A 3-DIMENSIONAL PARTICLE SIMULATION MODEL FOR ION THRUSTER PLASMA FLOW AND GRID EROSION

Final Report

JPL Task 991

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A. OBJECTIVES

Ion propulsion is a critical enabling technology for future deep space missions. A key issue in ion thruster development is grid design and thruster service life, which is primarily limited by grid erosion. In recent years, ion optics modeling has become an ever more important tool to help improve grid design, predict thruster service life, and understand thruster failure modes. The objective of this research is to develop a first-principle based, experimentally validated simulation model for ion optics.

B. PROGRESS AND RESULTS

1. Simulation Model

In this research, we developed the first fully three-dimensional ion optics model. The code is designed in such a way that not only single aperture but also multiple apertures can be included explicitly in the simulation domain. In addition, no assumptions are made to simplify the upstream and downstream boundary conditions. The upstream sheath and ion beam extraction from the discharge plasma are determined self-consistently in the simulation. The simulation is extended into the region far-downstream of the accelerator grid. The location where beamlets become neutralized and charge-exchange ions start to backflow are resolved for the first time in the simulation.

The simulation model includes a set of three particle-in-cell (PIC) codes: an ion beamlet code, a neutral particle code, and a charge-exchange ion code. In this model, propellant ions, charge-exchange ions, and neutrals are treated as macro-particles. Out of considerations for computational efficiency for large-scale simulations, these codes are built upon orthogonal grids and a finite-difference-based formulation. The 3-D optics aperture geometry is handled by a method of sub-grid scale placement of boundaries which explicitly includes the location of the optics wall in relation to the grid in the finite-difference form of Poisson's equation. A typical simulation set up is shown in Fig.1. In a simulation, the distances between the upstream/downstream boundaries and the ion optics is successively increased to search for the proper simulation domain size. The final domain size is determined by examining the potential gradient and local charge-exchange ion backflow rate near the boundary. A typical simulation involves over 10 million particles and requires 20-30 CPU hours on the Cray SV1-1A supercomputer.

2. Simulation Results

From the simulation, we may obtain information on the electric field, beam ion flow, and charge-exchange ion flow inside ion optics. For instance, Fig. 2 shows beam ion velocity direction vectors. The distributions of impingement charge-exchange ion current density, incident energy, and incident angle on the ion optics grid surface are also obtained from simulation. Then one would be able to calculate grid erosion based on simulation results.

During the long duration test of the DS1 flight spare NSTAR ion thruster, both laser profilometer measurements and post-test destructive exams were performed to measure accel grid erosion. Fig. 3 compares the measured erosion pattern and erosion depth on the downstream face of the accel grid with that obtained from simulations. The left panel is a photograph of erosion pattern after 8200 hours of operation. The middle panel overlays simulation results on experimental data. The right panel compares erosion depth along the groove. The figure shows that the simulation picks up all of the detailed features shown in the measured erosion pattern. Additionally, the simulation also shows an excellent quantitative agreement with the measured erosion depth.

C. SIGNIFICANCE OF RESULTS

This task developed a fully three-dimensional particle simulation model for ion thruster optics. This 3-D simulation model is applied to study plasma flow and grid erosion for the DS1-NSTAR ion thruster. Grid erosion predicted by simulation is compared against erosion measurements taken during the long duration test of the NSTAR ion thruster.

The results indicate that the simulation not only predicts accurately all the features in the measured erosion pattern, but also gives excellent quantitative agreement with the measured erosion depth. Hence, this experimentally-validated model may be used as a design tool for new ion thrusters currently being developed at JPL.

D. FINANCIAL STATUS

The total funding for this task was $25,000, all of which has been expended.

E. PERSONNEL

Other personnel involved: James Polk, Sec 353.

F. PUBLICATIONS

[1] J. Wang, J. Polk, J. Brophy, and I. Katz, “Three-Dimensional Particle Simulations of Ion Optics Plasma Flow and Grid Erosion,” submitted to *J. Propulsion and Power*, 2002.

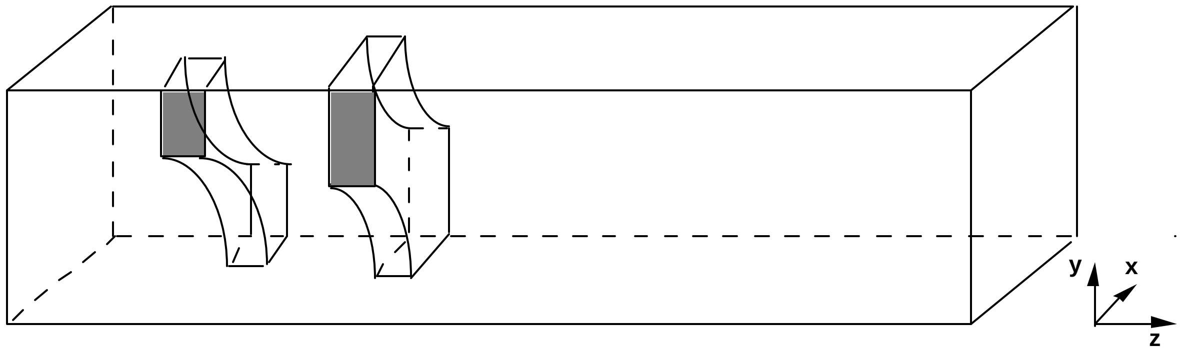

Figure 1: Typical simulation setup: a simulation domain with two quarter-size apertures

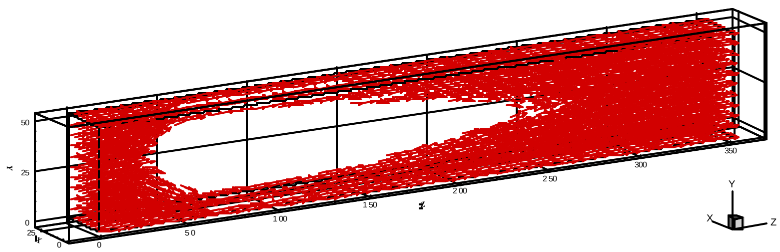

Figure 2: Beam ion velocity direction vectors

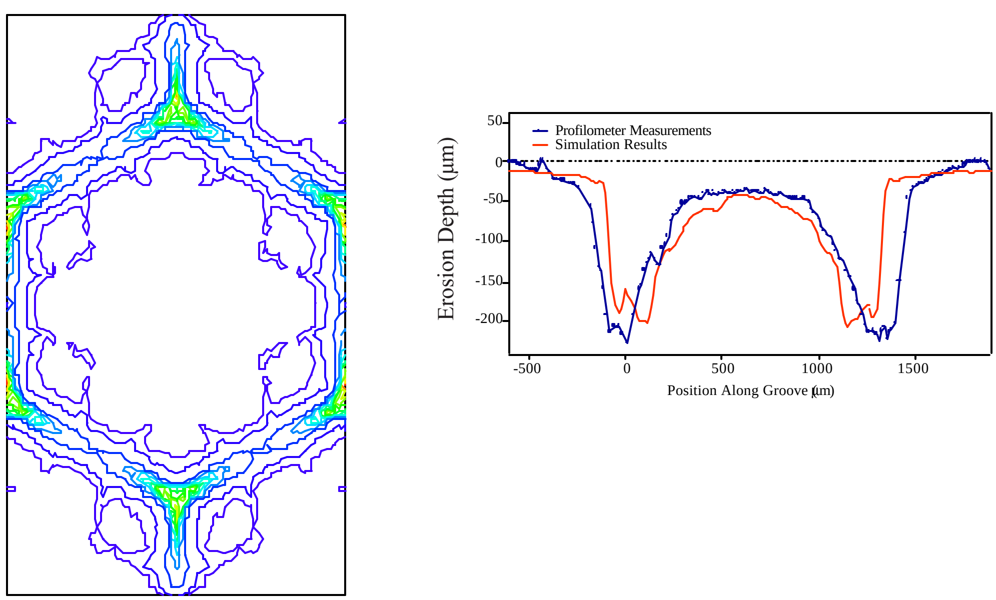

Fig. 3: Comparison of simulation results with experimental data.