Appendix

The J-2 and H-1 engines provide an appropriate comparison between engines with hydrogen or hydrocarbon fuel. The historical English units will be used only to get the dimensionless constants. Each delivers a vacuum thrust of about 230,000 lb (1023 kN), has a gas generator cycle, and was built for the Apollo program. The dry mass of the J-2 is 3576 lb (1622 kg) and of the H-1 2030 lb (921 kg). Assuming the vehicle thrust-to-weight ratio is 1.3 and adding 20% to account for sea-level thrust loss and thrust structure, the engine constant for hydrogen fuel is

$$E = (3676/230{,}000)(1.3)(1.2)$$

$$= 0.024$$

The equivalent value for hydrocarbon fuel is

$$E = (2030/230{,}000)(1.3)(1.2)$$

$$= 0.014$$

The specific impulse of the J-2 is 426 s and the effective exhaust velocity is the specific impulse multiplied by the reference acceleration of gravity, 9.8 m/s^{-2}, which gives 4175 m/s. For the H-1, the specific impulse is 295 s and the effective exhaust velocity is 2891 m/s.

The characteristics of the Space Shuttle external tank, before some of the mass-reduction programs, were used to evaluate T. The total dry mass was 75,834 lb (34.4 Mg). The hydrogen tank mass was 31,670 (14.4 Mg) and the hydrogen tank volume was 53,515 ft^3 (1515 m^3). The tank mass per unit volume k is given by

$$k = 31{,}670/53{,}515$$

$$= 0.59\ \mathrm{lb/ft^3}\ (9.5\ \mathrm{kg/m^3})$$

The corresponding calculation for the oxygen tank is

$$k = 12{,}663/19{,}609$$

$$= 0.65\ \mathrm{lb/ft^3}\ (10.3\ \mathrm{kg/m^3})$$

These values indicate that k is a weak function of the density of the propellant. To get the total external tank mass, the mass of the individual tanks must be multiplied by

$$\frac{72{,}000}{31{,}670 + 12{,}662} = 1.62$$

where the total mass is reduced somewhat for systems on the external tank that are not appropriate for this analysis.

The bulk density of oxygen and hydrogen at 6:1 mixture ratio is 22 lb/ft^3 (350 kg/m^3). This is between oxygen and hydrogen and a k value of 0.62 is selected. The tank constant is calculated

$$T = (0.62/22)1.62$$

$$= 0.046$$

For hydrocarbon fuel, the bulk density is 64 lb/ft^3 (1030 kg/m^3). The k value selected is 0.65 and the tank constant is calculated as

$$T = (0.65/64)1.62$$

$$= 0.016$$

Electron Collection by Multiple Objects within a Single Sheath

V. A. Davis,* M. J. Mandell,* and I. Katz†
S-CUBED Division, Maxwell Laboratories
La Jolla, California

Introduction

IN order to design reliable high-power spacecraft, it is necessary to understand the interactions between high-voltage power systems and the space plasma. A few space flight experiments with exposed high-voltage conductors have been flown[1,2] and more are being planned. NASCAP/LEO, a computer program that simulates in three dimensions the interaction of high-voltage surfaces with plasma, has been developed to extend the limited experimental data and aid in system design. NASCAP/LEO solves Poisson's equation and computes currents by following representative particle trajectories.[3] Although this model has been compared with the gross current through a sheath,[4] previously there has been no experimental data on how the currents are distributed among different high-voltage objects within the same plasma sheath. In this Note we report calculations that are directly comparable with recent ground test data published by Carruth[5] designed specifically to measure current distribution within a sheath. The conclusion is that, for at least this limited set of data, the electron charge transport within the sheath is dominated by quasistatic space charge fields, and that if anomalous transport between conductors exists, it is not of sufficient magnitude to influence the current measurements.

Carruth's Experiment

Carruth's experimental setup[5] consisted of a test article and two emissive probes in a tank along with a hollow cathode plasma source. The test article was a circuit board covered with a 2-mil Kapton sheet except for two slits under which were exposed conducting electrodes. The configuration modeled in the present paper has a slit width of 0.64 cm and a slit spacing of 3 cm. The emissive probes were suspended above the center of the circuit board, at distances of 0.8 cm and 1.8 cm, and could be moved normal to the slit direction. Current was collected only from the center 4.2-cm section of each of the slits in order to avoid fringing effects. The plasma source created an argon plasma with a temperature of 2–3 eV and a plasma density of $2\text{–}4 \times 10^6/\mathrm{cm}^3$.

NASCAP/LEO Calculation

Carruth's experiment was simulated using the NASA Charge Analyzer Program for Low Earth Orbit (NASCAP/LEO)[3] code, a computer code designed to study the interaction between a high-voltage spacecraft and a short Debye length plasma. In particular, NASCAP/LEO predicts the plasma currents and the electrostatic potentials both on insulating surfaces and in the surrounding plasma. The kernel of NASCAP/LEO is an electrostatic potential solver that uses analytical formulas for space charge and either potential or electric field boundary conditions at each surface cell. The only code input variables are the ambient plasma parameters and a description of the test object.

The printed circuit board was modeled as a rectangular solid with a top surface of Kapton with silver strips. The slits were biased with respect to plasma ground. The code automatically

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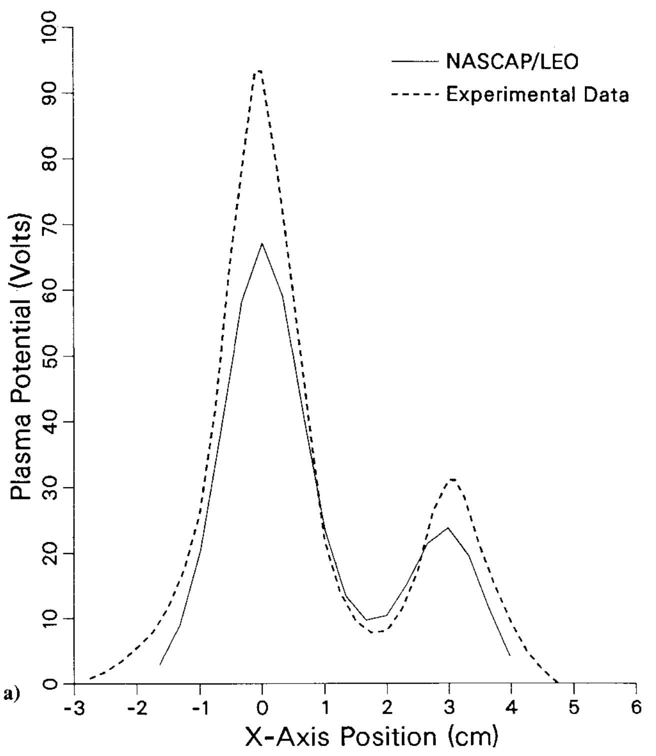
*Staff Scientist. Member AIAA.
†Program Manager. Member AIAA.



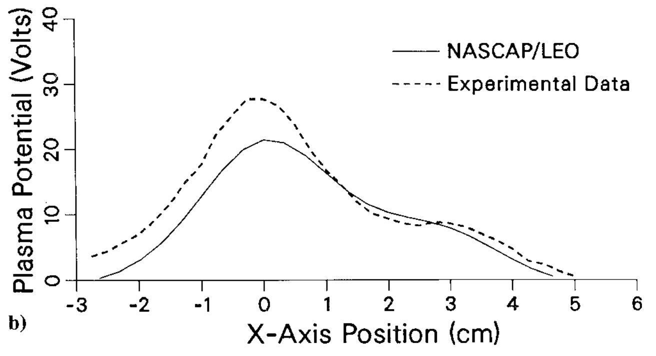


Fig. 1 Potentials: a) 0.8 cm and b) 1.8 cm above the center line for one slit at 128 V and one slit at 328 V.

generates a factor to estimate the space charge enhancement due to the current converging onto the slits. Calculations were performed using a plasma temperature of 2 eV and density of $2 \times 10^6/cm^3$ giving a Debye length of 0.74 cm. The floating potential of Kapton in this plasma was calculated to be -11 V, and the Kapton was fixed at this voltage.

Figure 1 shows potentials in space calculated by NASCAP/LEO, compared with Carruth's experimental results taken from Fig. 4 of Ref. 4. The shape and height of the voltage curves are similar; the differences are within the experimental and numerical uncertainties.

Current Collection

Figure 2 shows the current collected by each of the slits when one is held at 100 V and the other varied. The NASCAP/LEO current graphed is that which reaches the center 4 cm of each slit. For the cases where one slit is biased to 100 V and the other to less, the sheaths about the two slits are separate. The current collected by each slit is nearly the same as if the other slit were not present. For cases where the second slit is biased to greater than 100 V, the sheaths overlap and form a single sheath. As the voltage on the second slit is increased, the sheath expands and the total current collected increases. The slit with the higher bias then collects a larger fraction of the total current, and the current decreases to the slit with the fixed bias.

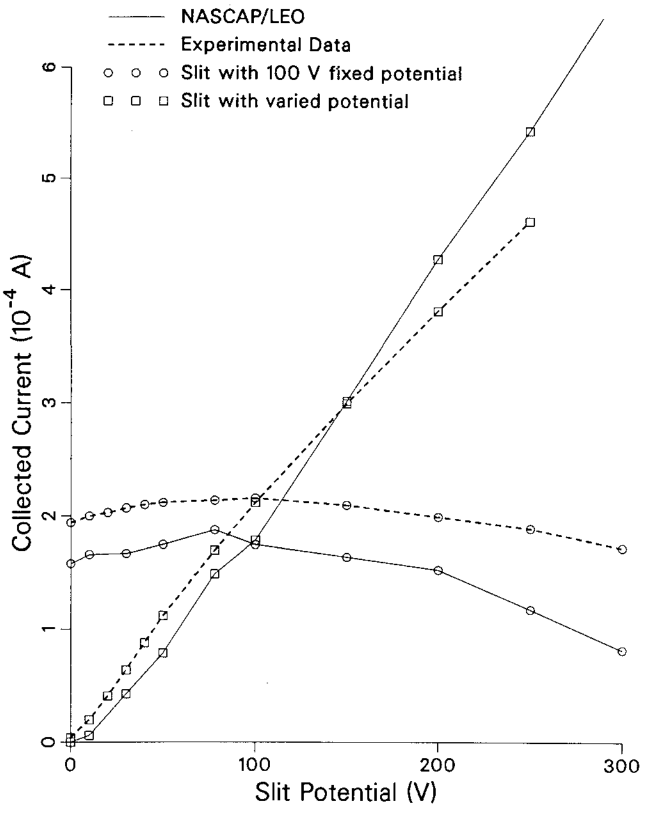


Fig. 2 NASCAP/LEO computed and experimental current collection by each of the slits.

Conclusion

The NASCAP/LEO simulations and Carruth's experiments agree for both individual and overlapping sheaths. NASCAP/LEO computes the potentials using analytic formulations for the space charge and only uses particle tracking to compute the current to the surfaces. The sheath structure is assumed to be unaffected by plasma instabilities or turbulence. This physical model appears adequate to describe the potentials and current collection properties of complex objects with differing potentials in plasmas similar to those found in low Earth orbit. The limitations on these results are the relatively low voltages (300 V) and the resultant diminished importance of magnetic fields. Data for higher potentials and magnetic effects should be obtained by the SPEAR I flight experiment scheduled for launch in November 1987.

Acknowledgment

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References

[1]Grier, N.T. and Stevens, N.J., "Plasma Interaction Experiment (PIX) Flight Results," *Spacecraft Charging Technology,* NASA CP-2071, AFGL-TR-79-0082, 1978, pp. 295–314.

[2]Grier, N.T., "Plasma Interaction Experiment II: Laboratory and Flight Results," *Spacecraft Environment Interactions Technology Conference,* NASA CP-2359, AFGL-TR-85-0018, 1983, pp. 333–348.

[3]Mandell, M.J., Katz, I., and Cooke, D.L., "Potentials on Large Spacecraft in LEO," *IEEE Transactions on Nuclear Science,* Vol. NS-29, Dec. 1982, pp. 1584–1588.

[4]Mandell, M.J., Katz, I., Jongeward, G.A., and Roche, J.C., "Computer Simulation of Plasma Electron Collection by PIX-II," *Journal of Spacecraft and Rockets,* Vol. 23, Sept.-Oct. 1986, pp. 512–518.

[5]Carruth, M.R., Jr., "Plasma Electron Collection Through Biased Slits in a Dielectric," *Journal of Spacecraft and Rockets,* Vol. 24, Jan.-Feb. 1987, pp. 79–85.