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EFFECTS OF ARGON ION INJECTIONS IN THE PLASMASPHERE

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In lifting massive space power system payloads from low earth orbit to geosynchronous earth orbit, Cargo Orbit Transfer Vehicles (COTV) using ion propulsion will inject energetic beams of argon ions into the plasmasphere. The argon ion beams have a fast velocity $V_b \lesssim V_A$ the Alfven velocity of the plasmasphere medium and $V_b >> V_{th}$ the thermal velocity of the plasmasphere ions. The relationship of the beam velocity to these characteristic velocities as a function of radial distance in the plasmasphere is shown in Figure 1 for positions near the earth's equatorial plane. The Alfven speeds are shown for the Chiu et al model[1] plasmasphere and the average and low Alfven speeds are calculated from OGO-5 observations analyzed by Chen et al[2]. As can be seen, the Chiu et al model gives an upper bound to the Alfven speeds. The average OGO-5 Alfven speeds give the best indication of the Alfven speeds which are of the order of the beam speed throughout most of the plasmasphere whose outer boundary is between 4 and 6 earth radii (R_e). Hence $V_b \lesssim V_A$. The thermal speeds in Figure 1 are taken from the Chiu et al model. In this case discrepancies between observations and the model are unimportant since $V_b >> V_{th}$ always. The spread velocity of the beam perpendicular to its direction of propagation is $\Delta V_b \approx 0.4\ V_b$. Thus the exhaust of the COTV's may be described as a fast, rapidly diverging ion beam. Due to these beam characteristics, the numerous potential plasma instabilities which could take energy from the beam and hence stop it are ineffective. This is due to the fact that the beam and background plasma parameters change sufficiently rapidly as not to allow amplification of instability generated waves to significant amplitudes[3]. Another beam stopping mechanism which models the fast ion beam as a slowly moving ion cloud[4] with $V_b << V_{th}$ and $V_b << V_A$ is not applicable given the relationship of V_b to V_A and V_{th} shown in Figure 1. In addition, to this inconsistency the ion cloud model assumes the beam plasma can be regarding as infinitely conducting. This frozen field line concept is not applicable here since a realistic model of the beam plasma[5] which accounts for both the initial plasma turbulence and that generated by the low amplitude plasma wave turbulence carried with the beam gives rapid diffusion times $\tau = \lambda_b^2/D_\perp^*$ as shown in Figure 2. Note that λ_b is the beam Debye length and $D_\perp^*$ the anomalous diffusion coefficient associated with the plasma turbulence. The currents resulting from the turbulence induced anomalous resistivity are insufficient to short out the polarization electric field. Despite the limitations on beam stopping mechanisms caused by the beam velocity characteristics and its finite conductivity, not all of the beam plasma escapes the plasmasphere. Since the polarization electric field imposed at the thruster to allow cross field propagation of the beam is nonuniform over the sheath of the beam, the plasma in this sheath is lost and deposited on local field lines. This beam sheath loss model[3] results in a deposition of argon ions and hence energy in the plasmasphere which is much less than that in models which call for ion clouds or plasma instabilities to rapidly stop the beam. In Figure 3, a comparison is given of the cumulative fractional mass loss of an ion beam injected at 1.5 R_e for the ion cloud and the ion beam sheath loss process. The ion cloud process yields total deposition very rapidly whereas all but a few percent of the beam in the ion beam sheath loss process escapes. In Figure 4 the integrated difference of these two deposition odels is shown for the construction of one SPS. The ion cloud process gives better than an order of magnitude greater energy and number density perturbation to the plasmasphere. The difference is not only quantitative but is also qualitative: the energy spectra of the argon ions deposited in the plasmasphere are dissimilar. For the ion cloud process accompanied by a weaker plasma instability loss process the solid line in Figure 5 gives a qualitative indication of the energy spectra of the argon ions. In the ion cloud model, most of the energy of the argon ions is dissipated in producing ionospheric currents caused by the cloud's field line dragging. This process yields the low energy peak. The higher energy tail and peak just below the injection energy of $\sim$5 keV would be produced by various instability processes. In contrast, the sheath loss model shown by the dotted line in Figure 5 results in the argon ions being deposited with energies near the injection energy.

The different beam stopping mechanism can produce very different environmental impacts. The sheath loss model predicts a large injection of energetic anisotropic argon ions which will drive plasma instabilities which may produce sufficient scintillation to impair radio communications with geosynchronous satellites[6]. The partial depletion by precipitation of the energetic ion belts surrounding the earth is also possible due to the pitch angle scattering caused by argon ion turbulence. Cold argon ions ($T \sim 1$eV) would result in the sheath loss model only via the loss of energy by plasma instability mechanisms and electron coulomb scattering. Since during the energy degradation processes, argon ions will be lost by charge exchange and precipitation, the cold Ar$^+$ plasma from the sheath loss mechanism will be much less than from the ion cloud mechanism. The environmental effects due to cold Ar$^+$ would be greatly reduced in the sheath loss picture as well as those effects due to ionospheric currents[4].

Finally, we note that in searching for observational support for ion beam stopping, the observations must correspond closely to the ion beam parameters envisioned for the COTV's. Specifically, the V_b, ΔV_b and the initial beam density and direction must be close to those planned for the COTV thrusters[5]. Arguments that barium release observations or high altitude nuclear blasts give evidence supporting a given beam model are therefore not valid. A far better experimental test would be a Space Shuttle-born ion beam experiment. This could be a scaled down COTV ion thruster with power levels of about a kilowatt and a nozzle diameter of a few centimeters rather than a megawatt and a meter. The other beam parameters could be the same as for a COTV. The required power levels could be within the limits of the planned solar powered auxiliary 20kW orbiter integral solar array or the 6kW orbiter mounted array.

[1] Chiu, Y. T., J. G. Luhmann, B. K. Ching and D. J. Bouchen, Jr., An Equilibrium model of Plasmaspheric Composition and Density, J. Geophys. Res., 84, 909, 1979.

[2] Chen, A. J., J. M. Grebowsky and K. Marubashi, Diurnal Variations of Thermal Plasma in the Plasmasphere, Planet. Space Sci., 24, 765, 1976.

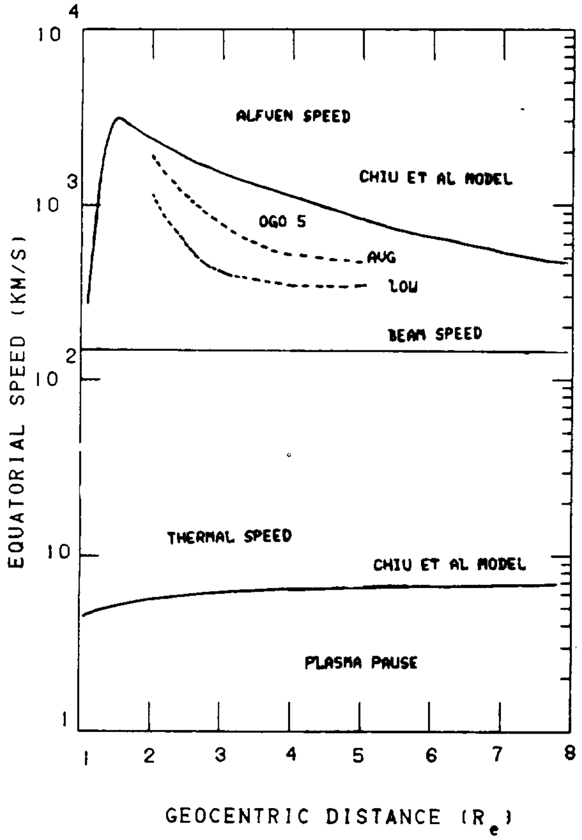
[3] Curtis, S. A. and J. M. Grebowsky, Energetic Ion Beam Magnetosphere Injection and the Solar Power Satellite, J. Geophys. Res., in press, 1980.

[4] Chiu, Y. T., J. G. Luhmann, M. Schultz and J. M. Cornwall, Effects of Construction and Operation of a Satellite Power System Upon the Magnetosphere, Aerospace Report No. ATR-80 (7824)-1, 1 December 1979.

[5] Ichimaru, S., Basic Principles of Plasma Physics: A Statistical Approach, W. A. Benjamin, Inc. (Advanced Book Program) Reading, Mass., 1973.

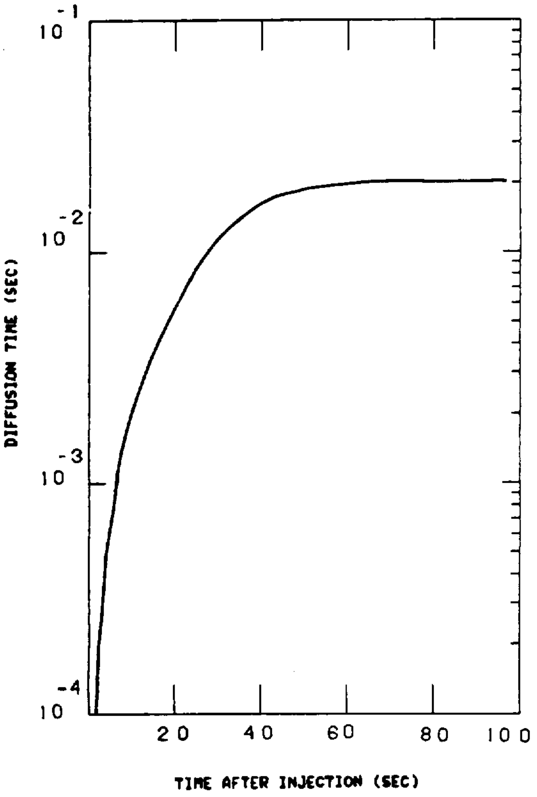
[6] Curtis, S. A. and J. M. Grebowsky, Changes in the Terrestrial Atmosphere - Ionosphere-Magnetosphere System due to Ion Propulsion for Solar Power Satellite Placement, submitted to Space Solar Power Review, 1979.

FIGURE 1



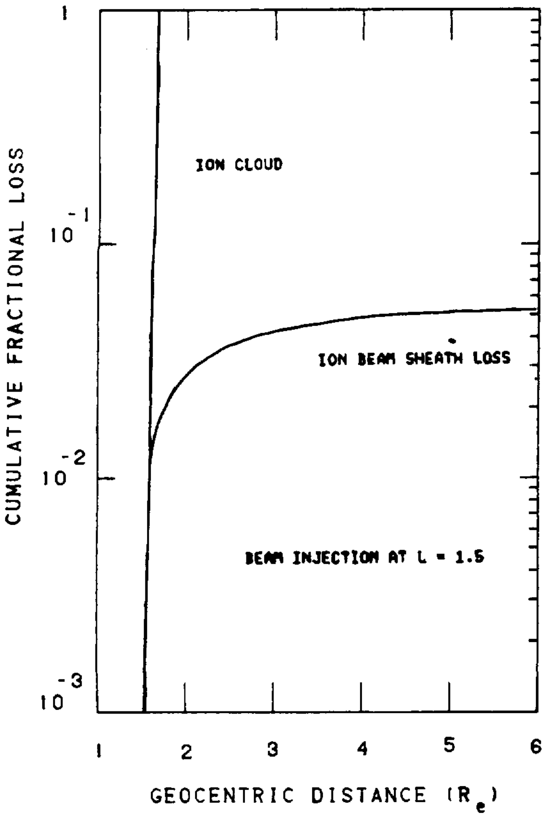
CHARACTERISTIC VELOCITIES

FIGURE 2



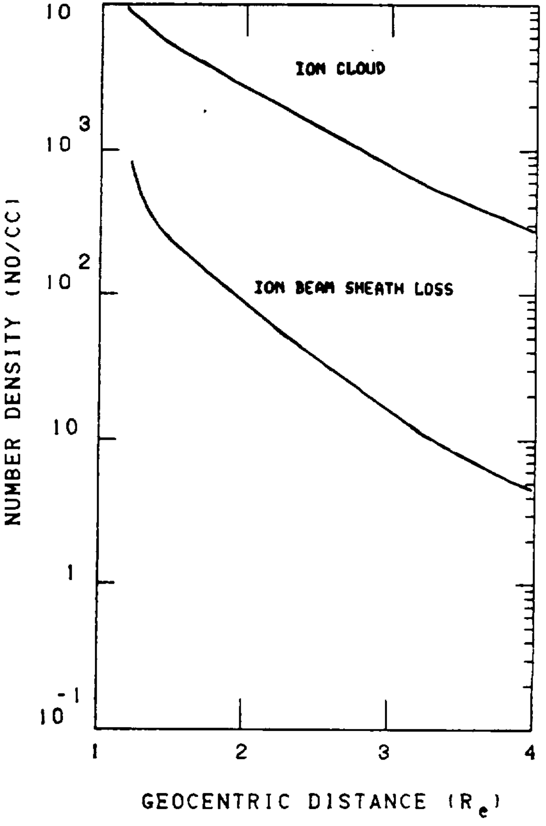
MAGNETIC FIELD DIFFUSION IN A TURBULENT ION BEAM PLASMA

FIGURE 3



DENSITY LOSS OF ION BEAM

FIGURE 4



DENSITY DEPOSITION PER SPS

FIGURE 5

COMPARISON OF ION CLOUD AND ION BEAM
SHEATH LOSS MODEL DEPOSITED ENERGY SPECTRA