High-beta toroidal equilibria with flow in reduced fluid models

A. Ito and N. Nakajima

National Institute for Fusion Science,322-6 Oroshi-cho, Toki 509-5292, Japan

atsushi@toki.theory.nifs.ac.jp

In improved confinement modes of magnetically confined plasmas where high-β is achieved, equilibrium flows play important roles like the suppression of instability and turbulent transport. In such equilibria, the scale lengths characteristic of microscopic effects not included in single-fluid magnetohydrodynamics (MHD) cannot be neglected. Small scale effects on flowing equilibria due to the Hall current have been studied with two-fluid or Hall MHD models [1]. However, these models are consistent with kinetic theory only for cold ions. A consistent treatment of hot ions in a two-fluid framework must include the ion gyroviscosity and other finite Larmor radius (FLR) effects. In the fluid formalism of collisionless magnetized plasmas, these effects are incorporated by means of asymptotic expansions in terms of the small parameter $\delta \sim \rho_i/a$, where ρ_i is the ion Larmor radius and a is the macroscopic scale length. With a slow dynamics ordering, $v \sim \delta v_{th}$ where v and v_{th} are the flow and thermal velocities respectively, the ion FLR terms [2] are much simplified in the reduced models for large-aspect-ratio, high-β tokamaks [3] after relating δ to the inverse aspect ratio expansion parameter $\varepsilon \equiv a/R_0 \ll 1$, where R_0 is the characteristic scale length of the major radius.
We have derived reduced sets of two-fluid equations for axisymmetric equilibria with flow comparable to the poloidal sound velocities. The poloidal-sonic flow is of interest because the equilibria show the transition at the point where the poloidal flow velocity crosses the poloidal sound velocity. This can be described by the reduced model with the relation $\delta \sim \epsilon$. While the poloidal-Alfvénic flow analysis follows the standard orderings of reduced MHD for high-β tokamaks, the poloidal-sonic flow analysis does not and higher-order terms must be taken into account [4]. Equilibrium states can be found by solving the expanded Grad-Shafranov (GS) equations order by order. In the single-fluid limit, we have found new analytical representations for MHD equilibria with both toroidal and poloidal flow [5]. We have developed a finite element method solver for reduced two-fluid GS equations. The FLR effects on two-fluid equilibria with flow are studied numerically. The equilibria with flow depend on the sign of the $E \times B$ flow in the presence of the FLR effects. The extension of these equilibrium models to helical systems will be discussed.

[1] A. Ito, J. J. Ramos, and N. Nakajima, Phys. Plasmas **14**, 062501 (2007).
[2] J. J. Ramos, Phys. Plasmas **12**, 052102 (2005).
[3] H. R. Strauss, Phys. Fluids **20**, 1354 (1977); Nucl. Fusion **23**, 649 (1983).
[4] A. Ito, J. J. Ramos, and N. Nakajima, Plasma Fusion Res. **3**, 034 (2008).
[5] A. Ito and N. Nakajima, submitted to Plasma Phys. Contr. Fusion.