The Effect of Plasma Shaping on Turbulent Transport and $E \times B$ Shear Quenching in Nonlinear Gyrokinetic Simulations

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(Dated: July 25, 2007)

Abstract

Nonlinear gyrokinetic simulations with kinetic electron dynamics are used to study the effects of plasma shaping on turbulent transport and $E \times B$ shear in toroidal geometry including the presence of kinetic electrons using the GYRO code. Over 120 simulations comprised of systematics scans were performed around several reference cases in the local, electrostatic, collisionless limit. Using a parameterized local equilibrium model for shaped geometry, the GYRO simulations show that elongation κ (and its gradient) stabilizes the energy transport from ion temperature gradient (ITG) and trapped electron mode (TEM) instabilities at fixed midplane minor radius. For scans around a reference set of parameters, the GYRO ion energy diffusivity, in gyroBohm units, approximately follows a κ^{-1} scaling which is consistent with recent experimental energy confinement scalings. Most of the κ scaling is due to the shear in the elongation rather than the local κ itself. The κ scaling for the electrons is found to vary can be stronger or weaker than κ^{-1} depending on wavenumber where the transport peaks. The κ scaling is weaker when the energy diffusivity peaks at low wavenumbers and is stronger when the peak occurs at high wavenumbers. The simulations also demonstrate a nonlinear upshift in the critical temperature gradient as the elongation increases due to an increase in the residual zonal flow amplitude. Triangularity is found to be slightly destabilizing and its effect is strongest for highly elongated plasmas. Finally, we find less $E \times B$ shear is needed to quench the transport at high elongation and low aspect ratio. A new linear $E \times B$ shear quench rule, valid for shaped tokamak geometry, is presented.

PACS numbers: PACS numbers: 52.65.Tt,52.25.Fi,52.55.Fa