The magnetohydrodynamic (MHD) flow of plasma through a magnetic nozzle is simulated by solving the governing equations for the plasma flow in the presence of a static magnetic field representing the applied nozzle. This work will numerically investigate the flow and behavior of the plasma as the inlet plasma conditions and magnetic nozzle field strength are varied. The MHD simulations are useful for addressing issues such as plasma detachment and can be used to gain insight into the physical processes present in plasma flows found in thrusters that use magnetic nozzles.

In the model, the MHD equations for a plasma, with separate temperatures calculated for the electrons and ions, are integrated over a finite cell volume with flux through each face computed for each of the conserved variables (mass, momentum, magnetic flux, energy) [1]. Stokes theorem is used to convert the area integrals over the faces of each cell into line integrals around the boundaries of each face. The state of the plasma is described using models of the ionization level, ratio of specific heats, thermal conductivity, and plasma resistivity. Anisotropies in current conduction due to Hall effect are included, and the system is closed using a real-gas equation of state to describe the relationship between the plasma density, temperature, and pressure.

A separate magnetostatic solver is used to calculate the applied magnetic field, which is assumed constant for these calculations. The total magnetic field is obtained through superposition of the solution for the applied magnetic field and the self-consistently computed induced magnetic fields that arise as the flowing plasma reacts to the presence of the applied field. A solution for the applied magnetic field is represented in Fig. 1 (from Ref. [2]), exhibiting the classic converging-diverging field pattern.

Previous research was able to demonstrate effects such as back-emf at a super-Alfvenic flow, which significantly alters the shape of the magnetic field in both the near- and far-field regions. However, in that work the downstream domain was constrained to a channel of constant cross-sectional area. In the present work we seek to address this issue by modeling the downstream region with a domain that permits free expansion of the plasma, permitting a better evaluation of the downstream effects the applied field has on the plasma. The inlet boundary conditions and applied magnetic field values will also be varied to determine the effect the initial plasma energy content and applied magnetic field energy density have on the near- and far-field plasma properties on the MHD code. This will determine the effect of inlet boundary conditions on the results downstream and address issues related to the restrictive numerical domain previously used.
References


Figure 1:
a) Magnetic flux lines of the applied field in the r-z plane of the nozzle.
b) Magnitude of the applied field.