Fluid Simulations of Magnetic Nozzle Thruster Including Plasma Source

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Magnetic nozzles are plasma acceleration devices in which a plasma expands along a divergent magnetic field, accelerating to produce thrust. Magnetic nozzles offer several potential advantages over traditional electric propulsion devices like Hall thrusters and gridded ion thrusters. They are propellant and plasma source-agnostic, making them an attractive general-purpose plasma acceleration mechanism with possible applicability to in-situ resource utilization. Additionally, as plasma is confined away from the device walls by a strong axial magnetic field, low power (less than 100 W) devices employing magnetic nozzles may suffer from lower plasma wall losses than competing technologies, making them ideal for the emerging smallsat market. However, these possible advantages have not yet materialized, and efficiency remains fairly low. Thus, no magnetic nozzles have yet been flown on orbit.

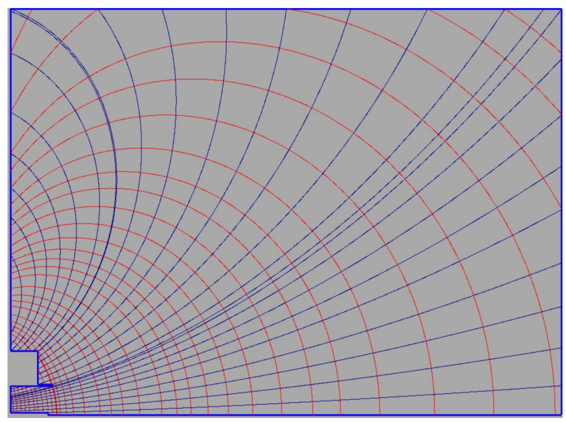

Figure 1 – The mesh used in this work. Note the field-aligned coordinate system.

Recently, rapid design optimization has succeeded in making remarkable efficiency gains in devices employing magnetic nozzles[1], but this has been limited to manually altering device geometry, testing, and repeating. This process is expensive and slow, and would be dramatically improved and sped up if sufficiently predictive fluid models were available. However, gaps in our knowledge of the physics of electron detachment from the guiding field lines and the nature and type of electron cooling in the nozzle plume prevent current fluid models from being predictive enough to be useful in rapid design optimization.

In this work, we present an advanced fluid model of a magnetic nozzle and plasma source using the Hall2De fluid Hall thruster code developed at the Jet Propulsion Laboratory. This model solves the 2D axisymmetric ion and electron fluid equations on a magnetic field-aligned mesh and treats neutrals as ballistic. Most notably, this model solves a full electron fluid energy equation instead of pre-supposing a polytropic equation of state, allowing more nuanced investigation of the mechanism of electron cooling. Comparisons between the present model and experiment show that classical fluid physics alone cannot explain electron cooling in the studied devices and suggest that wave-driven anomalous resistivity may be needed to correctly model plasma expansion in magnetic nozzles. This is in line with recent experimental results suggesting that wave driven collisionality due to the lower hybrid drift instability (LHDI) may dominate classical collisions in magnetic nozzle plumes[2].

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References

[1] T.Vialis, J. Jarrige, D. Packan, A. Aanesland. J. Propulsion and Power, AIAA, 2018, pp.1-11.
[2] S. Hepner, B. Wachs, B. Jorns, Appl. Phys. Lett. **116**, 263502 (2020).