Simulation of magnetic nozzle plasma rockets

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Introduction

Strong guiding magnetic fields known as magnetic nozzles, shown in Figure 1, are key components in the design of electrodeless plasma thrusters. Many of these thrusters, such as the CubeSat Ambipolar Thruster, operate at conditions that are challenging to simulate with conventional simulation techniques[1].

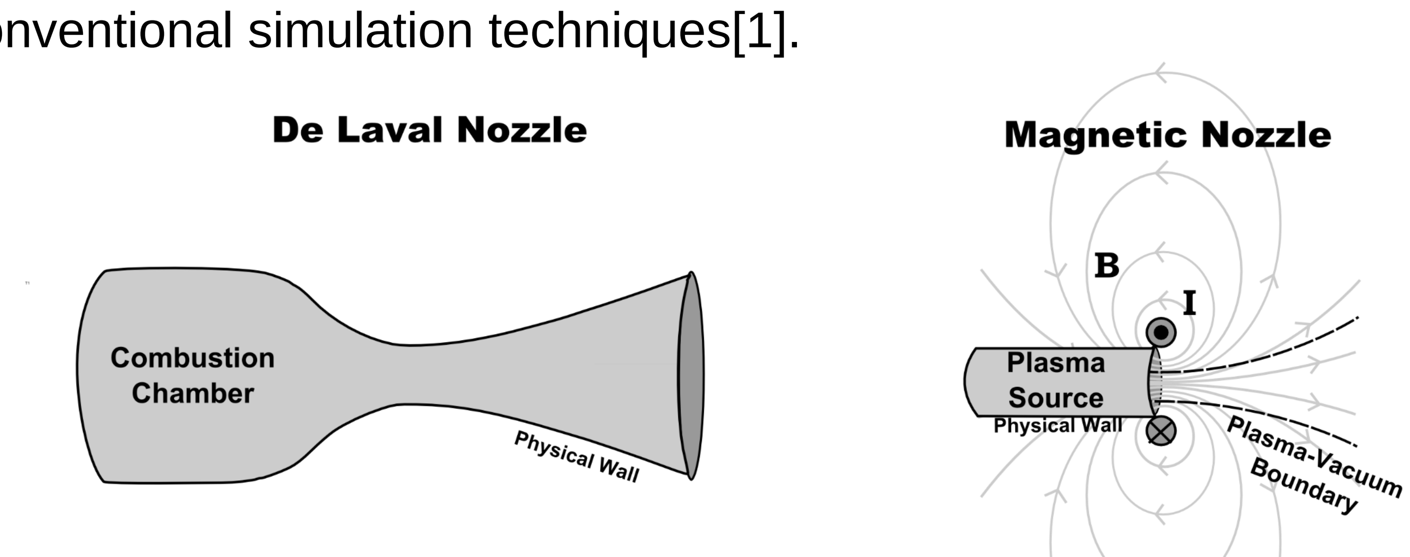

Figure 1: Comparison of De Laval nozzle to magnetic nozzle [1].

Figure 2: A rendering of the CubeSat Ambipolar Thruster.

Objectives

1. Simulate helicon plasma thruster incorporating a magnetic nozzle.
2. Study ion acceleration mechanisms to help determine optimal operating conditions.

Methodology

A novel quasi-one-dimensional electrostatic particle-in-cell (PIC) method was developed which focuses on studying ion acceleration in magnetic nozzles.[2] Electrostatic PIC is outlined in Figure 3 below.

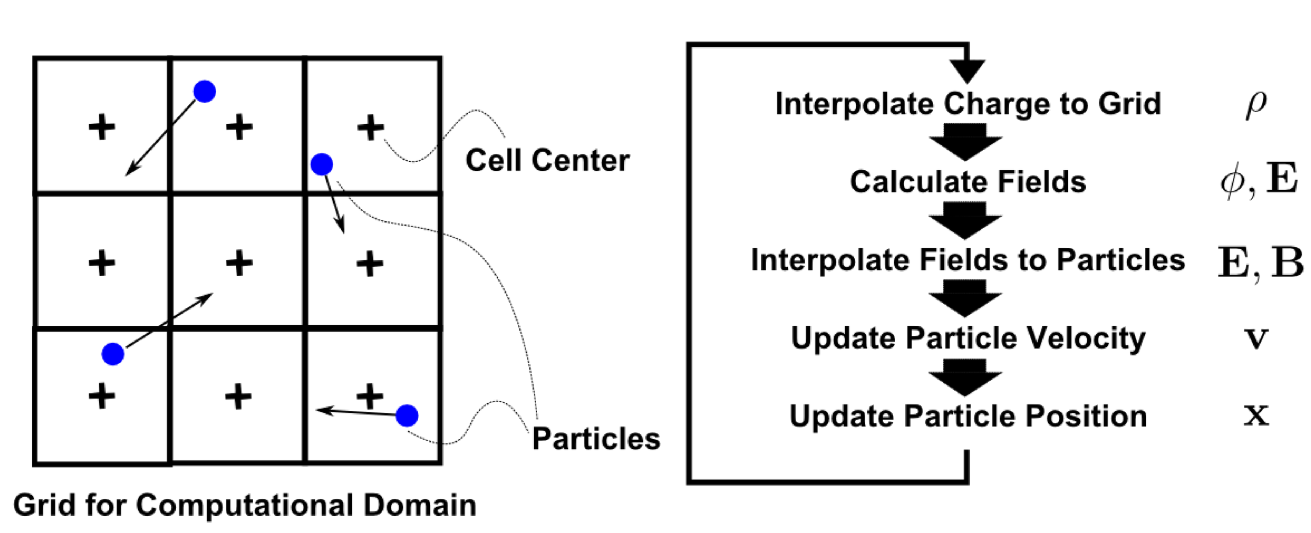

Figure 3: Basics of a electrostatic Particle-In-Cell code.

The centerline axis of the magnetic nozzle, shown in Figure 4, was resolved and the two dimensional effects of the plasma expansion and magnetic field forces were modelled .

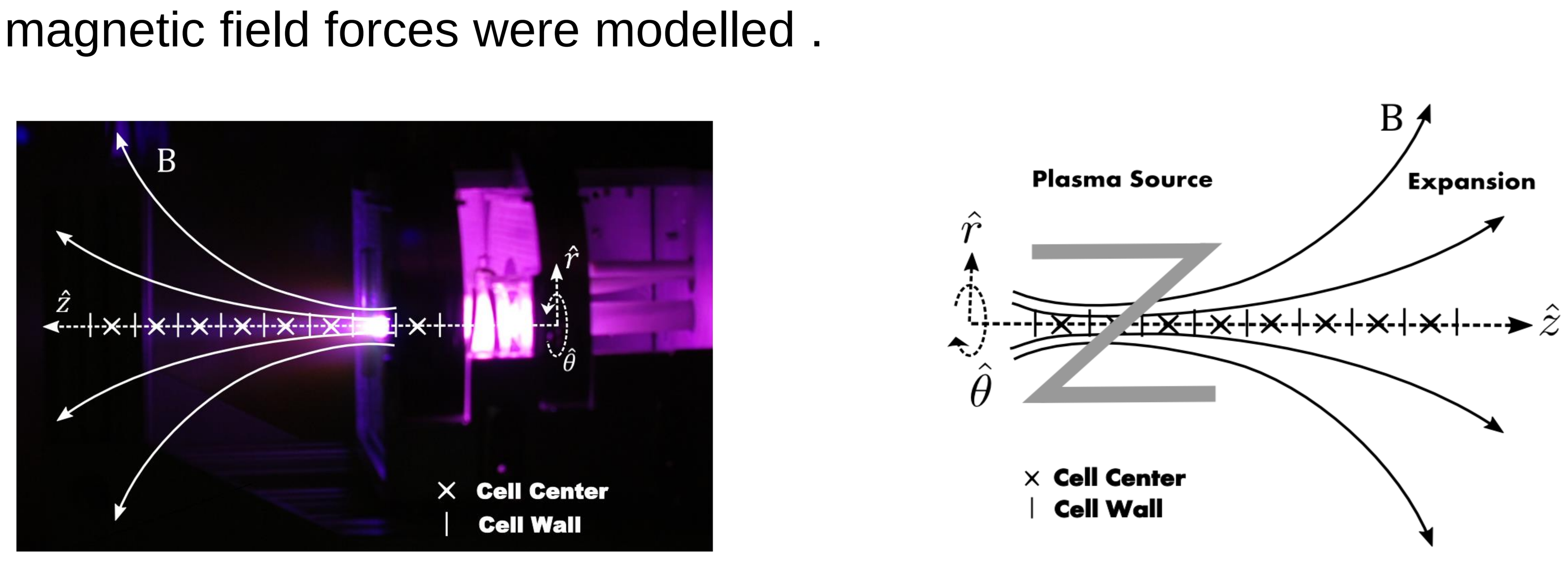

Figure 4: Simulation domain overlaid on the CAT experiment plasma plume and a diagram of the different regions.

Results and Discussion

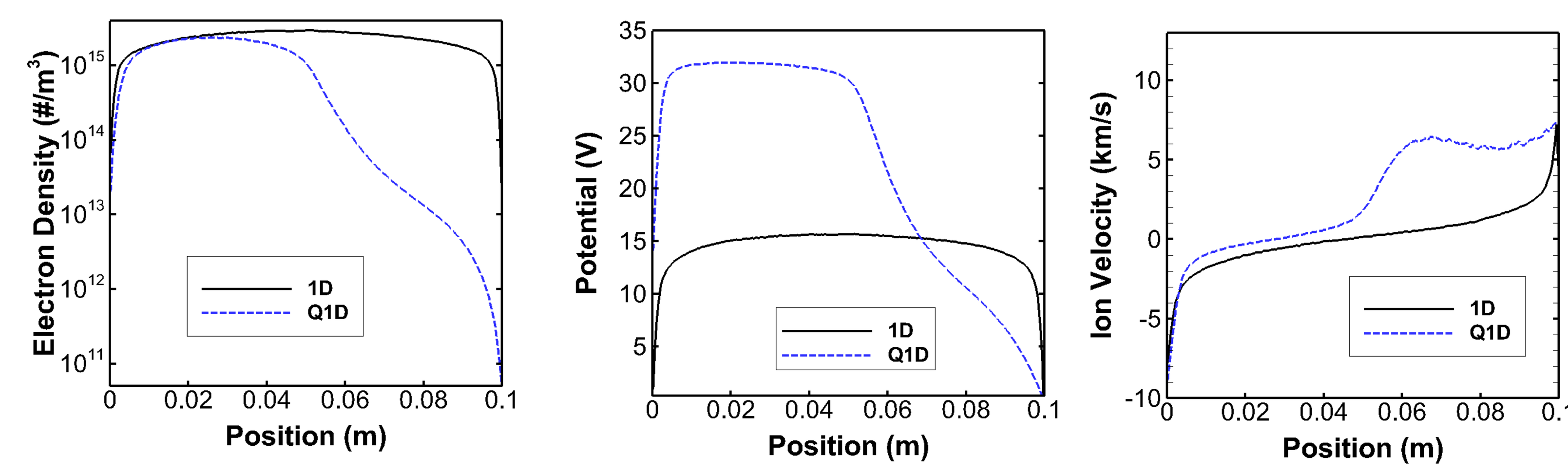

Figure 5: Thruster simulation results for electron density, potential, and ion velocity.

The new quasi-1D method captured important two-dimensional effects. A decrease in plasma density was seen as the plasma expands as well as the formation of a potential drop which accelerated the ions.[2]

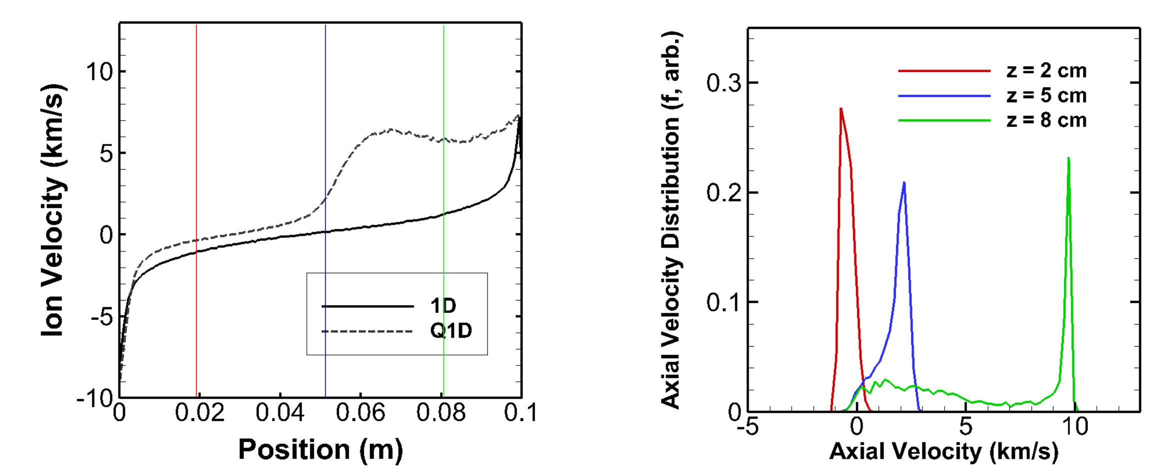

Figure 6: Ion axial velocity distribution showing formation of ion beam.

An ion beam was formed as the ions were accelerated by the potential drop. This is promising for thruster performance. A low energy peak was seen due to charge-exchange collisions.

The forces due to the magnetic field rapidly accelerate the light, high-energy electrons out of the plasma source region. This results in a charge imbalance which sets up an electric field that drags the ions out along with the electrons. [3]

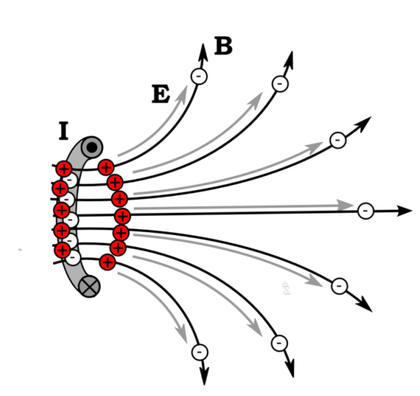

Figure 6: Diagram of ion acceleration mechanism

Conclusions

The new quasi-1D particle-in-cell code captured important physical processes in magnetic nozzles. Potential structures develop in the magnetic nozzle due to the magnetic field forces accelerating electrons in the expansion region. This potential structure creates an ion beam.

Acknowledgements

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References

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