§4. Effects of Finite Larmor Radius on Equilibria with Flow in Reduced Two-Fluid Models

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In improved confinement modes in magnetically confined plasmas, equilibrium flows may play an important role for the formation of transport barriers or pedestals. In such equilibria, the scale lengths characteristic of microscopic effects not included in single-fluid magnetohydrodynamics (MHD) cannot be neglected. In particular, consistent treatment of hot ions in a two-fluid framework must include the ion gyroviscosity and other finite Larmor radius (FLR) effects.

We have derived a reduced set of two-fluid equations for high-beta tokamak equilibria with FLR effects in the presence of flow in the order of the poloidal sound velocity[1)] by extending the formalism of the one for the single-fluid model[2)]. This reduced set consists of the reduced Grad-Shafranov-type equations for the first- and the second-order quantities of the magnetic flux and can describe either single-fluid, Hall MHD or two-fluid with ion FLR by switching on or off the non-ideal effects. All the effects of flow, two-fluid and the FLR appear only in the equations for the higher order quantities.

We have solved the partial differential equations for two-fluid equilibria with flow and FLR effects numerically by using the finite element method with 40×40 grid points. Figures 1 (a) – (c) show the isosurfaces of the magnetic flux ψ, the pressure p and the ion stream function Ψ respectively. In the single-fluid limit, this equilibrium is singular because the poloidal flow velocity is equal to the poloidal-sound velocity[3)]. This singularity is shifted due to the diamagnetic flow in the Hall MHD and two-fluid. In the case of the Hall MHD, this equilibrium has singularity in the convective term at the boundary. This singularity is resolved by the gyroviscous cancellation in the two-fluid model with the FLR. Thus, this solution is regular only in the presence of both two-fluid and FLR effects. Figures 1 (a) – (c) also show that these isosurfaces do not coincide with each other, which is a key feature of the two-fluid equilibria. Figures 1 (d) – (f) show the profiles of ψ, p and Ψ respectively in the midplane.. The solid (dashed) lines are for the case where the signs of E×B and the ion diamagnetic flows are the same (opposite). This asymmetry in the direction of E×B flow is another feature of the two-fluid equilibria.

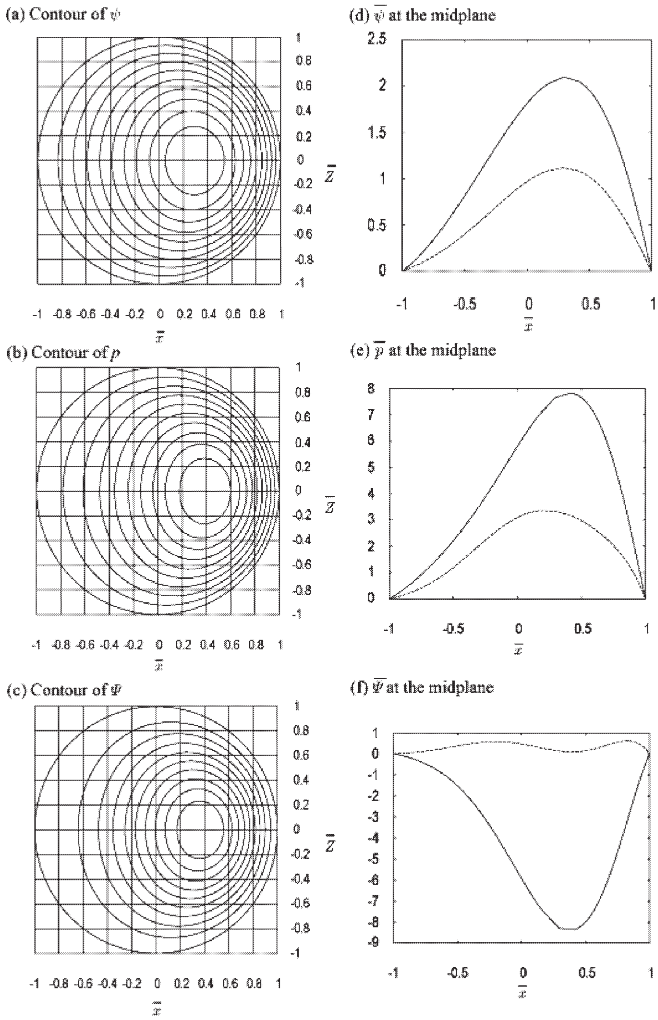

Fig1. Isosurfaces of (a) the magnetic flux ψ, (b) the pressure p and (c) the ion stream function Ψ and profiles of the normalized values of (d) ψ (e) p and (f) Ψ in the midplane.

1) Ito, A. and Nakajima, N.: AIP Conf. Proc. **1069**, 121 (2008).

2) Ito, A., Ramos, J. J., and Nakajima, N.: Plasma Fusion Res. **3**, 034 (2008).

3) Ito, A. and Nakajima, N.: Plasma Phys. Control. Fusion **51**, 035007 (2009).