Model for Impact of Wall Material on ECR Magnetic Nozzle Operation

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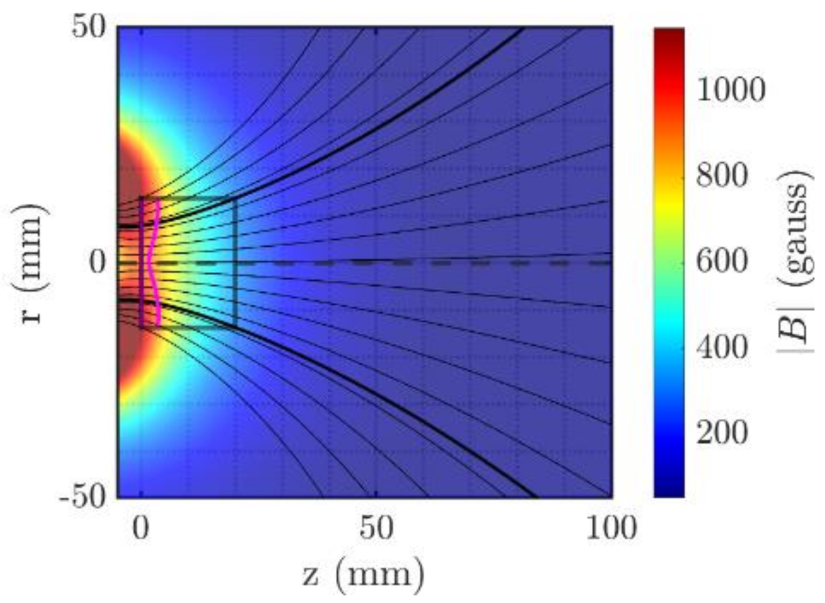
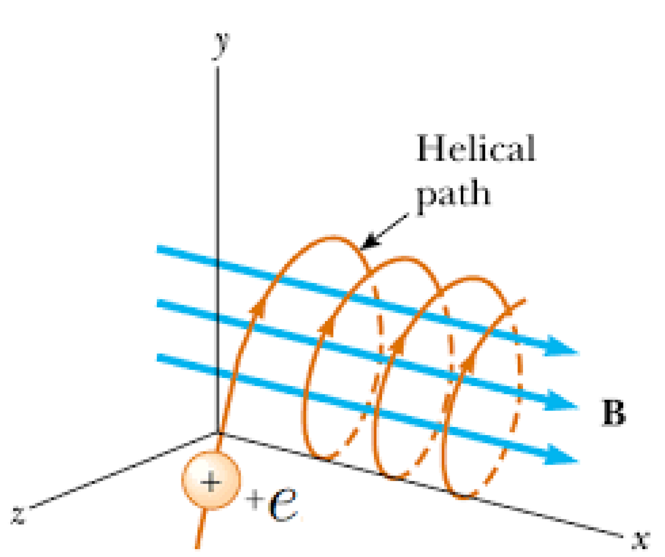
Introduction

- Magnetic nozzles convert random thermal energy into directed kinetic flow.
- Magnetic nozzles are inherently advantageous for small satellite propulsion applications.
- Electron Cyclotron Resonance (ECR) heating utilizes the natural gyration of charged particles in a magnetic field.

$$\omega_{ce} = \frac{qB}{m_e}$$



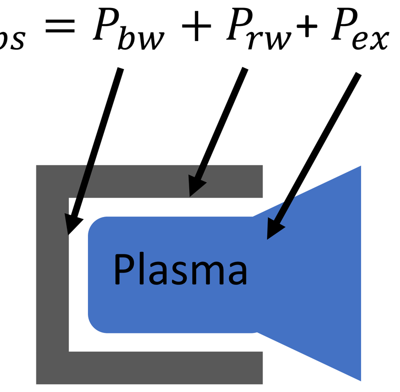


Thruster Operation

- Neutral gas is injected into the source tube.
- Microwave radiation (2450MHz) is injected into the source tube through an antenna.
- Electrons within the resonance zone (875G) are heated.
- These electrons collide with neutrals ionizing them thus forming a plasma.
- Electrons follow the weaker B-field downstream.
- An ambipolar electric field between the electrons and ions accelerates ions from the source tube.

Discharge Model

$$P_{abs} = P_{bw} + P_{rw} + P_{ex}$$



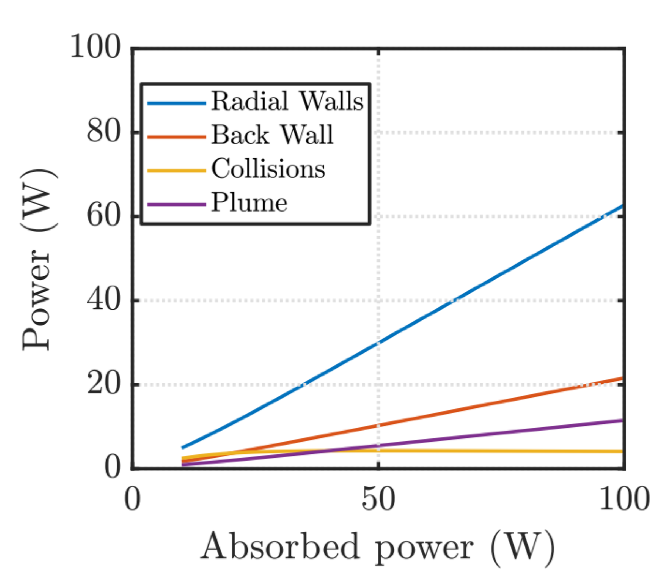
$$P_{bw} = I\varepsilon = q\Gamma A(\varepsilon_c + \varepsilon_{ic} + \varepsilon_{ec})$$

$$P_{rw} = I\varepsilon = q\Gamma A(\varepsilon_c + \varepsilon_{ir} + \varepsilon_{er})$$

$$P_{ex} = I\varepsilon = q\Gamma A(\varepsilon_c + \varepsilon_{io} + \varepsilon_{eo})$$

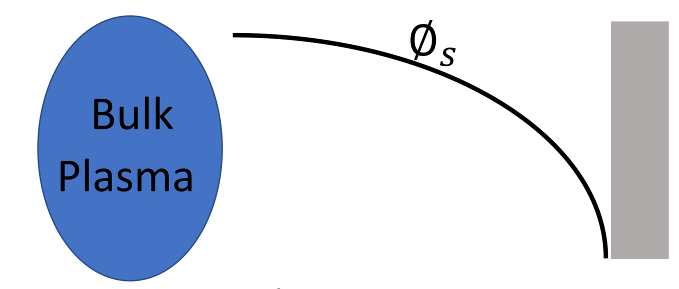
Quasi-1D analytical discharge model

This global source model builds on the helicon thruster model first proposed by T. Lafleur [1], which uses semi-empirical 1D mass and momentum conservation equations coupled to a 0D energy conservation equation, to predict thruster performance.

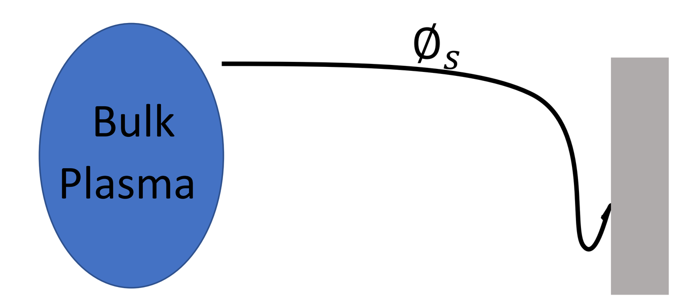


Wall Material Impact

- Wall losses are a dominate power loss mechanism in these devices.
- As the energy is primarily injected into the electrons, we look to accurately model the electron energy loss to the walls.
- We incorporate the effect of secondary electron emission (SEE) in the sheath potential to more accurately model the electron energy loss to the walls.



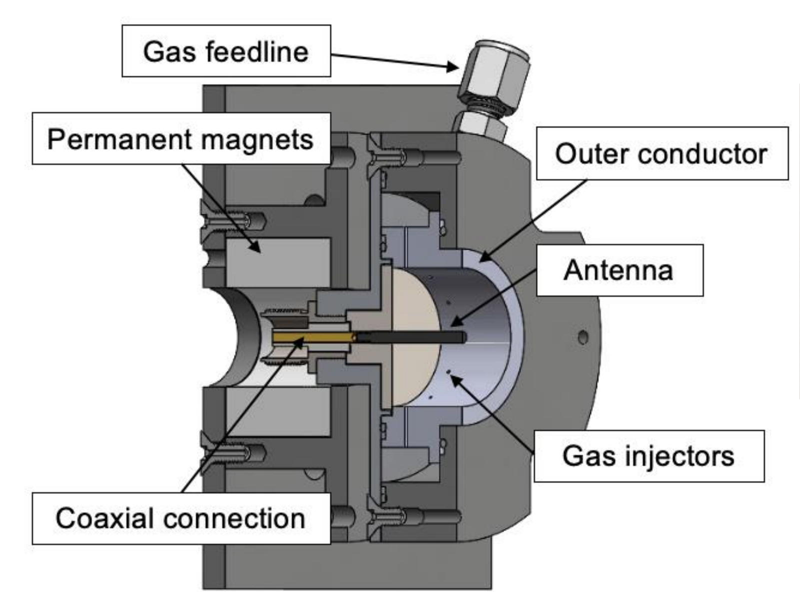
No SEE, $\Delta\phi$ is high, $\Gamma_i = \Gamma_e$

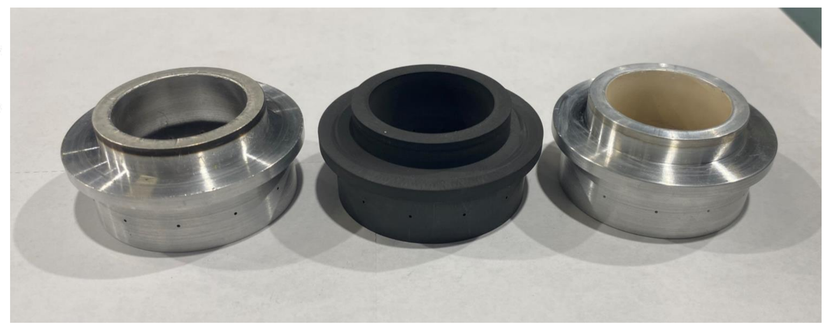


SEE, $\Delta\phi$ is lower, $\Gamma_i + \Gamma_{se} = \Gamma_e$

$$\gamma = \frac{emission}{primary}, \quad \phi_s = \frac{T_e}{2}\ln[(1-\gamma)\frac{2m_i}{\pi m_e}]$$

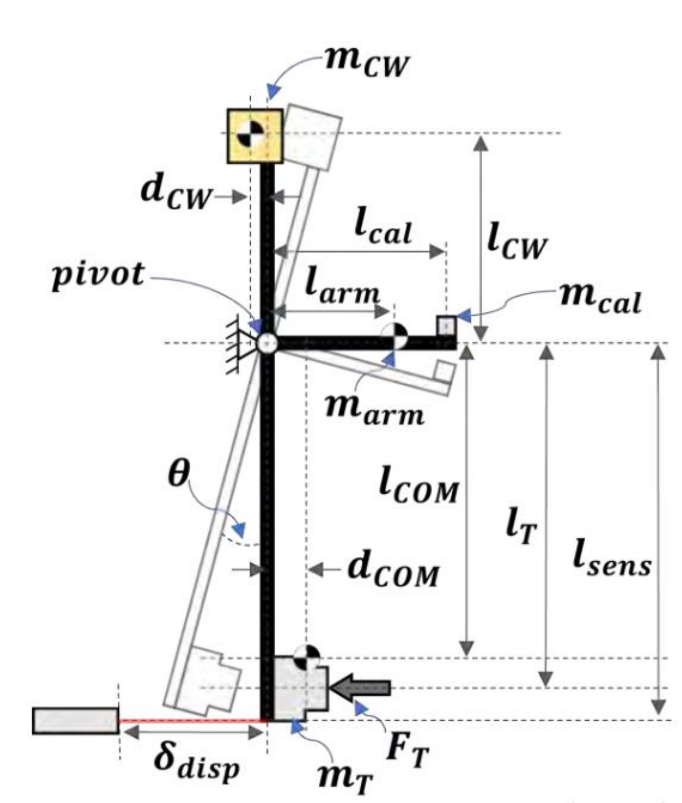
Experimental Setup

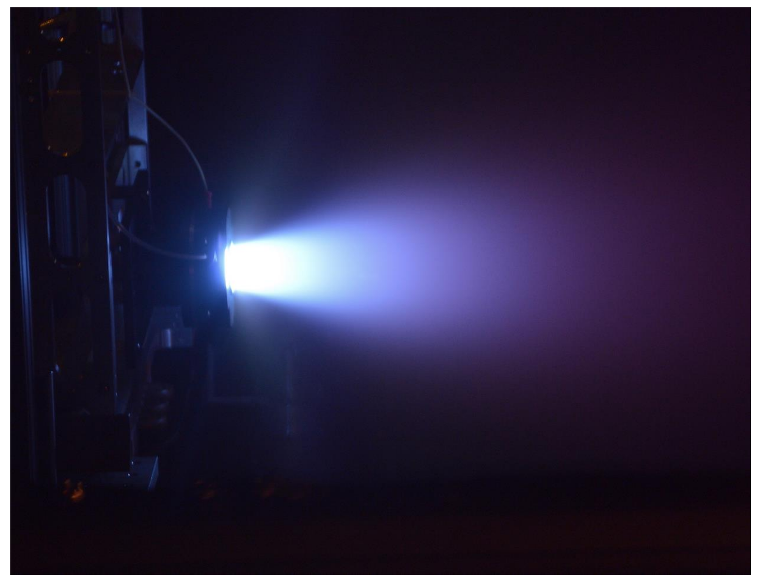




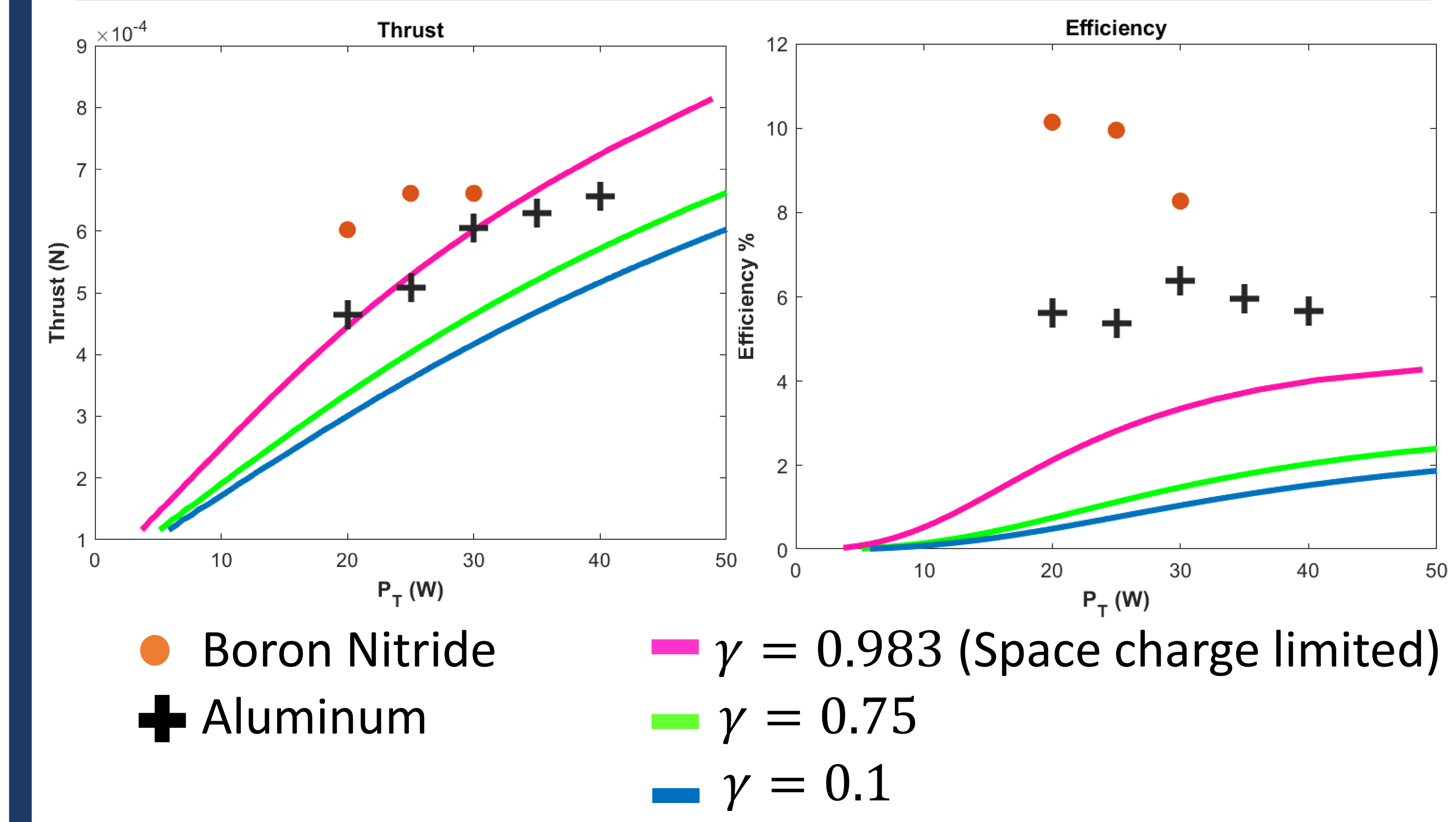
Materials

- Aluminum
- Graphite
- Boron Nitride
- Aluminum Oxide





Results



Conclusions & Future Work

Conclusions

- Thrust efficiency predictions from our model has yet to coincide with data even in the case of a space charge limited sheath potential.
- Thrust predictions begin to coincide with experimental data as the SEE yield goes towards unity. However, data from insulating materials still show higher thrust than predicted.
- These results imply that perhaps a smaller sheath potential due to SEE may not be the only factor contributing to the lower wall losses we observe with insulating source tube materials.

Future Work

- SEE yield as a function of primary electron temperature energy.
- SEE yield is different for different areas of the source region.
- Langmuir Probe measurements of electron temperature.

References

- [1] T. Lafleur, Phys. Plasmas 21, 043507 (2014).
- [2] Wachs, B. N., "Optimization and Characterization of Facility Effects for a Low-Power Electron Cyclotron Resonance Magnetic Nozzle Thruster," Ph.D. thesis, University of Michigan, 2022.
- [3] Dan M Goebel and Ira Katz. Fundamentals of electric propulsion: ion and Hall thrusters, volume 1. John Wiley & Sons, 2008.

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