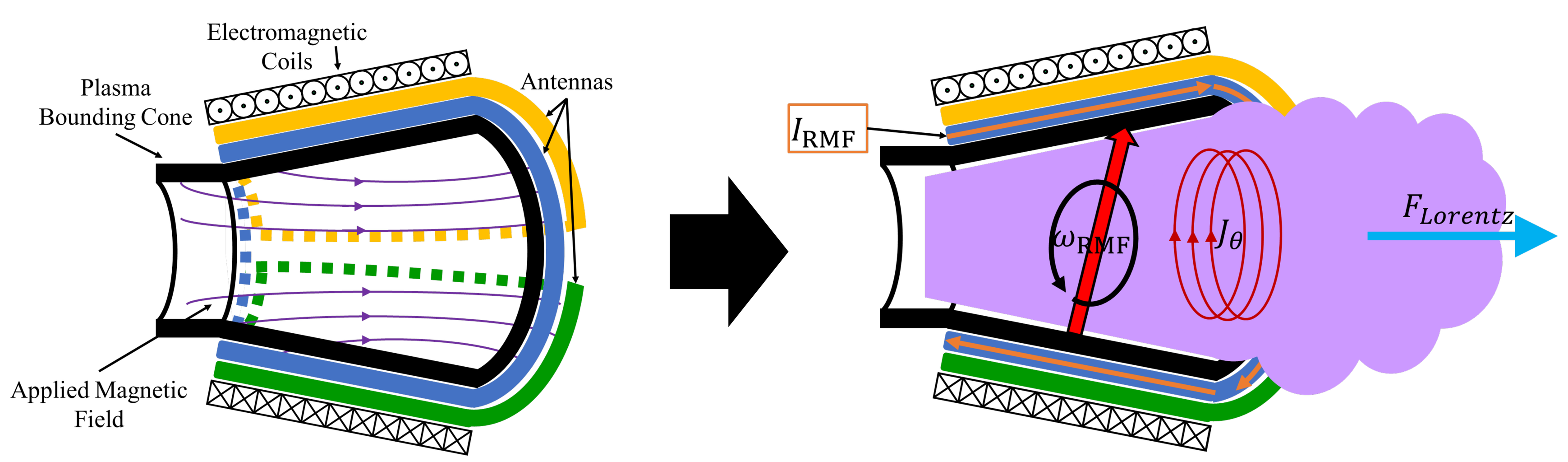
Fluid Model Performance Predictions of a Coaxial Electrodeless Magnetoplasmadynamic (E-MPD) Thruster

UNIVERSITY OF MICHIGAN

Grace Zoppi, Tate Gill, Christopher Sercel, and Benjamin Jorns
University of Michigan, Department of Aerospace Engineering, Ann Arbor, MI 48109

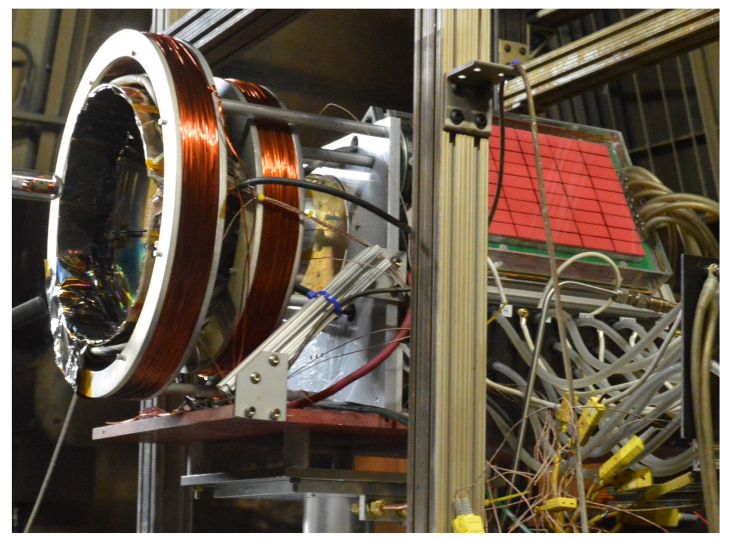
Michigan Institute for Plasma Science and Engineering

Thruster Operating Principles



The E-MPD thruster couples energy inductively into the plasma.

Thruster Architecture Motivation



Benefits of E-MPD Thruster

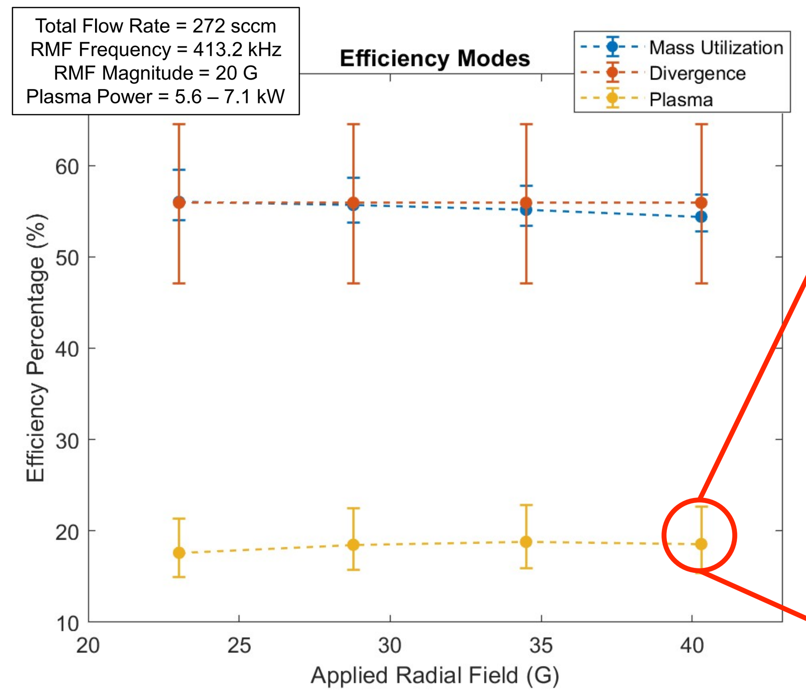
High Power Densities → Favorable geometric scaling for high power applications

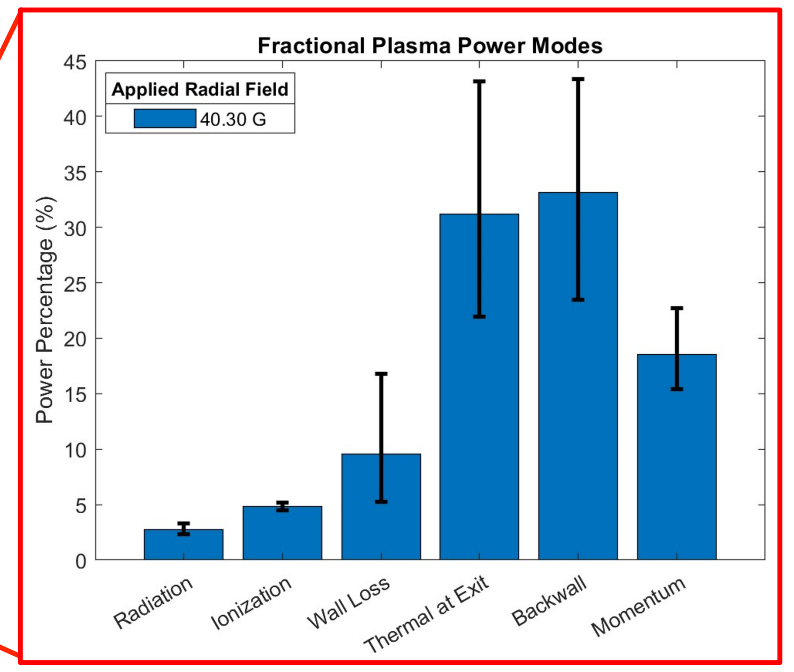
Electrodeless → Eliminate common failure point & allow for the ability to operate on alternative propellants

Performance of E-MPD Prototype

Challenge: Efficiency to date has been < 3%

We created a quasi-1D plasma-neutral fluid model to characterize the dominate loss processes of a conical E-MPD. [1]





How do we improve performance?

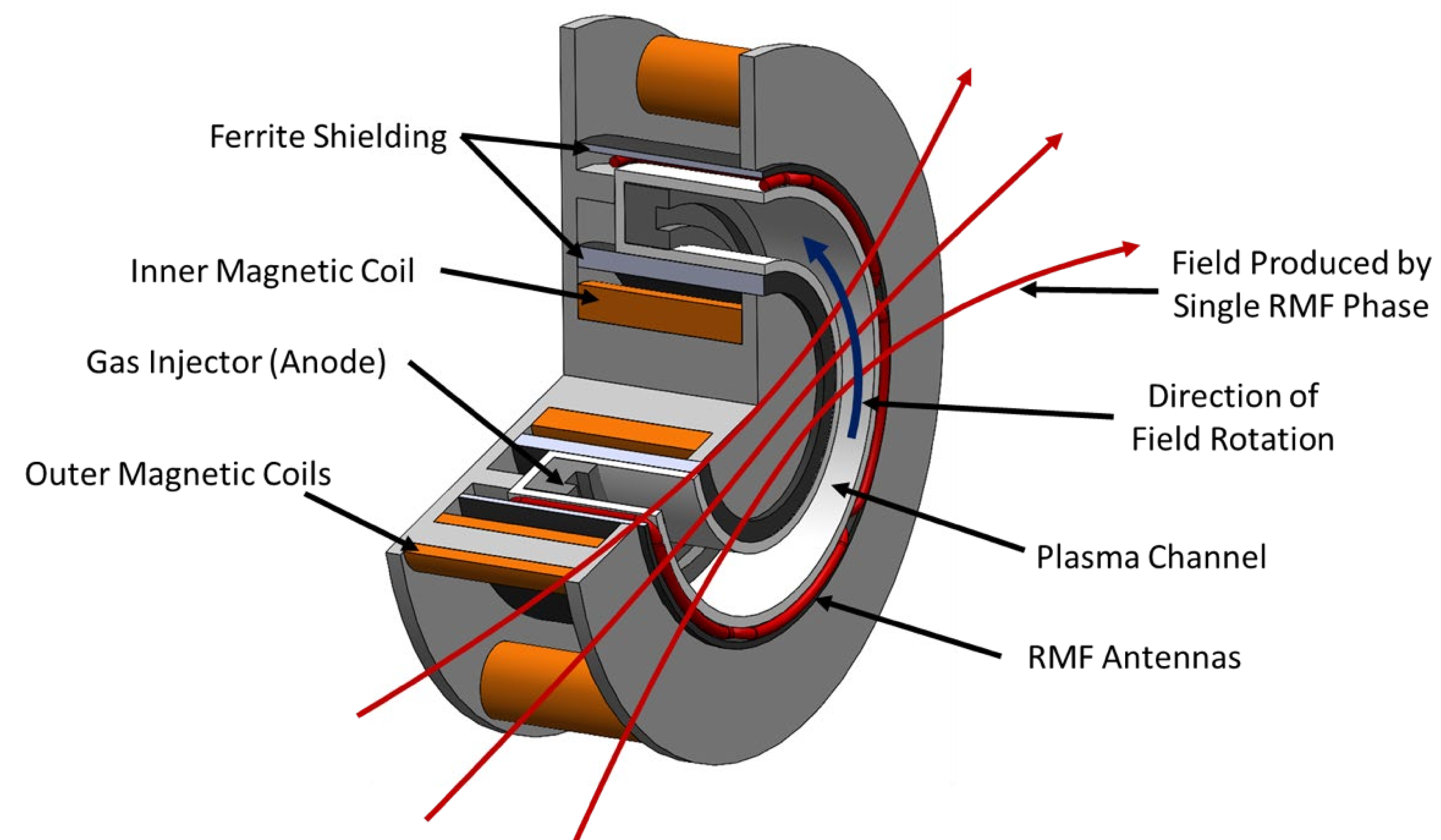
Boost momentum power by boosting Lorentz force. Accomplished by increasing the radial applied field.

Coaxial E-MPD Design

What would an ideal thruster look like to boost the applied radial field?

An annular geometry with strong magnets surrounding the plasma discharge region.

As proof of concept, we will use a recycled Hall thruster to approximate this geometry, allowing for faster and cheaper design development.



Idea → Insert RMF antennas into H6 geometry.

Problem → H6 iron core will consume the power from the RMF antennas.

Solution→ Add ferrite shielding to concentrate the magnetic field flux to the channel.

Modifying the H6, by adding three-phase antennas and ferrite shielding, allows for RMF generation at stronger rotating and applied field strengths.

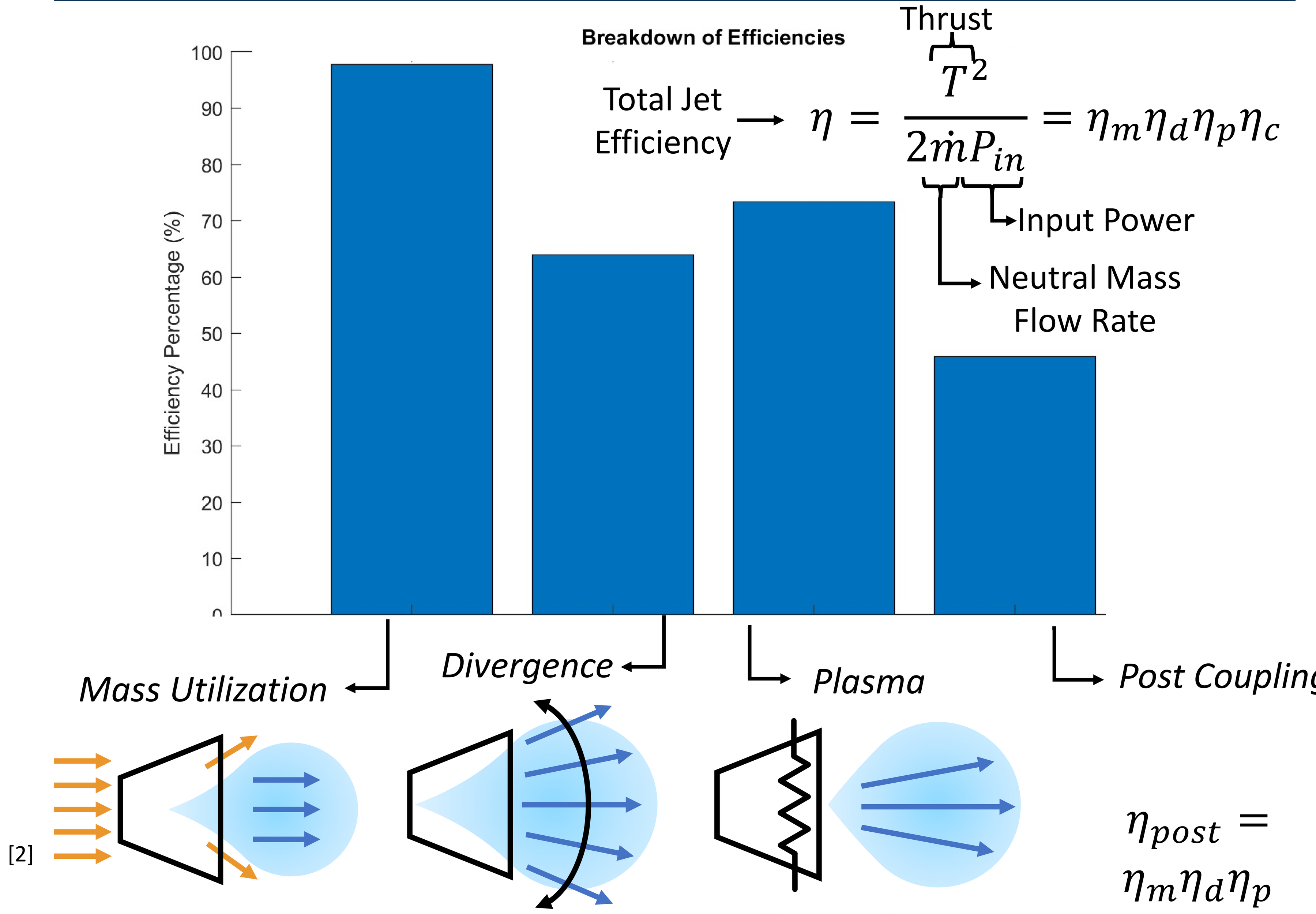
References

[1] G. Zoppi, T. M. Gill, C. L. Sercel, and B. A. Jorns, "Geometric Trade Study of the Rotating Magnetic Field Thruster Informed by a Two-Fluid Model," in 38th International Electric Propulsion Conference, 2024. IEPC Paper 2024-761.

[2] T. M. Gill, C. L. Sercel, G. Zoppi, and B. A. Jorns, "Efficiency Analysis of a Rotating Magnetic Field Thruster in Pulsed and Continuous-Wave Mode," *76th Annual Gaseous Electronics Conference*, Poster, 2023.

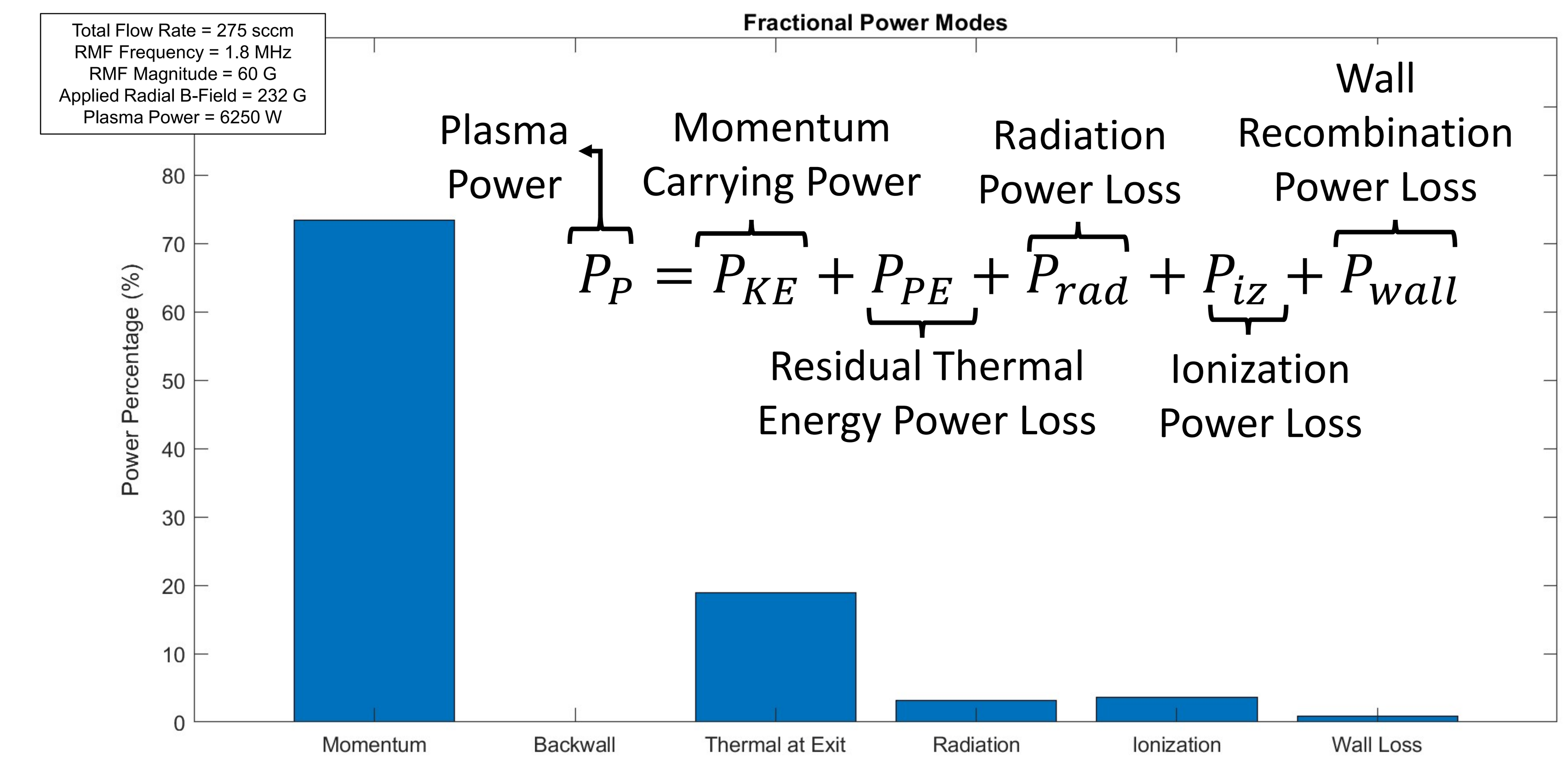
Contact: gzoppi@umich.edu

Model Based Performance Predictions



$$\underbrace{\eta}_{\text{Total Jet Efficiency}} = \frac{\overbrace{T^2}^{\text{Thrust}}}{2\underbrace{\dot{m}}_{\text{Neutral Mass Flow Rate}}\underbrace{P_{in}}_{\text{Input Power}}} = \eta_m\eta_d\eta_p\eta_c$$

$$\eta_m = \frac{\text{Ion Mass}}{\text{Total Mass}} \qquad \eta_d = cos^2(\theta_d) \qquad \eta_p = \frac{\text{Kinetic Power}}{\text{Plasma Power}} \qquad \eta_{post} = \eta_m\eta_d\eta_p$$



$$\underbrace{P_P}_{\text{Plasma Power}} = \underbrace{P_{KE}}_{\text{Momentum Carrying Power}} + \underbrace{P_{PE}}_{\text{Residual Thermal Energy Power Loss}} + \underbrace{P_{rad}}_{\text{Radiation Power Loss}} + \underbrace{P_{iz}}_{\text{Ionization Power Loss}} + \underbrace{P_{wall}}_{\text{Wall Recombination Power Loss}}$$

*Modeling only the MAP point of the posterior free parameter set.

Conclusions

Overall, the model predicts that the coaxial E-MPD thruster geometry will improve performance due to the higher available magnetic field strengths. Increasing the Lorentz force boosts momentum power, significantly reducing fractional power losses. Additionally, the annular geometry enhances mass utilization efficiency by increasing particle density at equivalent flow rates.