Appendix A
Nomenclature

A.1 Constants

A_v	Avogadro's number (atoms/mole)	$6.02214179 \times 10^{23}$
AMU	atomic mass unit	$1.6602176487 \times 10^{-27}$ kg
c	velocity of light	2.9979×10^{8} m/s^2
e	electron charge	$1.602176487 \times 10^{-19}$ C
g	gravitational acceleration	9.80665 m/s^2
k	Boltzmann's constant	1.3807×10^{-23} J/K
m	electron mass	$9.1093822 \times 10^{-31}$ kg
M	proton mass	$1.67262164 \times 10^{-27}$ kg
e/m	electron charge-to-mass ratio	1.75882×10^{11} C/kg
M/m	protron-to-electron mass ratio	1836.153
M_{xe}	mass of a xenon atom	131.293 AMU 2.17975×10^{-25} kg
ε_o	permittivity of free space	8.8542×10^{-12} F/m
μ_o	permeability of free space	$4\pi \times 10^{-7}$ H/m
πa_0^2	atomic cross section	8.7974×10^{-21} m^2
e/k	temperature associated with 1 electron volt	11604.5 K
eV	energy associated with 1 electron volt	$1.602176487 \times 10^{-19}$ J

T_o	standard temperature (0 deg C)	273.15 K
p_o	standard pressure (760 torr = 1 atm)	1.0133×10^5 Pa
n_o	Loschmidt's number (gas density at STP)	2.6868×10^{25} m^{-3}

A.2 Acronyms and Abbreviations

0-D	0-dimensional
1-D	one-dimensional
2-D	two-dimensional
3-D	three-dimensional
AC	alternating current
accel grid	accelerator grid
AEPI	Atmospheric Emissions Photometric Imaging
AMU	atomic mass unit
BaO	barium oxide
BN	boron nitride
BOL	beginning of life
CC	carbon–carbon
CEX	charge exchange
CL	Child–Langmuir
CM	center of mass
CVD	chemical-vapor-deposition
DC	direct current (steady-state)
decel grid	decelerator grid
DS1	Deep Space 1 (mission)
ECR	electron cyclotron resonance (microwave)
EITA	Electron-bombardment Ion Thruster Assembly
ELT	extended life test (NSTAR thruster life test)
EP	electric propulsion

EPIC	Electric Propulsion Interactions Code
ESA	European Space Agency
ETS	Engineering Test Satellite
ETS-6	Engineering Test Satellite (Japanese ETS-6)
eV	electron volt
eV/ion	electron volts per ion
FEEP	field emission electric propulsion
GRC	Glen Research Center
HET	Hall effect thruster
HiPEP	High Power Electric Propulsion
I.D.	inside diameter
ISTI	International Space Technologies Incorporated
JAXA	Japanese Aerospace Exploration Agency
JPL	Jet Propulsion Laboratory
LaB_6	lanthanum hexaboride
LDT	life demonstration test (8200-hour NSTAR thruster wear test)
LIF	laser-induced fluorescence
MELCO	Mitsubishi Electric Corporation
MiXI	Miniature Xenon Ion
MPD	magnetoplasmadynamic thruster
NASA	National Aeronautics and Space Administration
NEXIS	Nuclear Electric Xenon Ion Thruster System
NEXT	NASA's Evolutionary Xenon Thruster
NSTAR	NASA Solar Electric Propulsion Technology Applications Readiness
PG	pyrolytic graphite
PIC	particle in cell
PPT	pulsed-plasma thruster
PPU	power processing unit

rf	radio frequency
RIT	radio-frequency ion thruster
RITA	Radio-Frequency Ion Thruster Assembly
RPA	retarding potential analyzer
RSU	remote sensor unit
sccm	standard cubic centimeters per minute
SEM	scanning electron microscope
SEPAC	Space Experiments with Particle Accelerators
SI	International System
SMART	Small Mission for Advanced Research in Technology
SmCo	samarium cobalt
SPT	stationary plasma thruster (a type of Hall thruster)
SSC	Space Station contactor
STEX	Space Technology for Advanced Research in Technology
STP	standard temperature and pressure
TAL	thruster with anode layer
torr-l/s	torr-liter per second
TWT	traveling-wave tube
UV	ultraviolet
W/A	watts per ampere
XIPS	Xenon Ion Propulsion System (manufactured by L-3 Communications, Electron Technology, Inc.)

A.3 Defined Terms

Isp	specific impulse
F_t	correction to thrust force due to beam divergence
T_e	electron temperature in K
T_{eV}	electron temperature in electron volts
$\ln \Lambda$	Coulomb logarithm

Q_{injested}	gas flow recycled into thruster from vacuum system

A.4 Variables

A	cross-sectional area
A_a	electron loss area at anode
A_{as}	total surface area of anode exposed to plasma
A_c	surface accommodation coefficient
A_g	area of grid
A_p	primary electron loss area at anode
A_s	area of screen grid
A_w	discharge chamber wall area
B	magnetic field
B_r	radial magnetic field
$\bar{c}$	neutral gas thermal velocity
C	constant, conductance of grids
C_1	experimental fitting coefficient in barium depletion model
d	gap distance (between electrodes), distance
d_a	accel grid aperture diameter
d_b	beamlet diameter
d_s	screen grid aperture diameter
D	diffusion coefficient, Richardson–Dushman coefficient, beamlet diameter
D_a	ambipolar diffusion coefficient
D_B	Bohm diffusion coefficient
D_i	ion diffusion coefficient
$D_\perp$	perpendicular diffusion coefficient
E	electric field
E_{accel}	electric field at the accel grid
E_{screen}	electric field at the screen grid

$\mathcal{E}$	energy
E_{eff}	effective atom activation energy
f	fraction of ions with a radial velocity
f_a	open area fraction of accel grid
f_b	beam flatness parameter
f_c	ion confinement factor for fraction of Bohm current lost
f_i	current fraction of the *i*th species, frequency of ion oscillations
f_n	edge to average plasma density ratio in cathode plasma
f_p	electron plasma frequency
F	force
F_{accel}	force on the accel grid
F_e	force on the electrons
F_i	force on the ions
F_{is}	flux of scattered ions
F_c	force due to collisions causing momentum transfer
F_L	Lorentz force
F_p	pressure gradient force
F_{screen}	force the screen grid
F_t	thrust vector correction factor
h	plume expansion parameter
$H(T)$	total heat lost by hollow cathode (a function of the temperature)
I_a	electron current leaving plasma to anode
I_A	accel grid current
I	current
I_b	beam current
I_B	Bohm current
I_{ck}	current to the discharge cathode keeper
I_d	discharge current
I_{DE}	decel grid current

I_e	electron current, emission current from hollow cathodes
I_{ea}	electron current to anode
I_{eb}	electron backstreaming current
I_{ec}	electron current flowing backwards in a Hall thruster
I_{ew}	electron current to the wall
I_H	Hall current
I_i	ion current
I_{ia}	ion current lost to anode
I_{ib}	ion current in the beam
I_{ic}	ion current lost to cathode
I_{iw}	ion current to the wall
I_k	ion current back to the hollow cathode
I_L	primary electron current lost directly to anode
I_{nk}	current to the neutralizer cathode keeper
I_p	ion production rate in the plasma
I_r	random electron flux
I_s	ion current to the screen grid
I_t	thermionic emission current
I_w	current to the walls
I^+	singly charged ion current
I^{++}	doubly charged ion current
I^*	excited neutral production rate in the plasma
J	current density
j_o	equilibrium current density
j_1	perturbed current density
J_e	electron current density
J_i	ion current density
J_{Hall}	Hall current density
J_{max}	maximum Child–Langmuir current density

$J_{0,1}$	zero and first-order Bessel functions
k	wave number = $2\pi/\lambda$
$k_{0,1,2,3}$	fit parameters for Randolph's plume divergence formula
K	proportionality constant
l	length
ℓ	length for radial ion diffusion between cusps
l_d	distance to merged beamlets in plume
l_e	sheath thickness length
l_g	grid gap length
L	primary electron path length, plasma length, microwave interaction length, length of the plasma in Hall thrusters
L_c	total length of magnetic cusps
L_g	path length for electron gyration
L_T	total path length for helical electron motion
m	mass, electron mass
m_a	mass flow injected into the anode region
m_c	mass flow injected through the cathode
m_d	delivered spacecraft mass
m_i	propellant mass due to ions
m_p	propellant mass
m_s	mass of species "s"
m_t	total mass flow
$\dot{m}_a$	Hall thruster anode mass flow rate
$\dot{m}_c$	Hall thruster cathode mass flow rate
$\dot{m}_i$	ion mass flow rate
$\dot{m}_p$	total propellant mass flow rate
M	ion mass, total spacecraft mass, dipole strength per unit length
M_a	ion mass in AMU
M_p	propellant mass

N	total number of particles, number of magnet coil turns
n	particle density
n_a	neutral atom density
n_b	beam plasma density
n_e	electron density
n_f	neutral density flowing from cathode
n_i	ion density
n_o	neutral density, plasma density at center of symmetry
n_p	primary electron density
n_s	source or sink density term, secondary electron density, density of species "s"
n^+	singly ionized particle density
n^{++}	doubly ionized particle density
p	plasma pressure
p_e	electron pressure
p_i	thruster plume ion pressure
p_o	thruster plume neutral pressure
P	neutral pressure, probability of a collision, power, perveance
P_a	power into the anode
P_{abs}	absorbed rf power
P_b	beam electrical power
P_d	discharge electrical power
P_f	final neutral pressure
P_{in}	power into the plasma discharge
P_{jet}	jet power (kinetic power in the thrust beam)
P_k	keeper discharge electrical power
P_{max}	maximum perveance
P_o	initial neutral pressure, other electrical power in the thruster
P_{out}	power out of the plasma

P_T	total electrical power into thruster, pressure in Torr
P_w	power into the wall
q	charge, number of magnetic dipoles
q_s	charge of species "*s*"
Q	total charge = qn, propellant flow rate or throughput
r	radius
r_a	aperture radius
r_e	electron Larmor radius
r_h	hybrid Larmor radius
r_i	ion Larmor radius
r_L	Larmor radius
r_p	primary electron Larmor radius
R	major radius, ratio of beam voltage to total voltage in ion thrusters
R	resistance
R_m	mirror ratio
R_s	mean change in the momentum of particles "*s*" due to collisions
R^{++}	rate of double ion production
$\dot{\Re}$	erosion rate of the walls
S	ionization energy loss, pumping speed
t	time
t_a	accel grid thickness
t_s	screen grid thickness
T	thrust, temperature [K]
T_a	optical transparency of the grid
T_e	electron temperature [K]
T_{eV}	electron temperature [eV]
T_g	grid transparency
T_i	ion temperature [K]
T_{iV}	ion temperature [eV]

T_m	sum of thrust from multiple species
T_n	temperature of *n*th species
T_o	temperature of the neutral gas
T_s	effective transparency of the screen grid, temperature of secondary electrons from wall, temperature of species "*s*"
T_w	wall temperature
U^+	ionization potential
U^*	average excitation potential
v	velocity
v_a	ion acoustic velocity
v_b	beam velocity
v_B	Bohm velocity
v_D	diamagnetic drift velocity
v_e	electron velocity
v_E	$E \times B$ drift velocity
v_{ex}	exhaust velocity
v_f	final velocity
v_i	ion velocity, initial velocity
v_n	velocity of the neutral species, velocity of the *n*th species
v_o	neutral velocity, initial ion velocity
v_p	primary electron velocity
v_{th}	thermal electron drift velocity
$v_\perp$	perpendicular velocity
$v_\parallel$	parallel velocity
V	volume, voltage
V_a	accel grid voltage
V_b	net beam voltage (screen voltage minus beam plasma potential)
V_{bp}	potential of beam plasma
V_{ck}	potential of discharge cathode keeper

V_c	voltage drop in hollow cathode, coupling voltage from neutralizer common potential to beam potential
V_{cg}	cathode to ground potential
V_d	discharge voltage
V_f	floating potential
V_G	coupling voltage relative to ground in ion thrusters
V_k	voltage of electrons (primaries) from the cathode
V_m	magnet volume, minimum potential in grids
V_{nk}	potential of neutralizer cathode keeper
V_p	voltage drop in plasma, plasma generator potential
V_s	screen power supply voltage
V_T	total voltage across accelerator gap = $V_s + V_a$
w	width
x	distance, characteristic length of beam column
y	insert thickness
Y	sputtering yield
Y_{ad}	adatom production yield on cathode surface
Y_{ps}	sputtered particle yield from cathode surface
Z	atomic number

A.5 Symbols

α	thrust correction factor for doubly charged ions, work function correction constant, *e*-folding distance for plasma density decrease, constant in Bessel's function argument
α_m	mass utilization correction factor due to the multiply charge ions
β	adjustable coefficient to Bohm collision frequency
γ	total thrust correction factor = αF_t, secondary electron yield
γ_o	secondary electron yield at the space-charge limit
Γ	flux of particles

Γ_o	initial flux of particles
$\Gamma(x)$	Gamma function
Δv	change in velocity
ΔV	potential modification in grids due to space charge
δ	magnet half-height
ε	electron energy density
ε_b	electrical cost of a beam ion
ε_e	energy than an electron removes from the plasma
ε_i	energy than an ion removes from the plasma
ζ	viscosity
η	total plasma resistivity
η_a	anode efficiency of a Hall thruster
η_b	beam current fraction of discharge current
η_c	Clausing factor (conductance reduction)
η_d	discharge loss
η_e	electrical efficiency
η_{ei}	plasma resistivity due to electron–ion collisions
η_{en}	plasma resistivity due to electron–neutral collisions
η_m	mass utilization efficiency
η_{m+}	mass utilization efficiency for only singly ionized particles
η_{md}	mass utilization efficiency of the discharge chamber
η_o	electrical efficiency for other power in a Hall thruster
η_T	total thruster efficiency
η_v	beam voltage fraction of discharge voltage
κ	parameter in double sheath equation ≈ 1/2, thermal conductivity
λ	mean free path, wavelength

λ_D	Debye length
λ_{01}	first zero of the Bessel function
μ	mobility
μ_B	Bohm mobility
μ_e	electron mobility
μ_{ei}	electron mobility due only to electron–ion collisions
μ_i	ion mobility
ν	collision frequency
ν_{ee}	electron–electron collision frequency
ν_{ei}	electron–ion collision frequency
ν_{en}	electron–neutral collision frequency
ν_{ii}	ion–ion collision frequency
ν_{in}	ion–neutral collision frequency
ν_m	total momentum transferring collision frequency
ν_{sn}	collision frequency between species "*s*" and the *n*th species
ν_{scat}	scattering frequency
ξ	normalized dimension = x/λ_D
ρ	charge density = qn
ρ_m	ion mass density = Mq
ρ_o	initial ion mass density
σ	cross section, surface charge density
τ	collision time, mean electron or ion confinement time
τ_c	time for electron–neutral collision
τ_m	total collision time for momentum transferring collisions
τ_p	primary electron confinement time
τ_s	Spitzer electron thermalization time with plasma electrons

τ_t	total thermalization time
ϕ	potential, work function
ϕ_o	potential at sheath edge
ϕ_s	sheath potential
ϕ_{wf}	work function of a material or surface
χ	normalized potential = $e\phi/kT$
ω	cyclic frequency (=$2\pi f$)
ω_c	electron cyclotron frequency
ω_p	electron plasma frequency
Ω_e	electron Hall parameter