r) - \alpha_1\varepsilon - \alpha_2\left[\frac{r}{q}\frac{\partial}{\partial r}\left(\frac{q}{r}\frac{E_r}{B_\phi}\right)\right]^2\right\}\varepsilon + \frac{1}{r}\frac{\partial}{\partial r}\left(rD\frac{\partial \varepsilon}{\partial r}\right) \tag{2}$$

where γ is the average growth rate, α_1 is a coefficient for the nonlinear transfer of energy due to wave-wave interaction, and α_2 corresponds to suppression of fluctuations due to $\mathbf{E}\times\mathbf{B}$ shearing. To model TJ-II plasmas, a resistive-ballooning model is used for the growth rate, $\gamma = \gamma_0\left[q^2\left|d\left(\ln n + \ln T_e\right)/dr\right|\right]^{2/3}$.

The evolution equation for the poloidal flow is given by

$$\frac{\partial V_\theta}{\partial t} = -\mu V_\theta + \alpha_3\frac{1}{r^2}\frac{\partial}{\partial r}\left[r^2\varepsilon^2\left(\frac{\partial E_r}{\partial r}\right)\right] + \frac{1}{r}\frac{\partial}{\partial r}\left(rD_{V_\theta}\frac{\partial V_\theta}{\partial r}\right) \tag{3}$$

where V_θ is the flux-surface averaged poloidal flow, μ is the coefficient of magnetic pumping, α_3 is the the coefficient of Reynolds stress flow generation, and D_{V_θ} is the poloidal momentum diffusion coefficient.

Finally, radial force balance is used to determine the radial component of the electric field:

$$E_r = -B_\phi V_\theta + B_\theta V_\phi + \frac{1}{e}\left(\frac{dT_i}{dr} + \frac{T_i}{n}\frac{dn}{dr}\right) \tag{4}$$

where B_ϕ and B_θ are the toroidal and poloidal components of the magnetic field, V_ϕ is the toroidal flow (here, V_ϕ is fixed at zero), and T_i is the ion temperature.

Motivated by comparison with the TJ-II stellarator, an equilibrium is obtained using only an edge particle source and electron cyclotron heating as the only power input. The ECH heating profile is peaked on axis and results in a peaked temperature profile. On the other hand, the absence of a core particle source results in broad density profile with a sharp gradient at the edge. Density profiles have core values on the order of 10^{12} cm^{-3} and vary with the strength of the particle source, S_0.

III. Numerical results

The equations of the transport model are integrated with an adaptive time-step, modified second-order Runge-Kutta algorithm. Results are presented for subcritical flows (flows that do not trigger a transition to an improved confinement regime) and critical flows (flows that do trigger a transition). Subcritcal flows correspond to smaller values of the flow drive parameter α_3 and hgiher rates of flow damping, μ.

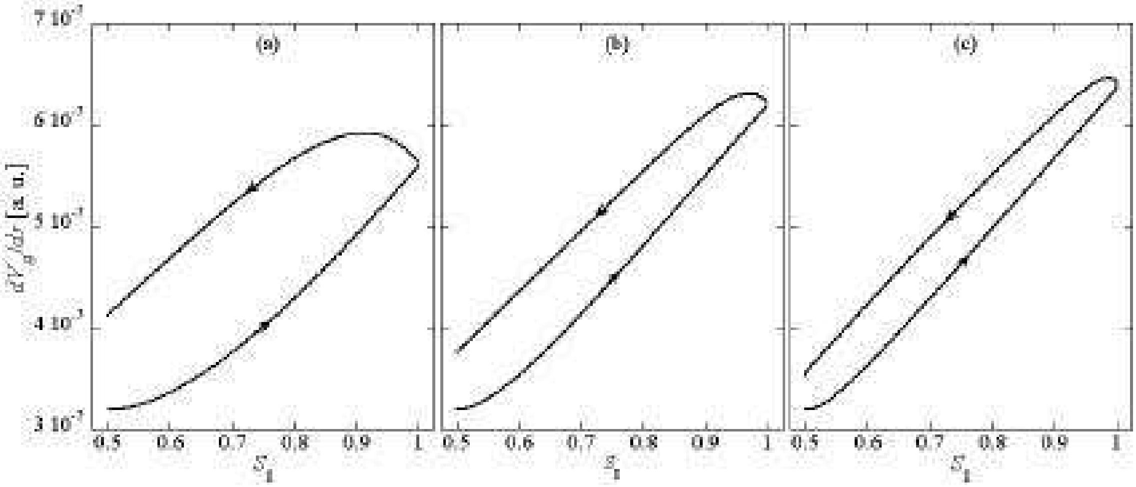

Figure 1. The flow shear at $r/a = 0.9$ as a function of the source strength in a ramp up and then down for ramp rates of (a) $\Delta t = 89.5$ ms, (b) $\Delta t = 300$ ms, and (c) $\Delta t = 580$ ms. For these cases, the flow is subcritical throughout the ramp.

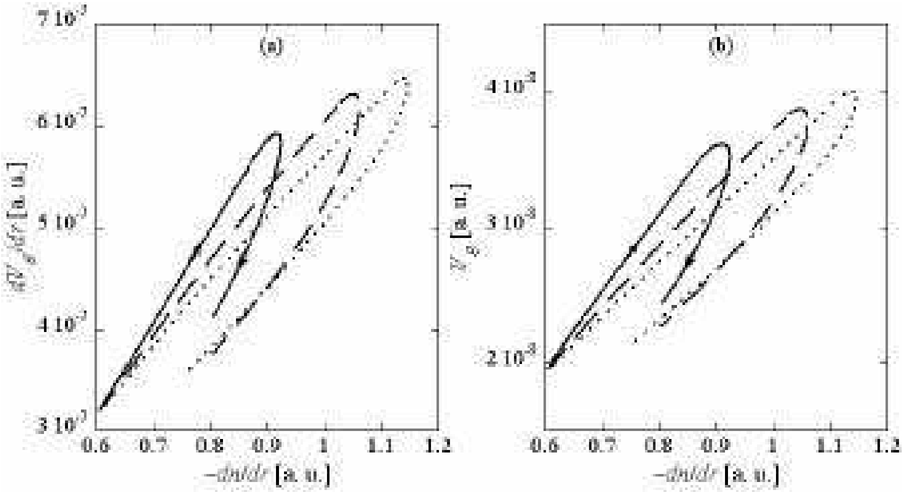

Figure 2. (a) The poloidal flow shear and (b) the poloidal flow magnitude at $r/a = 0.9$ as a function of the local density gradient for ramp rates of $\Delta t = 89.5$ ms (solid), $\Delta t = 300$ ms (dashed), and $\Delta t = 580$ ms (dotted).

a. Subcritical flows

Starting with an equilibrium at the lower source value, the source is ramped up to the higher value and then back down again to the lower value, at varying ramp rates. For flows that do not trigger a transition, there is no actual hysteresis in the dependence of the flow gradient on the source term. In Figure 1, the flow shear is shown as a function of the source magnitude for three different ramp durations, $\Delta t = 89.5$ ms, $\Delta t = 300$ ms, and $\Delta t = 580$ ms (the ramp down is symmetric in each case). As the ramp time is increased, the system has more time to adjust to the new source value and the apparent hysteresis is reduced.

The poloidal flow shear and (b) the poloidal flow magnitude at $r/a = 0.9$ are shown as a function of the local density gradient in Figure 2. Here, there does seem to be a lag between the ramp up and ramp down, even for the longer ramp times.

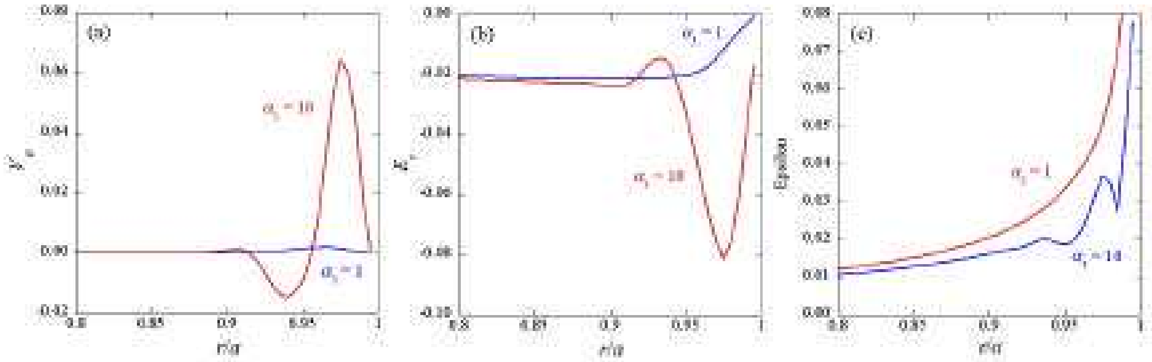

Figure 3. Edge profiles of (a) V_θ, (b) E_r, and (c) ε fortwo different Reynolds stress parameters, $\alpha = 1$ and $\alpha = 10$.

b. Critical flows

For lower μ and higher α_3, the poloidal flow generated is large enough to trigger a transition to an improved confinement regime. This is demonstrated in Figure 3 which shows edge profiles of (a) V_θ, (b) E_r, and ε. For the smaller value of α_3, poloidal flow is small and E_r is primarily determined by diamagnetic contributions from the pressure gradient. For larger α_3, an edge flow develops, E_r shear increases and fluctuations at the edge are suppressed (but not quenched). Further studies of ramping the particle source for critical flows are underway.

Acknowledgements: This research was supported by the U.S. Department of Energy under Grant No. DE-FG02-03ER54699 at the University of Montana.

References

[1] Ch. P. Ritz, H. Lin, T. L. Rhodes, and A. J. Wootton, Phys. Rev. Lett. **65**, 2543 (1990).

[2] C. Hidalgo, M. A. Pedrosa, L. Garcia, and A. Ware, Phys. Rev. E **70**, 067402 (2004).

[3] M. A. Pedrosa, *et al.*, Plasma Phys. Control. Fusion **47**, 777 (2005).

[4] B. Goncalves, *et al.*, Phys. Rev. Lett. **96**, 145001 (2006).

[5] D. E. Newman, *et al.*, Phys. Plasmas **5**, 938 (1998).