Two-fluid magnetic reconnection with arbitrary guide-field

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The following new set of reduced equations governing 2-D, two-fluid, magnetic reconnection with arbitrary guide-field is derived:

$$\begin{aligned}
\frac{\partial \psi_e}{\partial t} &= [\phi, \psi] + d_\beta\,[\psi, Z] + \eta\,\nabla^2\psi,\\
\frac{\partial Z_e}{\partial t} &= [\phi, Z] + d_\beta\,[\nabla^2\psi, \psi] + c_\beta\,[V_z, \psi] + c_\beta^2\,\eta\,\nabla^2 Z,\\
\frac{\partial U}{\partial t} &= [\phi, U] + [\nabla^2\psi, \psi] + \mu\,\nabla^2 U,\\
\frac{\partial V_z}{\partial t} &= [\phi, V_z] + c_\beta\,[Z, \psi] + \mu\,\nabla^2 V_z,
\end{aligned}$$

where ψ is the magnetic flux-function, ϕ the ion stream-function, Z the normalized perturbed magnetic field in the z-direction, $U = \nabla^2\phi$, $\psi_e = \psi - d_e^2\,\nabla^2\psi$, and $Z_e = Z - c_\beta^2\,d_e^2\,\nabla^2 Z$. Also, $[A, B] \equiv \nabla A \wedge \nabla B \cdot \hat{\mathbf{z}}$. Here, $c_\beta = \sqrt{\beta/(1+\beta)}$, $d_\beta = c_\beta\,d_i$, where β is the plasma beta calculated with the guide-field, d_i the collisionless ion skin-depth, and d_e the collisionless electron skin-depth. It is assumed that $\partial/\partial z \equiv 0$. The reduction process involves the removal of the compressible Alfvén wave, which plays no role in magnetic reconnection.

The above equations, which are easy to solve numerically, represent a significant advance in magnetic reconnection theory, since all existing sets of reduced equations used to study reconnection are only valid in either the large or the small guide-field limits (*i.e.*, either $\beta \gg 1$ or $\beta \ll 1$). The new equations are used to investigate the scaling of the rate of forced magnetic reconnection in the so-called Taylor problem, in which a tearing stable plasma is subject to a suddenly applied resonant magnetic perturbation. In the non-linear regime with arbitrary guide-field (and $d_e = 0$), the peak reconnection rate is independent of the resistivity, and scales like $d\Psi/dt \sim [\beta/(1+\beta)]^{3/4}\,d_i^{3/2}\,\Xi_0^2$, where Ξ_0 the amplitude of the external perturbation. This result cannot be accounted for in terms of the "universal" reconnection rate recently proposed by the Maryland group.