Numerical calculation of neoclassical electron distribution function in an axisymmetric torus

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Building upon prior analytic results [1], we seek to numerically solve for a stationary, axisymmetric electron distribution function in a torus. We begin with a Chapman-Enskog-like set of electron fluid equations with the transport variables defined as integrals over the distribution function. The system is then closed using a drift-kinetic equation with a complete Fokker-Planck-Landau collision operator for the electron distribution function. All terms are kept to gyroradius and collisionality orders relevant to high-temperature tokamak experiments. Such an ordering for electrons is equivalent to the neoclassical banana regime. The distribution function is taken to be a Maxwellian at the zeroth-order. A solubility condition then determines the non-Maxwellian part of the distribution function, f_{NMe}, to the relevant orders. We assume an axisymmetric toroidal geometry and work in a 4D phase space $(\psi, \theta, v, \lambda)$, where ψ defines a flux surface, θ is the poloidal angle, v is the total velocity, and λ is the pitch angle parameter. We expand $f_{NMe}(\psi, v, \lambda)$ in linear finite elements in both v and λ. The Rosenbluth potentials, $\Psi(\psi, \cos\chi, \theta, v)$ and $\Phi(\psi, \cos\chi, \theta, v)$, are used to define the Landau collision operator. Both potentials are expanded in Legendre series in $\cos\chi$, where χ is the pitch angle, Fourier series in $\cos\theta$, and linear finite elements in v. At fixed ψ, we then use a block tridiagonal algorithm to solve for f_{NMe}, Ψ, and Φ simultaneously. Applying this to every flux surface results in a neoclassical electron distribution function for the entire torus. Our goal is to demonstrate that such a formulation of kinetic-fluid hybrid equations can be accurately and efficiently solved numerically. Results will be compared to other neoclassical codes, such as NCLASS (W.A. Houlberg, Oak Ridge National Laboratory) and NEO (E. Belli, General Atomics). Future work will extend the problem to non-axisymmetric configurations and use the results to solve for the neoclassical bootstrap current and heat flux. These quantities could then be used as a kinetic closure for an extended magnetohydrodynamics (MHD) code such as M3D-C1 to allow for the investigation of neoclassical tearing modes.

[1] Ramos, J.J. "Fluid and drift-kinetic description of a magnetized plasma with low collisionality and slow dynamics orderings. I. Electron theory." 2010. Physics of Plasmas, 17, 082502.

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