

Reduced Order Modeling Of Electric Propulsion Vacuum Chambers Using COMSOL

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Abstract

Ground based vacuum facilities are widely used to create low pressure environments for testing electric propulsion (EP) devices such as Hall effect and ion thrusters to predict the life and performance of EP devices in real space conditions. NASA has funded the Joint Advanced Propulsion Institute to improve these predictions and support higher power EP thrusters [1]. Pumping limitations result in finite background particle density within the chamber that affects thruster operation and obfuscates comparisons to in-space performance, primarily through the sputtering of particles from facility surfaces and the transport of those particles along with residual propellant back to the thruster face. Efforts to model these particles and reduce their presence are in progress, but the total particle flux to the thruster remains non-zero and causes variation in thruster operation both between facilities and between ground-based testing and in-space operation. As such, successful extrapolation from ground to space environments depends on models that can estimate the particle density and movement within the facility.

This study is to simulate the local particle profile in a representative vacuum facility. While done traditionally using direct simulation Monte-Carlo (DSMC) methods, we leveraged COMSOL Multiphysics to reduce the time complexity by using free molecular flow physics. For many modeling efforts, the complexity of the directed ion beam within a rarefied gas environment has required a combination of free molecular and transitional flow modeling. Instead, we assume (with support from the literature) that ions flowing from the thruster to the downstream facility surfaces undergo neutralization, thermalization, and reflection (100% diffusely) once they collide with the surfaces; therefore, the downstream facility surfaces can be simulated as primary sources of propellant mass entering the vacuum chamber. In this way, we restrict the physics within the model and avoid directly simulating the plasma flow (ion beam), significantly reducing the computational time.

Particle density calculations from the model matched experimental observations during a recent test campaign to within 10%. Additionally, the fast run time for the model allows for uncertainty quantification (using COMSOL's UQ Framework) and facility design optimization; for example, we determined the impact of a grated flooring within the chamber as a 3-5% increase in flux directed at the thruster face, suggesting potential improvements to the facility during testing. This method may be similarly applied to other mixed regime modeling efforts beyond the electric propulsion community.

Reference

[1] Richard E Wirz, et al. 'Predictive engineering model for life and performance assessment of high-power electric propulsion systems', 37th International Electric Propulsion Conference, IEPC-2022-410 (2022).

Figures used in the abstract

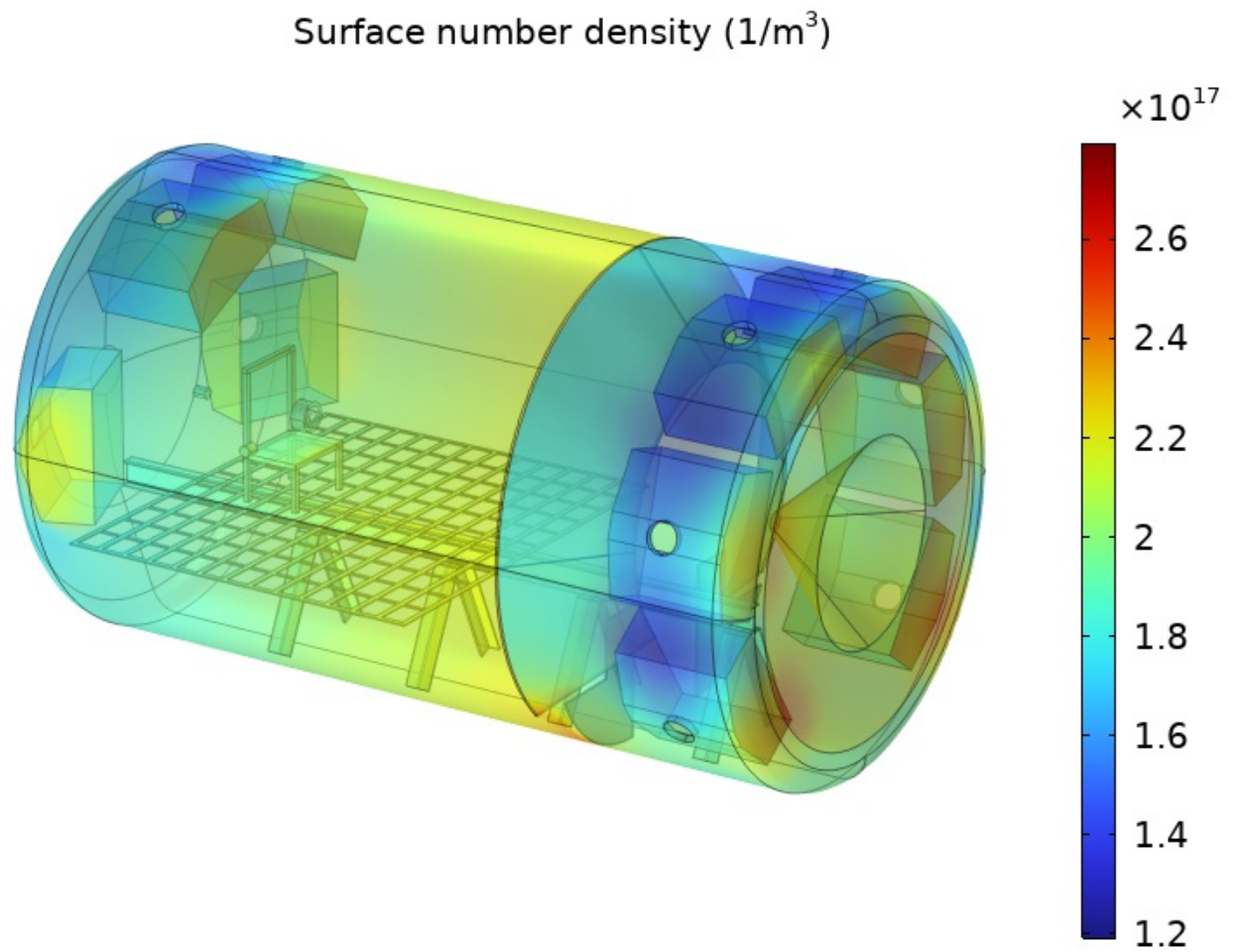


Figure 1 : The simulated 3D surface neutral number density distributions for krypton through the H9 Hall effect thruster in the VTF-2 facility at Georgia Institute of Technology.

Surface number density ($1/m^3$)

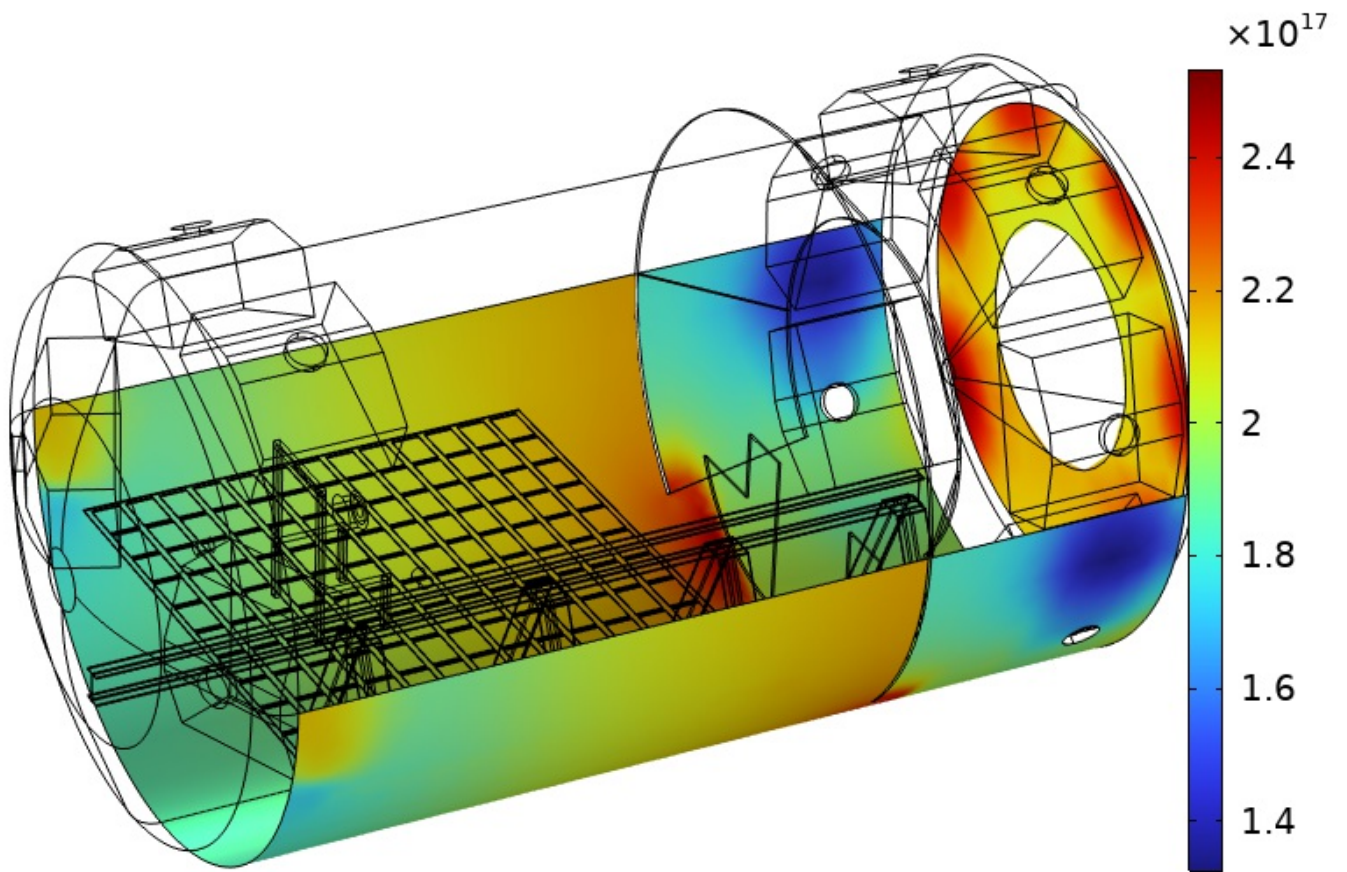


Figure 2 : The simulated 3D surface neutral number density distributions for krypton through the H9 Hall effect thruster in the VTF-2 facility at Georgia Institute of Technology.

Surface number density ($1/m^3$)

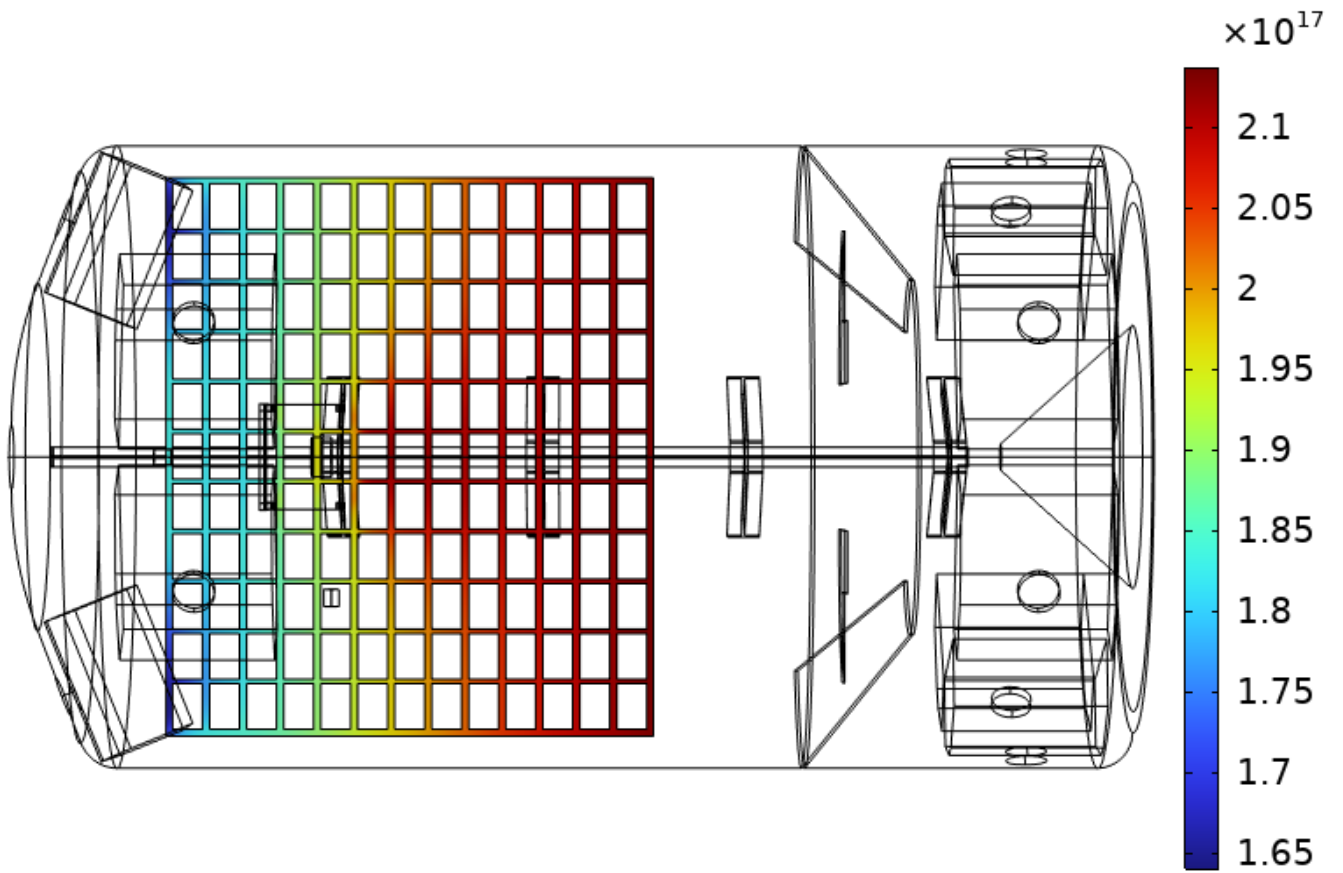


Figure 3 : The simulated 3D surface neutral number density distributions for krypton through the H9 Hall effect thruster in the VTF-2 facility at Georgia Institute of Technology.