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Plasma Acceleration in the Magnetic Nozzle

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The acceleration of plasma in a magnetic nozzle has many important applications including nuclear fusion in magnetic mirrors, helicon thrusters for space propulsion and plasma based etching of semiconductors. The goal is to study the acceleration mechanism, determine what factors give rise to larger plasma acceleration and how plasma parameters such as density, pressure, electrostatic potential are affected.

The flow of plasma is described in the paraxial approximation using a two fluid MHD model. Electrons are assumed to be isothermal while ions are fully magnetized, have anisotropic pressures and follow CGL model where heat fluxes are neglected. The magnetic field of the nozzle has no time-dependence, is constant at the left end, increases until it reaches a maximum near the middle of the nozzle and then decreases again and becomes constant at the right end. The flow of plasma is studied in both the absence and presence of ionization and charge-exchange.
From the continuity and CGL equations, the equations that describe ion dynamics were derived. \begin{equation}
\left(M^2-1-\frac{3 p_\parallel }{n T_e}\right)\frac{\partial M}{\partial z}= -\left(1+\frac{p_\perp}{n T_e}\right) M \frac{\partial\log B}{\partial z}
\end{equation}

A singularity occurs for values of $M = \sqrt{1+\frac{3p_\parallel}{nT_e}}$. Stationary solutions for ion dynamics are obtained using the Shooting Method and time-dependent solutions are obtained using the PDE solver BOUT++. In the Shooting Method differential equations are integrated numerically from the singular point, occurring in the middle of the nozzle where $\frac{\partial \log B}{\partial z} = 0$, in both directions. Initial values of $T_{i\parallel}$ and $T_{i\perp}$ are chosen at the singular point such that when integrated to the left the will result in $T_{i\parallel} = T_{i\perp} = 200eV$ at the left end of the nozzle where the plasma is completely thermalized. Time-dependent solution are then compared to stationary solutions for large time intervals. Ionization and charge-exchange are added to the model to investigate their effects on plasma acceleration and the shift of the sonic point

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