

# Numerical Simulation of SMART-1 Hall-Thruster Plasma Interactions

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DOI: 10.2514/1.36654

SMART-1 has been the first European mission using a Hall thruster to reach the moon. An onboard plasma diagnostic package allowed a detailed characterization of the thruster exhaust plasma and its interactions with the spacecraft. Analysis of in-flight data revealed, amongst others, an unpredicted large cyclic variation of the spacecraft floating potential and a mysterious asymmetry in the plasma surrounding the spacecraft. To investigate the details of the anomalies, we developed the numerical software tool SmartPIC to characterize and predict spacecraft–plasma interactions. Technical details, such as solar arrays and onboard diagnostic devices, have been modeled with high accuracy. All basic plasma parameters, the spacecraft floating potential, backflow distributions, and ion impact energies are calculated by the code and are available in high spatial resolution throughout the computational domain containing the entire satellite. It was possible to clearly identify the rotating solar cells arrays as the source of the cyclic variation of the spacecraft floating potential. Furthermore, the asymmetry of the plasma formation around the spacecraft is linked to the location of the neutralizer causing a region of increased charge-exchange collisions particle generation. Both of these results have significant impact on the implementation of electric propulsion systems on satellites.

## Nomenclature

$d$	=	geometric distance
$e$	=	electron charge, $1.60217 \times 10^{-19}$ C
$I_E$	=	thruster ion current
$I_{B,I/E}$	=	ion/electron backflow current
$I_N$	=	neutralizer electron current
$k_B$	=	Boltzmann constant, $1.38065 \times 10^{-23}$ J/K
$\dot{m}$	=	total mass flow
$m_e$	=	electron mass, $9.10938 \times 10^{-31}$ kg
$m_i$	=	xenon ion mass, $2.19901 \times 10^{-25}$ kg
$n_e, n_i, n_{CEX}$	=	electron, ion, and charge-exchange collisions ion densities
$P_{i,j}$	=	collision probability
$PPP_\alpha$	=	particle per superparticle ratio, $10^8$ – $10^{10}$
$r_i, r_o$	=	radii, 28, 50 mm
$s_{cath}$	=	cathode mass flow ratio, 8%
$T_e, T_i, T_{CEX}$	=	electron, ion and charge-exchange collisions particle temperatures
$U_{acc}$	=	thruster acceleration voltage, 350 V
$v, \Delta v$	=	velocities, differences of
$Z$	=	charge multiplier, one or two
$\alpha$	=	solar array rotation angle
$\alpha_i, \alpha_o$	=	geometry angles
$\Delta t$	=	time step
$\epsilon_0$	=	permittivity of vacuum, $8.85419 \times 10^{-19}$ F/m
$\eta_{double}$	=	relative fraction of double charged ions, 10%
$\eta_{ion}$	=	ionization efficiency, 95%

$\eta_{sh,ic/diel}$	=	shielding coefficient for interconnectors/glass, varies
$\lambda_D$	=	debye length
$\sigma_{ij}$	=	collision cross section
$\phi, \phi_P$	=	local plasma potential
$\phi_{CEX}$	=	charge-exchange plasma potential
$\phi_f$	=	spacecraft floating potential
$\phi_{SC}$	=	spacecraft surface potential

## I. Introduction

BACK in 2003, ESA started an ambitious program called SMART (Smart Missions for Advanced Research and Technology), which is dedicated to the development and demonstration of innovative concepts needed for future precursor missions, such as Bepi Colombo. The focus lies on propulsion, energy, sensor technology, and autonomous systems. SMART-1 has been the premiere satellite within the framework. Its main purpose was the demonstration of an electric propulsion system applied as the primary drive for an interplanetary mission. SMART-1 was equipped with a PPS-1350 Hall thruster built by Societe Nationale d'Etude et de Construction de Moteurs d'Aviation, providing a constant thrust of 70 mN. In addition, several ambitious targets, such as tests of high-resolution spectroscopy, autonomous navigation systems, and geophysical imaging, have been achieved.

Electric propulsion is known to produce low-energetic ions resulting from scattering within the exhaust plume that can easily be redirected toward the satellite. On impact, these particles cause spacecraft surface degradation and might lead to differential surface charging. To investigate and characterize the plasma environment, SMART-1 was equipped with an electric propulsion diagnostic package (EPDP) and the so-called spacecraft potential electron and dust experiment (SPEDE). These instruments enabled the analysis of plasma densities and plasma energies as well as the measurement of the spacecraft floating potential relative to the surrounding plasma.

It has been a major objective of the mission to achieve an in-depth understanding of the physics governing the plasma environment around the satellite. Therefore, ESA initiated a working group including European companies and research institutes to study plasma spacecraft interactions on SMART-1. The present paper summarizes our efforts which led to the development of the plasma and spacecraft interaction simulation tool SmartPIC.

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