Entropic Theory of the Efficiency of Intrinsic Rotation Drive

Y. Kosuga, P.H. Diamond, O.D. Gurcan and J.E. Rice

CMTFO and CASS, UCSD, La Jolla, CA
WCI Center for Fusion Theory, NFRI, Gwahangno, Daejeon, RoK
LPP, Ecole Polytechnique, CNRS, Palaiseau Cedex, France
PSFC, MIT, Cambridge, MA, USA

A theory of the efficiency of the plasma flow generation is presented. A measure of the *efficiency* of plasma self-acceleration of mean flows from heat flux is introduced by analogy with engines, using the entropy budget defined by thermal relaxation and flow generation. The efficiency is defined as the ratio of the entropy destruction rate due to flow generation to the entropy production rate due to ∇T relaxation. The efficiency for toroidal intrinsic rotation is considered for a stationary state, achieved by balancing entropy production rate and destruction rate order by order in $O(k_\parallel/k_\perp)$, where k is the wave number. The efficiency of intrinsic toroidal rotation is derived and shown to be $e_{IR} \sim \rho_*^2(q^2/\hat{s}^2)(R^2/L_T^2) = \rho_*^2(L_s^2/L_T^2)$. The scaling form of toroidal flow velocity is also derived and shown to be $\langle V_\parallel \rangle / v_{thi} \cong (\rho_*/2)(\chi_i/\chi_\phi)(L_s/L_T)\sqrt{T_i/T_e}$, which suggests a machine size scaling and an unfavorable plasma current scaling which enters through the shear length. The theory is remarkably accurate in its prediction of intrinsic rotation levels and is robust upon detailed consideration of its domain of applicability.

Generically the theory predicts at stationarity $T = P_{\nabla T} - P_{ZF}$ where $P_{\nabla T}$ is production from ∇T, P_{ZF} is destruction from zonal flow growth and $T \equiv \int d^3v \langle \tilde{V}_r \delta f^2 \rangle / \langle f \rangle$. In the previous analysis for H-mode, where fluctuations are weak, we took $P_{\nabla T} \cong P_{ZF}$ to calculate $\langle V_E' \rangle$ and thus $\Pi_{r\parallel}^{res}$. More generally, however, T is finite (i.e. L-mode), so we find $P_{ZF} = P_{\nabla T} - T$, thus reducing zonal flows and intrinsic rotation in L-mode. Upon coupling the theory to a heat balance equation which encompasses transport bifurcation, a model emerges which can describe both L and H-mode. This model includes quenching of the nonlinear entropy flux at L$\rightarrow$H transition. Ongoing work is to extend the model from a local to a global picture.