Low Frequency Instabilities in a Magnetic Nozzle*

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Magnetic nozzles are a type of electric rocket consisting of a diverging magnetic field through which a plasma is ejected. As a radial pressure gradient forms, an electron diamagnetic drift induces a magnetic field that opposes the applied field, which in turn accelerates the electrons outwards. The electrons thus generate an ambipolar electric field that accelerates the ions, generating thrust. Given that the magnetic field is primarily parallel to the thruster body, erosion is mitigated, allowing the potential for long duration missions. Furthermore, as most plasma generation mechanisms involved in magnetic nozzles rely on electron heating, they can operate on a wide array of propellants, enabling mid-mission refueling.

Despite their prolific advantages, magnetic nozzles have not yet operated in space. The main reason behind this fact is that there are several important aspects of these devices that are not well understood. One of these issues is the interaction between the electrons and the magnetic field. While they are commonly assumed to follow field lines perfectly [1], this cannot be the case in practice, as they will inevitably return to the thruster and negate the ambipolar electric field that accelerates the ions. The question then remains as to if and how they can travel across field lines.

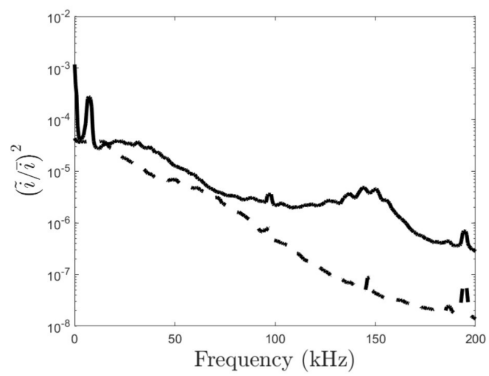

Figure 1 – Power spectrum of waves in the plume of a magnetic nozzle for a low (solid) and high (dashed) flow condition. The high Flow dampens all modes, but the low Flow maintains distinct peaks at 10 kHz, 40 kHz, and 100 kHz.

While several theories have been proposed to explain electron cross-field transport in magnetic nozzles [2], this work focuses on the role of instabilities. As instabilities grow, they induce an effective drag on the electrons, allowing transverse motion. While we have previously investigated the role of an incoherent azimuthal mode [3], we have also observed a series of lower frequency, coherent modes that exist in the plume (Fig. 1). In this work, we focus on these modes, explaining them theoretically using linear kinetic theory. Furthermore, we quantify their impact on electron transport by defining an effective collision frequency with quasilinear theory. We have taken this approach in the past in determining the impact of the incoherent mode, and it is commonly taken in literature to describe the impact of instabilities on electron transport. We compare this impact on electron motion to that induced by the incoherent mode.

* This work is funded under NASA Space Technology Research Fellowship grant number 80NSSC17K0156.

References

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