Numerical Simulations of a 20-kW Class Hall Thruster Using the Magnetic-Field-Aligned-Mesh Code Hall2De

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Abstract: This paper reports on numerical simulations of the NASA-300M, a 20-kW class Hall thruster developed at the NASA Glenn Research Center (GRC). The numerical simulations have been performed with a 2-D axisymmetric, magnetic field-aligned-mesh (MFAM) plasma solver developed at the Jet Propulsion Laboratory (JPL). The main objective of the collaborative effort is to combine physics-based simulation, plasma diagnostics and recent findings on erosion physics to design and demonstrate a high-power, high-performance Hall thruster that exceeds the life of state-of-the-art Hall thrusters by more than one order of magnitude. The thruster simulations have been carried out at a discharge voltage of 500 V and discharge current of 40 A. The results indicate that although the impact energy of ions may attain values that are comparable to the discharge voltage along the downstream portions of the channel, a withdrawn ionization region and significant ion focusing combine to sustain erosion rates below 1 mm/kh. A more extensive evaluation of the baseline NASA-300M configuration and re-design of this thruster with magnetically shielded walls constitute the main focus of our work in the coming months.

I. Introduction

Hall thrusters below the 10-kW level provide an attractive combination of thrust and specific impulse for a variety of near-earth and robotic deep-space missions. At higher power levels Hall thrusters also could enable a variety of piloted and cargo NASA missions in support of human exploration. Yet, these thrusters have never flown onboard NASA spacecraft. As large amounts of power become increasingly available in space the major impediment that remains unsettled is related to thruster life. A critical wear process known to exist in Hall thrusters that has limited their application to near-earth missions is erosion of the acceleration channel.

As part of a collaborative effort to develop a high-power Hall thruster system, NASA GRC and JPL are using an existing Hall thruster, the NASA-300M, to assess driving plasma and erosion physics during high power operating conditions. The effort is supported by the Advanced In-Space Propulsion (AISP)

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Project, a Foundational Domain project supporting the Enabling Technology Development and Demonstration (ETDD) Program. ETDD was established by NASA in 2010 to increase the capabilities and reduce the cost of future exploration activities. A major objective of the AISP Project is to develop the next generation of high-power, high-efficiency electric propulsion systems scalable to the multi-MW power levels required for future human exploration missions.

The NASA-300M is a 20-kW class Hall thruster that was designed, fabricated, and assembled at NASA GRC in 2004-2005 but its performance was not evaluated (due to premature termination) until only recently.[1] The performance tests have been motivated by ongoing needs of the NASA Flagship Technology Demonstration (FTD) program, which focus on developing, maturing, testing, and demonstrating technologies that will reduce the cost and expand the capability of future space exploration. One of the missions proposed by the FTD program is to demonstrate a 30-kW class electric propulsion system powered by the Fast Access Spacecraft Testbed (FAST) concentrator array[2] for which the NASA-300M is a suitable candidate. This thruster is one of several Hall thrusters developed and/or tested at GRC since 1997 which include, among others, the (10 kW) T-220[3,4] and the (50 kW) NASA-457M.[5] Wear testing of the NASA-300M has not yet been performed. Hence the detailed erosion characteristics of this thruster are unknown.

In this paper we present numerical simulations of the baseline NASA-300M design operating at the 20-kW (nominal) condition. The simulations are performed with Hall2De,[6] a physics-based solver of the partially ionized gas in Hall thrusters that has been under development at JPL since 2008. Hall2De uses a magnetic-field-aligned computational mesh (MFAM)[7] that allows for the determination of the wall erosion rates in regions of the acceleration channel that are near complex magnetic field topologies. To validate our understanding of plasma and erosion physics in high-power Hall thrusters the computational effort will be supported by a variety of plasma diagnostics. A major objective of the computational and experimental work, performed jointly by the two centers, is to re-design the thruster such that the channel walls are "magnetically shielded"[8] from any significant ion bombardment. The ultimate goal is to demonstrate the ability to design and develop high-power high-performance Hall thrusters with life >10x the state of the art.

Section II provides a description of the NASA-300M and summarizes the results of recent performance tests conducted at NASA GRC. A more detailed description of the tests is provided by Kamhawi, *et al*.[1] Section III-A summarizes the main features of Hall2De and reports on recent code augmentations. Numerical simulation results for the plasma and assessments of the channel erosion are provided in sections III-B-1 and III-B-2, respectively.

II. The NASA-300M Hall Thruster

A. Thruster and hollow cathode assembly

The NASA-300M design is based on a scaled version of the improved NASA-457M (dubbed NASA-457Mv2[9]), and has incorporated lessons learned from high-power Hall thrusters developed and tested in the past at GRC.[9] A photograph of the thruster (without the hollow cathode) is shown in Figure 1-left. A main objective of the design was to minimize the size of the thruster while optimizing the applied magnetic field to improve propulsive performance. The magnetic field topology in the NASA-300M is similar to that in the NASA-457Mv2. At the nominal power level of 20 kW the thruster has been operated stably and below any thermal limitations, with xenon and krypton propellants, up to discharge voltage of 600 V and discharge current of 50 A. The hollow cathode assembly (HCA) unit is the same unit that was used in the NASA-457M and NASA-400M[9] during testing of these thrusters at GRC, and is based on the design of the discharge HCA unit in NASA's Evolutionary Xenon Thruster (NEXT). In the NASA-300M the cathode is located at the center of the thruster as shown in Figure 1-right.

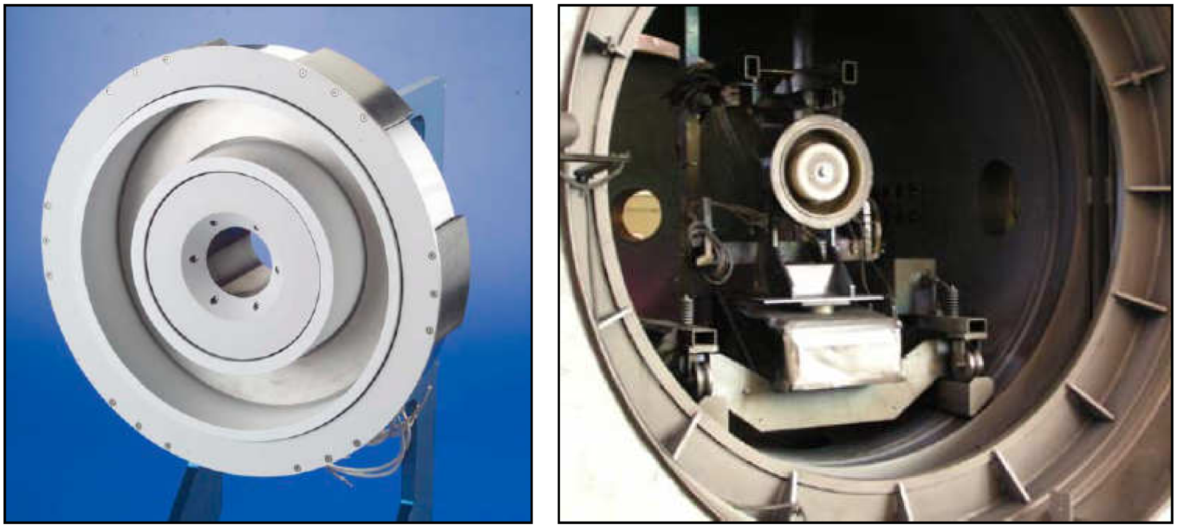

Figure 1. The NASA-300M is nominally a 20-kW Hall thruster that was developed and tested at NASA GRC. Left: photograph of the thruster (without the HCA unit). Right: The thruster installed in Vacuum Facility 5 (VF5) at GRC with the HCA unit located at the center of the thruster.

B. **Performance**

Performance tests of the NASA-300M were conducted recently in VF5 at NASA GRC (see Figure 1-right), and are described in detail by Kamhawi *et al*.[1] Here we provide only a brief summary of the tests. The main chamber of VF5 is 4.6 m in diameter and 18.3 m in length. Although the facility can be evacuated with cryopanels and oil diffusion pumps only cryopanels were used during the NASA-300M tests. The propellant feed system utilized two mass flow controllers (MFCs) to provide the anode and cathode flows and a Null-type inverted pendulum thrust stand was used to measure thrust. Although both xenon and krypton were tested, here we summarize test results only for the first since the numerical simulations have been conducted for xenon. The range of operating conditions tested was 5-20 kW and 200-600 V for the total power and discharge voltage, respectively. The discharge current in all tests did not exceed ~50 A. Thruster operation was stable and no anomalous behavior was observed throughout the full range of operating conditions.

Figure 2 describes test results for the thrust, total specific impulse and total thrust efficiency at various power levels and discharge voltages (see also Ref. 1). Maximum thrust and total efficiency, 1.13 N and 0.67 respectively, were attained at 20 kW and 400 V. At this operating point the total specific impulse was 2445 s. By comparison to other xenon-fed Hall thrusters tested at GRC, the maximum total thrust efficiency and specific impulse of the NASA-300M exceed those attained by the NASA-457M and the NASA-400M. Figure 2-top-left shows a photograph of the thruster operating at 20 kW.

The numerical simulations have been performed for the operating condition of 20 kW and 500 V for which the thrust, total specific impulse and total efficiency were 1.02 N, 2701 s and 0.66, respectively. We note that these measured values were obtained for magnetic circuit conditions that were fine-tuned during the test to optimize thruster performance by minimizing the discharge current. This adjustment produced a magnetic field topology that was not precisely the same as the one used in the simulations. The simulations employed a topology that retained closely (within 2%) the centerline radial magnetic field profile used in the performance tests. However, by contrast to the tests, the inner and outer magnet currents were made equal to produce a topology that was more symmetric relative to the channel centerline, and matched closely the designed topology before testing. Therefore, in addition to discrepancies between measured and computed performance that are due to numerical and physical errors, we expect also some discrepancies related to differences in the applied magnetic field.

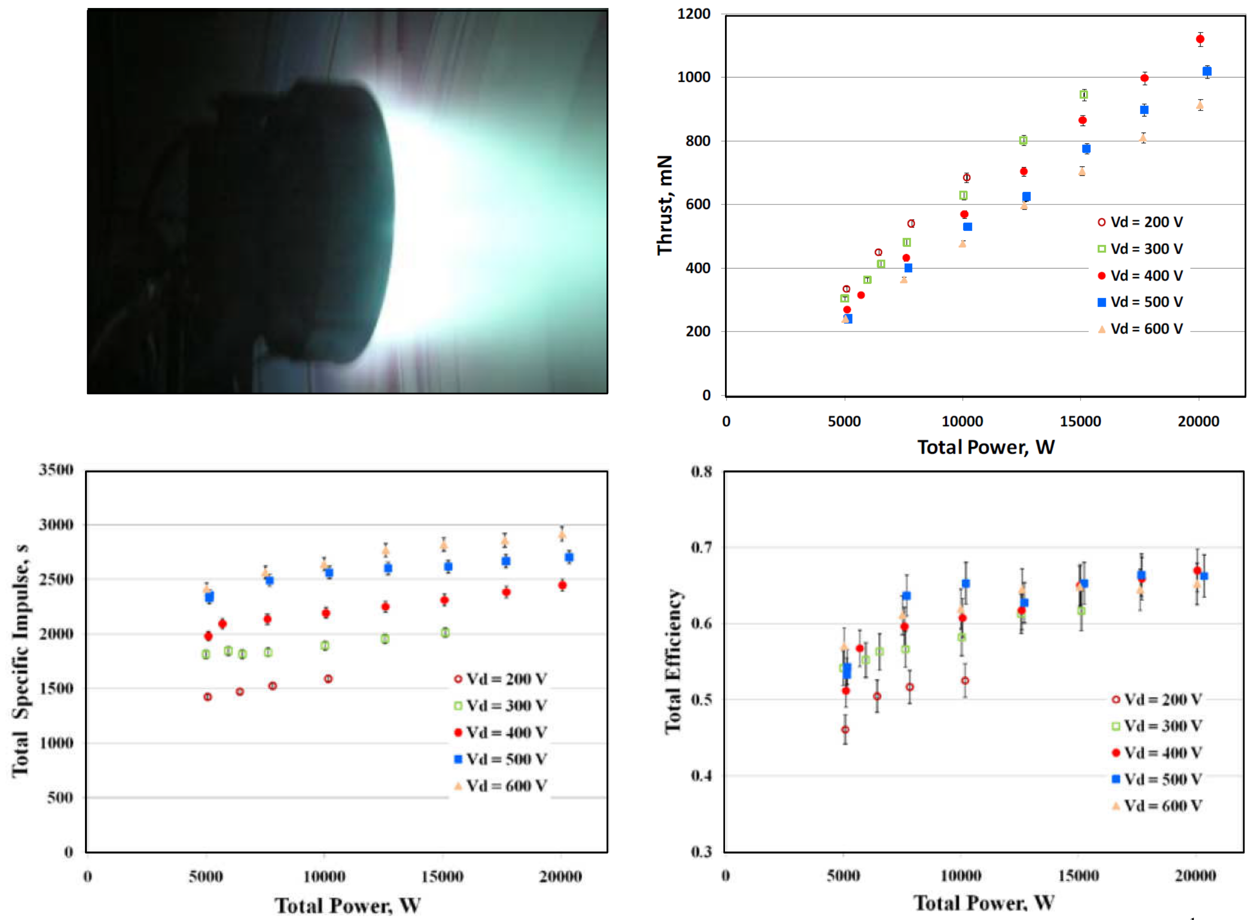

Figure 2. Selected performance charts for the NASA-300M Hall thruster (from Kamhawi *et al.*[1]). A photograph of the thruster operating with xenon at 20 kW is shown in the top left.

III. Numerical Simulations with Hall2De

A. General description of the Hall2De code

Hall2De is a 2-D computational solver of the conservation equations that govern the evolution of the partially ionized gas in Hall thrusters. The code is a descendant of OrCa2D, a 2-D computational model of electric propulsion hollow cathodes that employs a combination of implicit and explicit algorithms.[10,11] The Hall2De governing equations, numerical methodology, simulation results and comparisons with performance and plasma measurements have been presented elsewhere.[6] Here, we provide only a brief overview of the code.

The main distinctive features of Hall2De may be summarized as follows: (1) discretization of all conservation laws on a MFAM, (2) numerical solution of the heavy-species conservation equations without invoking discrete-particle methods, (3) large computational domain that extends several times the thruster channel length in the axial direction, encompassing the cathode boundary and the axis of symmetry. Shown in Figure 3 is a schematic of the computational domain for the NASA-300M simulations with naming conventions of various thruster components and boundaries to be cited in this paper. Also, because a main objective of this effort is to mitigate erosion and protect the magnetic circuit components from plasma bombardment, Figure 3 and all other 2-D plots in this paper point out (for reference) the locations of the magnet corners relative to the channel insulators.

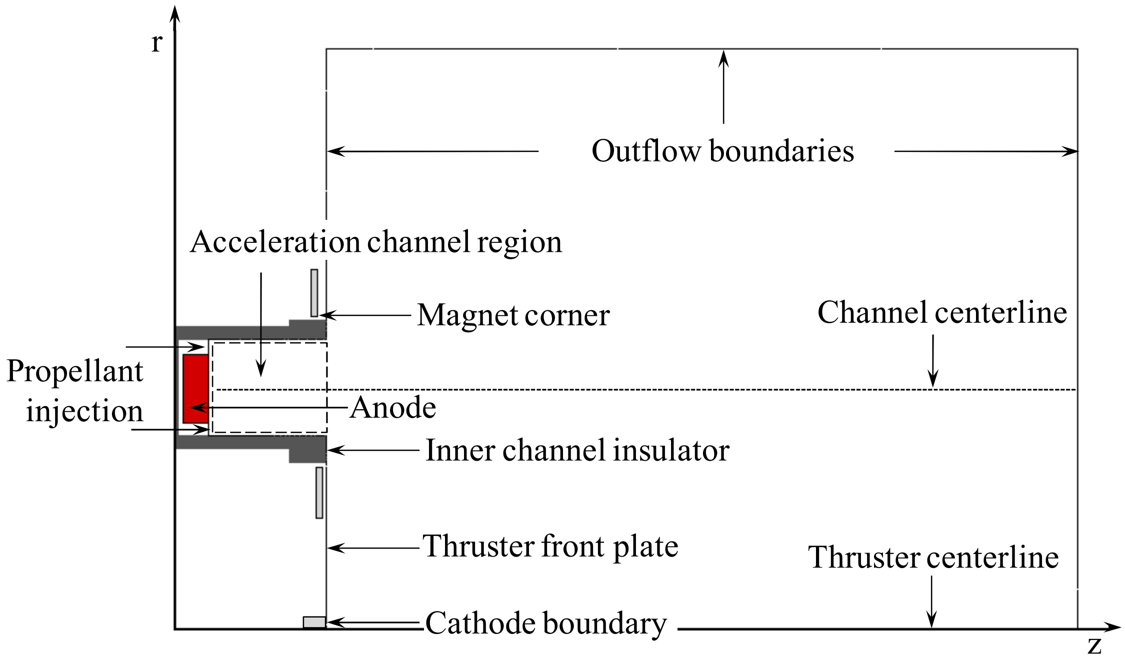

Figure 3. Computational domain for the numerical simulations of the NASA-300M showing naming conventions for various thruster components and boundaries to be cited throughout this paper.

In Hall2De excessive numerical diffusion due to the large disparity of the transport coefficients parallel and perpendicular to the magnetic field is evaded by discretizing the equations on a computational mesh that is aligned with the applied magnetic field. This MFAM capability was largely motivated by the need to assess the life of Hall thrusters with complicated magnetic field topologies. The evolution of ions is computed using a hydrodynamic approach that accounts for up to triply-charged ions and up to four distinct ion fluids. The latter implies that more than one ion momentum equations can be solved in Hall2De. This multi-fluid capability was developed in recognition of the disparate equilibration times that ions may possess, especially in the near-plume and cathode regions of the thruster. In the present study only a single ion fluid has been considered. Both the ion pressure gradient force and the drag force on ions due to collisions with other heavy species are included. The momentum and continuity equations are marched forward in time explicitly. The ion conservation laws are closed with conditions specified at all boundaries as described in Refs. 6 and 8.

The electron population is treated also as a fluid. The vector form of Ohm's law is solved in the frame of reference of the magnetic field and the electrical resistivity accounts for contributions from collisions of electrons with all other species. It has also been suggested that the diffusion of electrons in Hall thrusters is enhanced in a non-classical manner by plasma turbulence (e.g. see Refs. 12, 13, 14). Attempts to emulate this enhancement in numerical simulations have been made typically through the use of an effective collision frequency, which we term here "ν_α". In this work we have imposed the general function $f_\alpha(r,z)$ to define $\nu_\alpha \equiv f_\alpha \omega_{ce}$. Finally, to account for collisions with channel surfaces a "wall collision frequency" is included that is dependent upon the electron secondary yield. The model is described in greater detail in Ref. 8.

The electron energy conservation equation in Hall2De accounts for thermal conduction, energy exchange between electrons and the heavy species due to deviations from thermal equilibrium,[15] and inelastic energy losses due to ionization and excitation.[16] The conservation equations for the electrons are closed with conditions specified at all boundaries. The channel walls and the thruster front plate are dielectric boundaries at which a zero-current condition is imposed. At these surfaces the convective heat loss boundary conditions (BC) follow the formulations of Hobbs and Wesson[17] for the potential drop in the sheath with secondary electron emission. At the anode conductor BCs are prescribed that account for the presence of the sheath. At the cathode boundary the particle fluxes of neutrals and ions, plasma potential and electron temperature are specified directly. The energy equation is solved in a semi-implicit fashion; the thermal conduction term is implicit whereas all other terms are evaluated explicitly.

In Hall thrusters the neutral species are collisionless. In Hall2De their evolution is computed with an algorithm that eliminates discrete-particle statistical fluctuations.[18] The algorithm takes advantage of the fact that the majority of neutral particles proceed along straight-line, constant-velocity trajectories until they are either ionized, strike a wall, or leave the physical domain. The algorithm assumes that the particle velocity distribution function for neutrals emitted from a given surface remains unchanged except for a scale factor that reflects the loss of neutrals by ionization. Then the algorithm solves for the neutral gas density by integrating forward in time the linear Boltzmann equation in the absence of any forces on the particles. The sources of neutrals are gas inlets and isotropic, thermally-accommodated propellant atoms emanating from thruster surfaces. Emission from solid boundaries accounts for ions that recombined with electrons at the surface.

In addition to its role in theoretical investigations of fundamental physics in Hall thrusters, Hall2De has been developed also to guide the design of Hall thrusters and to support their qualification for space flight. These latter objectives have motivated an upgrade of Hall2De with two new computational capabilities in an effort to reduce time and cost. The first capability is a fast MFAM generator that allows interactive mesh generation through the use of a graphics user interface (GUI).[7] The second capability allows for execution of a simulation from arbitrary initial conditions ("cold starts").[7] The addition of the new MFAM generator and cold-start capabilities have reduced the time associated with the design iteration cycle by about one order of magnitude.

B. **Simulation results**

In this section we present numerical simulations of the NASA-300M operating with xenon at discharge voltage (V_d) of 500 V and discharge current (I_d) of 40 A (see Table **1**). The channel geometry of this thruster is relatively simple and the hollow cathode is located at the thruster centerline as shown in Figure 3. This cathode-thruster arrangement is of great interest in numerical simulations because it is 2-D axisymmetric and therefore plasma measurements (to be performed in the near future) may be compared directly and unambiguously with the simulation results.

Table 1. Prescribed and computed performance parameters of the NASA-300M simulations at 20 kW. Diagnostics are being developed at NASA GRC in collaboration with JPL to provide a variety of plasma measurements in this thruster. The measurements will be used to extend model validation.

Hall Thruster Design	NASA-300M
Prescribed	
Discharge voltage, V_d (V)	500.4
Discharge current, I_d (A)	40.36
Anode flow rate, $\dot{m}_A$ (mg/s)	35.41
Cathode flow rate $\dot{m}_C$ (mg/s)	3.11
Computed	
Thrust, T (mN)	952.1
Total specific impulse, $T/(\dot{m}_A+\dot{m}_C)g$ (s)	2520
Beam current, I_b (A)	33.1
Xe^+ current fraction, I_i^+/I_b	0.582
Xe^{2+} current fraction, I_i^{2+}/I_b	0.343
Xe^{3+} current fraction, I_i^{3+}/I_b	0.075
Mass utilization, $\dot{m}_b/\dot{m}_A$	0.998
Current utilization, I_b/I_d	0.820

1. Plasma

The prescribed and computed operational characteristics for this thruster are provided in Table **1**. The ion currents for the three ion charge states, singly- (Xe^{+}), doubly- (Xe^{2+}) and triply-charged (Xe^{3+}), are denoted by I_i^{+}, I_i^{2+} and I_i^{3+}. The ion beam flow rate is $\dot{m}_b$. Additional information about the thruster has been provided in Sec. II. The maximum axial and radial dimensions of the computational domain are $(z/L)_{max}$=7.4 and $(r/L)_{max}$=4.9, respectively where L denotes the length of the acceleration channel region (see Figure 3).

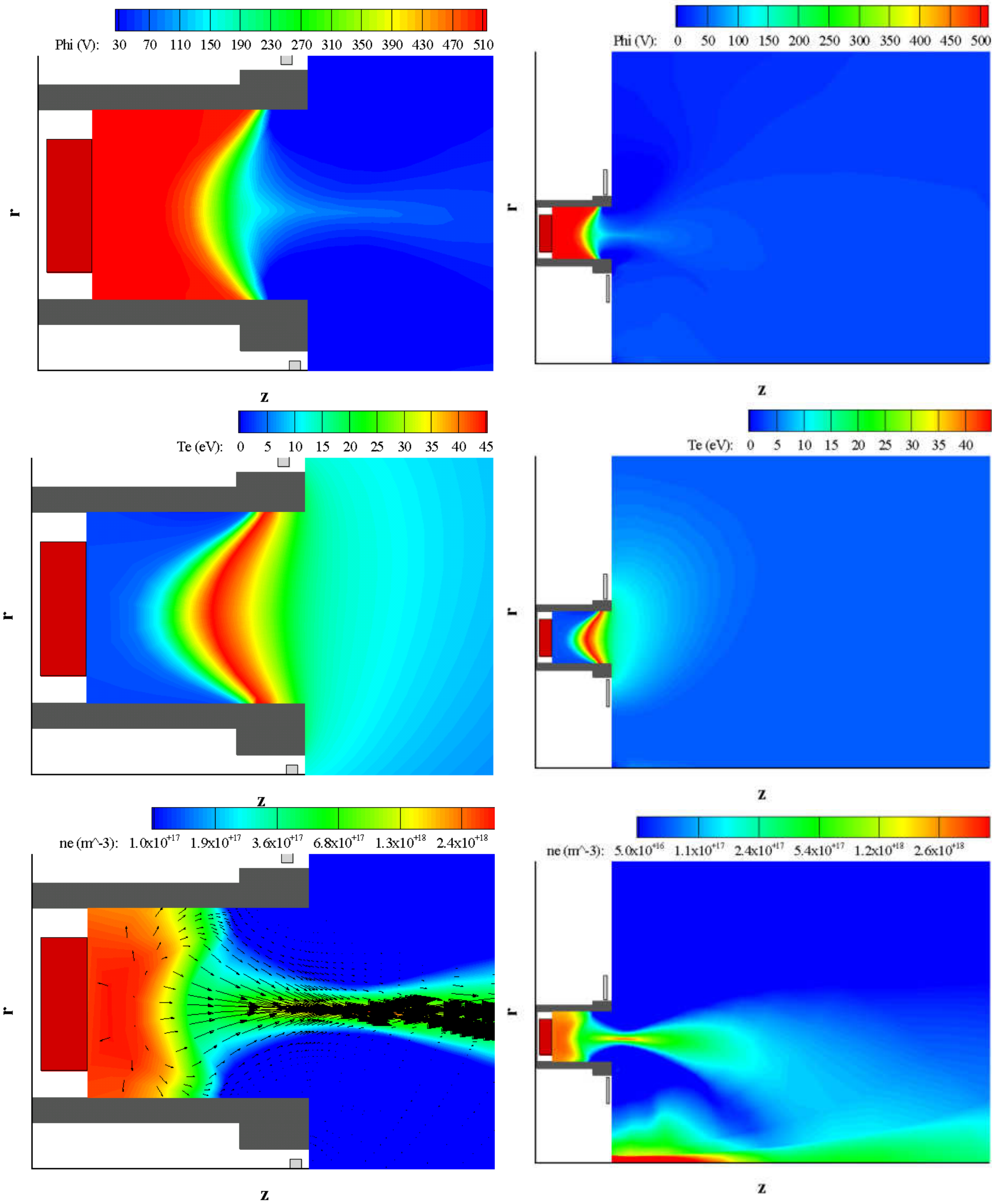

Figure 4. 2-D contours of the computed plasma potential (top), electron temperature (middle) and electron number density (bottom) in the NASA-300M. Left column: Solutions in the acceleration channel. The electron number density contours are overlaid by flux vectors of Xe^{+}. Right column: Solutions over the full computational domain. The domain extends to $(z/L)_{max}$=7.4 and $(r/L)_{max}$=4.9.

The 2-D simulation results for the plasma potential, electron temperature and electron number density are illustrated in Figure 4. The left column of plots concentrates on results in the acceleration channel whereas the right column depicts 2-D contours over the full computational domain (which includes the cathode). Figure 4-bottom-left also overlays to the electron number density contours ion flux vectors for Xe^{+}. Noted is the formation of ion focusing in this thruster and the location of the ionization zone, both of which occur relatively deep into the acceleration channel by comparison to other thrusters that have been simulated with Hall2De.[8,7] The implications of this on channel erosion are discussed in Sec. III-B-2.

The computed profiles for the electron temperature and plasma potential along the channel centerline are shown in Figure 5. Since the physics of electron transport from the cathode to the acceleration channel remain unclear today, despite decades of research on this topic, the Hall2De plasma solution is in part dependent upon the collision frequency ν_α the profile of which is plotted in Figure 5-right. Also plotted for comparison are the electron-ion (ν_{ei}) and electron-neutral (ν_{en}) collision frequencies. In the absence of first-principles physics associated ν_α it has been customary in numerical simulations to exploit plasma measurements to guide its specification. Such measurements in the NASA-300M have not yet taken place. Hence our approach regarding the ν_α has been to assume that similar non-classical physics persist in the NASA-300M and the highest power Hall thruster simulated thus far by Hall2De, namely the 6-kW laboratory thruster H6.[7] In turn, we have imposed the same spatial functional form of ν_α in the two thrusters. Specifically, the profiles used in the NASA-300M simulations have employed along the channel centerline a continuous function f_α of the form $\exp(-|\underline{z}|^{\alpha}/\beta)$ where $\underline{z} \equiv (z-z_0)/L$. The constants z_0, α and β define the spatial variation of f_α. The values of α and β have been kept the same as those used in the H6 simulations whereas z_0 has been chosen such that the maximum value of f_α occurs in the two thrusters at the same distance from the channel exit. Then, iteration until the operating discharge current was attained determined the maximum value of f_α. In the next several months several plasma measurements in this thruster are planned. In part, the plasma data will be used to reduce the uncertainty associated with ν_α. Also, in light of the differences in the magnetic field topology between the simulated and tested thrusters (as alluded to in Sec. II) additional simulations and tests are planned to assess performance and erosion trade-offs as a function of the magnetic field topology. For these reasons, no additional effort has been undertaken in the present study to improve the correlation between measured and computed thrust by altering further the ν_α profile. For the abovementioned profile the maximum electron temperature and Hall parameter in the acceleration channel are found to be 43.7 eV and 411, respectively (Figure 5).

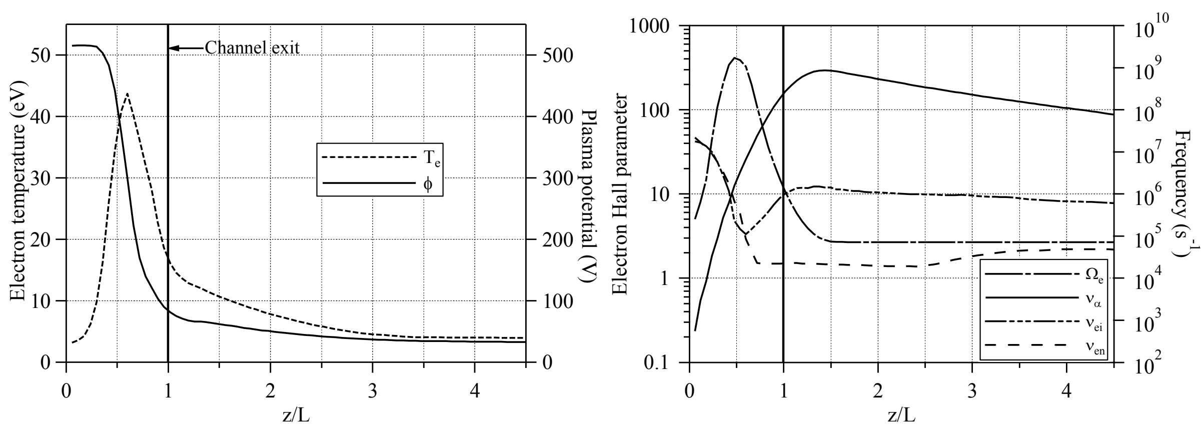

Figure 5. Axial profiles along the channel centerline from numerical simulations of the NASA-300M. Left: Computed electron temperature and plasma potential. Right: Computed electron-ion (ν_{ei}), electron-neutral (ν_{en}), non-classical (ν_α) collision frequencies and electron Hall parameter.

2. Channel erosion

The sputtering erosion rate (ε) due to ion bombardment is given by,

$$\varepsilon = j_{i\perp} Y \tag{1}$$

where the incident ion current density perpendicular to the channel wall $j_{i\perp}$ is dependent on the ion number density (n_i) and the ion velocity (u_i) at the wall. The sputtering yield (Y) of the channel material is a function of the ion impact energy (K) and incidence angle (θ). Because ions must traverse a sheath before striking the wall, the total impact energy is the sum of the kinetic energy $K_i=½m_iu_i^2$ ions of mass m_i have acquired in the plasma upon entrance to the sheath, and the sheath potential energy denoted here as Δϕ. That is,

$$j_{i\perp} = j_{i\perp}(q_i, n_i, u_{i\perp}) \qquad Y = Y(K_i + \Delta\phi, \theta) \tag{2}$$

where q_i is the ion charge. The potential energy Δϕ has been determined based on the solution to the one-dimensional sheath equations in the presence of secondary electron emission provided by Hobbs and Wesson.[17] The sputtering yield is determined using the fitting functions $f_K(K_i+\Delta\phi)$[19] for the energy dependence at zero angle of incidence and $f_\theta(\theta)$[20] for the angle dependence, as follows:

$$Y = f_\theta(\theta) f_K(K). \tag{3}$$

The channel wall material is boron nitride. Although some minor variations may occur in the sputtering yield of different Hall thrusters with the same or similar-grade channel material, we have used the same coefficients for the fitting functions f_K and f_θ as those cited in Refs 7 and 8. This choice has been made to permit one-on-one comparisons with erosion results in other Hall thrusters that have been obtained from simulations with Hall2De. The two functions are plotted in Figure 6. It is emphasized that there remains considerable uncertainty about the sputtering yield of this material for energies lower than ~50 V.

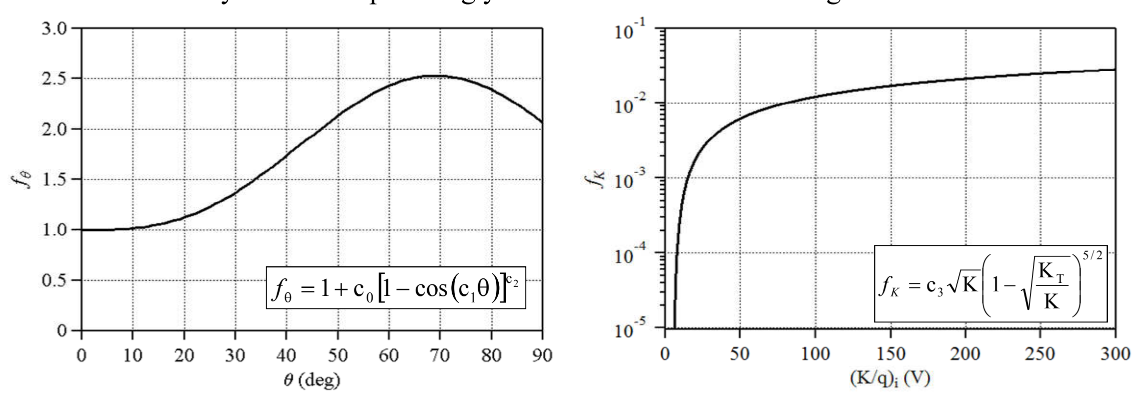

Figure 6. Fitting functions for the sputtering yield of the NASA-300M channel material (see Eq. (3)). The coefficients are c_0=0.52663, c_1=2.60506, c_2=1.53462, c_3=0.0023 and K_T=5.1.

Results that are pertinent to channel erosion are plotted in Figure 7. We found that for z/L≳0.78 the plasma potential along the channel walls decreased by approximately the full value of the discharge voltage. This maximizes the kinetic energy with which ions enter the sheath in these regions (e.g. see the kinetic energy of Xe^+ in Figure 7-top-left). However, due to a retreated ionization region and the significant ion focusing that is achieved in this channel (see Figure 4-bottom-left) the ion flux to the walls is reduced along those portions of the walls. For example, the current density of Xe^+ is found to be more than three orders of magnitude less than values computed near the anode as shown in Figure 7-bottom-right. This decline of current density reduces the maximum erosion rate to <1 mm/kh as depicted in

Figure 8. Moreover, the thickness of the channel walls downstream of z/L=0.69 has been made larger in this thruster which could increase further the life of the insulators. Nevertheless, although improved, such erosion rates may still be insufficiently low for some NASA missions which require, in general, wider throttling and significantly higher propellant throughput than near-earth missions. Also, unless time-dependent erosion simulations and or wear tests are performed, it is not yet known how the wear of the insulators will advance. Finally, as explained in Sec. II, the maximum performance of this thruster was attained with a magnetic field that was optimized during the tests, and is therefore different from the one used in the numerical simulations. Consequently, the extent of performance degradation (if any) with this different magnetic field topology also has not been assessed.

A more extensive evaluation of the baseline NASA-300M configuration and re-design of this thruster with magnetically shielded walls constitute the main focus of our work in the coming months. Magnetic shielding exploits the thermalized equipotentialization and isothermalization of the magnetic field lines in Hall thrusters to sustain high plasma potential and low electron temperature along the channel surfaces.[7,8] The first reduces significantly the ion kinetic energy and the second reduces the sheath energy both of which remain high in the present design of this thruster (Figure 7-top-left and -top-right) due to the specific topology of the magnetic field. The total impact energy of Xe^+ is plotted in Figure 7-bottom-left. It is noted that the profiles of ion energy and erosion rate are not the same along the inner and outer walls due to slight asymmetries of the magnetic field topology relative to the channel centerline. Finally, we also note that because the sputtering yield for boron nitride is highly uncertain for ion energies $\lesssim$50 V,[7] only erosion rates for $z/L \geq 0.6$ are plotted in Figure 8; in modern Hall thrusters like the NASA-300M detectable erosion is typically not observed upstream of (at least) z/L=0.5.

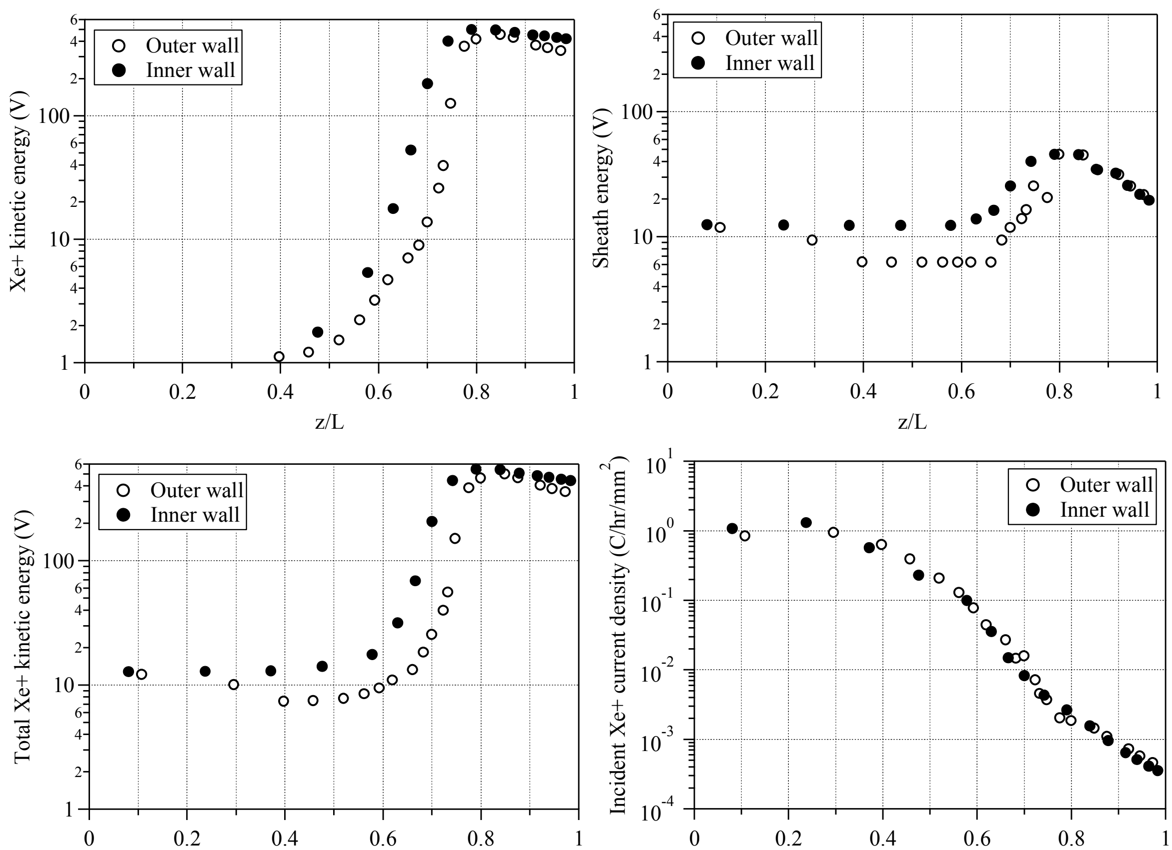

Figure 7. Hall2De results pertinent to erosion along the outer and inner channel insulators of the NASA-300M. Top-left: Impact kinetic energy of Xe^+. Top-right: Sheath energy. Bottom-left: Total energy of Xe^+. Bottom-right: Current density of incident Xe^+.

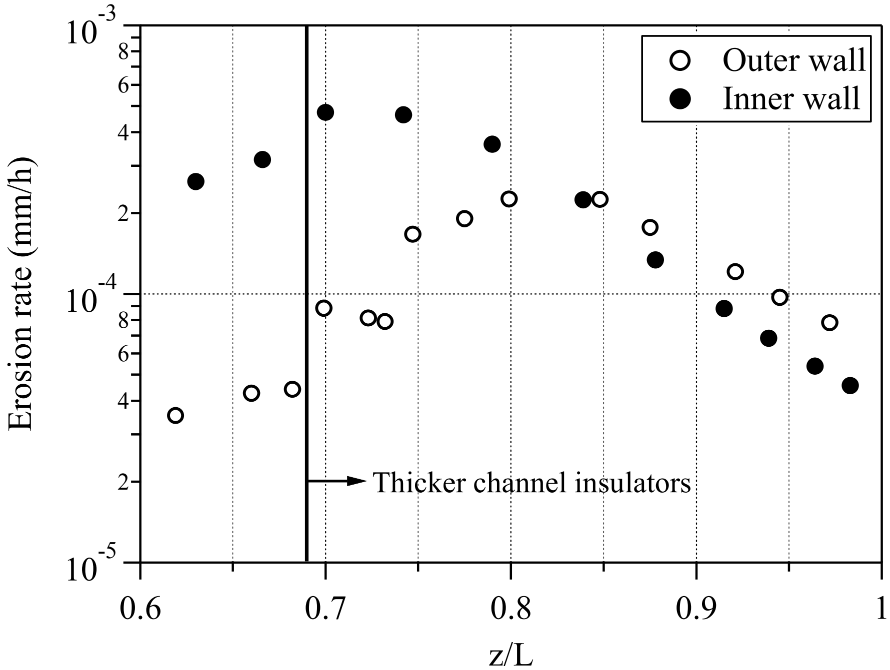

Figure 8. Erosion rate along the outer and inner channel insulators of the NASA-300M. In this thruster the thickness of the channel insulators downstream of the vertical line at z/L=0.69 has been enhanced (see also Figure 4-bottom) to increase thruster life.

IV. Conclusion

A first series of numerical simulations of a 20-kW class Hall thruster have been completed to establish the groundwork for the development of high-power, high-performance, long-life Hall thrusters. The effort is supported by the NASA AISP Project which intends to develop the next generation of electric propulsion systems scalable to the multi-MW power levels required for future human exploration missions.

To reduce flight risk as well as time and cost during the development and flight qualification of high-power Hall thrusters, GRC and JPL will employ physics-based numerical simulation, plasma and wear diagnostics, and thruster testing by combining unique capabilities at the two centers. The NASA-300M has been chosen due in part to its suitable power level (for missions of interest to AISP), and due to its high propulsive performance which was recently demonstrated to exceed or be comparable to that attained by other high-power Hall thrusters developed and tested at GRC.

The computational work presented in this paper was aimed at making a first assessment of the erosion rates in the existing design of the NASA-300M, and have been conducted concurrently at the two centers. The numerical simulations have been performed with Hall2De, a 2-D axisymmetric, MFAM plasma solver developed at JPL and exported recently to GRC. The simulation results indicate that the ionization zone in this thruster is located far upstream of the channel exit and that significant ion focusing is achieved due largely to the applied magnetic field topology. This combination leads to erosion rates along the channel insulators that do not exceed 1 mm/kh. Recent findings on erosion physics and related wear mitigation techniques suggest it may be possible to modify the magnetic circuit and channel geometry of this thruster to achieve “magnetic shielding,” a technique that seeks to reduce erosion rates at the channel walls by more than one order of magnitude. Extended simulations that include assessment of thermal loads to the thruster surfaces, plasma diagnostics and model validation, thruster modifications and testing constitute the focus of our effort in the next several months.

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