

## RECENT EXPERIMENTAL MEASUREMENTS OF SPACE PLATFORM CHARGING AT LEO ALTITUDES

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### ABSTRACT

The estimation of the extent of electrical charging of space platforms at low earth orbit (LEO) altitudes has been a subject of interest for a number of years. Early estimates based on theoretical current-voltage relationships of Langmuir and Blodgett and Parker and Murphy predicted a wide range of possible electrical potentials for a platform being actively charged at LEO altitudes. The experimental success of early electron beam experiments suggested that the early theories were incomplete. This has led to the development of space experiments specifically designed to study the degree of electrical charging resulting from electron beam emission, and also supplementary experiments to determine the current voltage relationship of large structures biased to high voltages in the LEO environment. The paper will discuss some of the results of vehicle electrical potential from recent sounding rocket experiments involving charging of a space platform by both electron beam emission, and by the application of differential bias between elements of the platform.

### INTRODUCTION

The study of the electrical charging of space platforms has been pursued both theoretically and experimentally since the early days of space flight. An important consideration in the determination of space platform charging is the relationship between plasma currents collected by a charged conductor and the electrical potential of that conductor. Theoretical studies by Beard and Johnson /3/ who applied the analytic analysis of Langmuir and Blodgett /1,2/ and the concept of charge sheaths to current collection by charged objects in the low earth orbit (LEO) space environment. The Langmuir and Blodgett theory ignored the effect of the ambient magnetic field in the plasma, but it was included in a theory developed by Parker and Murphy /4/ who developed an expression for the current-voltage characteristics of a sphere in a magnetized plasma. The Parker-Murphy theory allowed no cross-field current collection and predicted much lower currents than the Langmuir-Blodgett theory. Effects of collective plasma processes were considered by Linson /5/ who allowed for varying amounts of cross-field current as a result of the scattering of particles by plasma waves set up in the charge sheath.

Early studies of passive space platform charging resulting from its motion through the ionospheric plasma predicted relative low equilibrium potentials in the -0.5 to -2.0 volt range. However the inclusion of active devices such as intentional or accidental differential biasing on the platform, or the emission of charged particle beams were predicted to greatly increase the potential of the platform relative to the ionosphere. Early studies /3/ suggested a limit of about 50mA electron beam emission from a small space platform before the potential rose to a sufficiently high value to reduce the beam current to a value which could be matched by a limited return flux of electrons from the ionosphere.

In this paper we will discuss measurements of vehicle potential under conditions of both electron beam emission and differential biasing. The results discussed will be limited to two sounding rocket payloads, however, it should be noted that a considerable amount of platform charging measurements have been made from orbital platforms /6,7,8/.

### EXPERIMENTAL RESULTS

#### Electron Beam Experiments

The electron beam experiments to be presented were obtained from the CHARGE-2 sounding rocket experiment flown as part of the NASA sounding rocket program in December, 1985 /9,10/. The payload included a fast pulse electron gun (FPEG) which operated at a beam energy of 1keV and a variable current up to 40mA. The beam emission was controlled by a solid state switch which provided beam current

rise and fall times of about 200ns. The payload was divided into two parts connected by a conducting, insulated tether. A spring driven deployment system supplemented by gas jets resulted in separation of the payload sections at about 1m/sec up to a distance of 400m. This configuration allowed the payload to be used for both beam charging experiments and for differential biasing experiments with widely separated payload elements.

**Steady-state platform charging.** Electron beam emission pulses of durations exceeding a few mS enabled measurements of the steady state platform charging to be made. Detectable charging was observed for even the lowest beam current of 7mA. The charging of the payload relative to the deployed section depended on beam current, ambient plasma density and ambient atmospheric density. Typical values are shown below in Figure 1 (right panel) as a function of beam current. The variation of plasma density at the different beam currents is shown in the left panel, and reflects the altitude change during the flight.

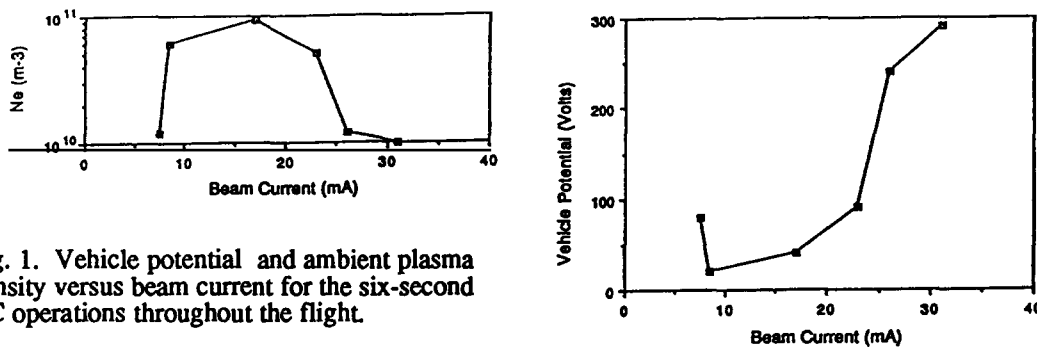


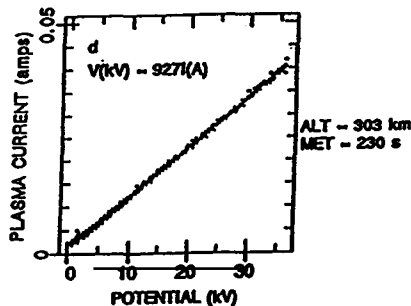
Fig. 1. Vehicle potential and ambient plasma density versus beam current for the six-second DC operations throughout the flight.

#### Differential Biasing Experiments

Differential biasing of a space platform was included in the CHARGE-2 flight sequence using a 500v power supply to bias the deployed section relative to the main section both with and without the electron beam being emitted.

Another sounding rocket payload designed to study differential biasing up to 45kV was the SPEAR-1 payload flown in December, 1987. In this experiment, capacitors were charged to various potentials up to 45kV, and then connected to each of two spherical collectors with diameters of 20cm and mounted on potential graded booms, each being approximately 1m long and attached to a common point remote from the spheres which was deployed 2.1m from the rocket body on a telescopic fiberglass boom. The capacitor stored sufficient charge to result in a discharge time constant of approximately 1sec, thus in a 5sec biasing period the potential fell slowly enough for essentially steady state current voltage characteristics to be measured over the whole voltage range from the peak capacitor potential to low voltages. The monitored voltage was the differential voltage between the rocket body and the deployed sphere. Due to the failure of the intended grounding device, a plasma contactor, to be exposed, the spheres were driven positive while the rocket body was driven negative resulting in a bipolar experiment with the complication of two charge sheaths which generally intersected for the high potentials used.

**SPEAR-1.** An example of the plasma current through the two sheaths in series as a function of the applied potential is shown in Figure 2. It can be seen that the sheath impedance behaved as a linear resistor with a value of 927k $\Omega$  in this example. The current flowing is rather low, and is generally close to that predicted by the Parker-Murphy theory, although the two sheaths resulting from the bipolar operation make it inappropriate to compare directly with the Parker-Murphy theory. The low current is



consistent with geomagnetically confined space charge limited collection. This is supported by low light level TV (LLLTV) images of the sphere which showed no evidence of discharge around the sphere.

Fig. 2. Plasma current versus differential potential for the SPEAR-1 payload when one sphere was biased.

There were a few occasions when we believe the main payload was connected to the ionosphere by the emission of gas from the attitude control system (ACS) jets into the charge sheath. In this configuration we had a unipolar system and the currents collected were more directly comparable with the existing theories. Figure 3 shows plots of the current as a function of sphere voltage for the unipolar

cases at two different altitudes. The solid line is the Parker-Murphy theory and the broken line the Langmuir-Blodgett theory for the measured plasma densities indicated. It can be seen that the current collected is closer to the Parker-Murphy prediction below 10kV, but shows an increasing tendency to deviate when the sphere is above about 12kV until it exceeds the Langmuir-Blodgett values above about 17kV. It has been suggested by Katz /11/ that this is a result of the sphere sheath growing to encompass the gas jet at the higher sphere potentials, and it is therefore not a good representation of the theoretical model.

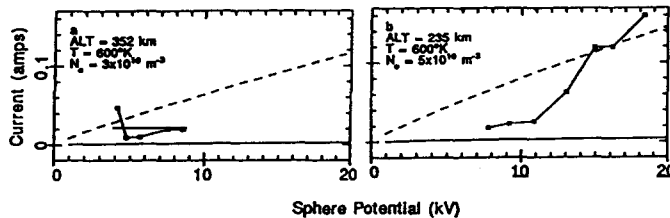
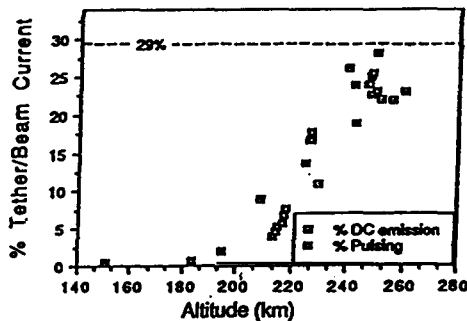


Fig. 3. Plasma current versus sphere potential for the SPEAR-1 payload when the rocket body was ground through a discharge at an operating ACS gas jet for two different capacitor discharges.

**CHARGE-2.** A compilation of current collection by the deployed, tethered part of the CHARGE-2 payload is shown in Figure 4. The current collected is shown as a fraction of the emitted beam current.



If it is assumed that the total return current is equal to the beam current, then, if no other effects were involved, the fraction of return current collected by the deployed section should equal the fraction of its surface area to the total surface area.

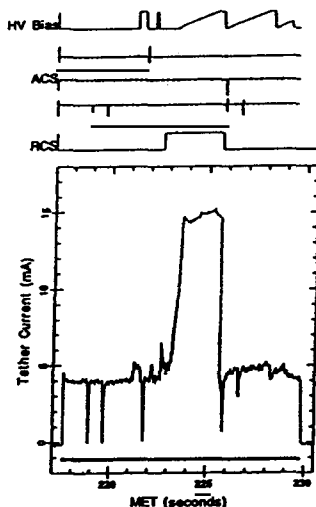
Fig. 4. Percentage of CHARGE-2 daughter current collection of the beam current versus altitude. Below 240km the beam-atmosphere interaction at the mother enhanced the mother current collection and the daughter collected a smaller percentage of the beam current.

The figure shows that only near apogee does the collected current ratio approach the ratio of the areas. At lower altitudes, the return current flows increasingly to the beam emitting platform. Discussion of this result will be deferred until the following section.

#### Platform Neutralization

Both the SPEAR-1 and CHARGE-2 results showed strong evidence of the ability to provide a good connection of the platform to the ionosphere by the emission of gas from the charged platform. The effect was apparent for both positive (CHARGE-2) and negative (SPEAR-1) bias on the platforms. The SPEAR-1 effect is discussed above. In addition the CHARGE-2 result on the distribution of the return current between the beam emitting platform and the deployed payload section showed the enhanced return current due to the beam atmosphere interaction at altitudes below about 270km, thereby favoring return currents to the mother section as shown in Figure 4.

**CHARGE-2.** The separation assistance jets on the deployed section of the CHARGE-2 payload operated for about 3sec every 30sec. During one of these periods, the electron beam was being emitted from the



main payload and driving it to a positive potential and the HV bias was also applied. When the gas jet fired the current collected by the deployed part of the payload showed a marked increase as illustrated in Figure 5. We interpret this effect as being due to a decrease in the sheath impedance resulting from increased ionization in the sheath. The timing of the RCS thruster firing and the HV biasing is shown in the top panel, the beam emission period is shown by the heavy line at the bottom of the lower panel.

Fig. 5. Tether current increase when RCS gas jet operated at deployed payload section of CHARGE-2 (lower panel). The beam emission period is shown by the dark line in the lower panel, the gas jet operation and the biasing program are shown in the upper panel.

The result of the distribution of return current between the deployed, and beam emitting parts of the payload discussed above is attributed to increasing local ionization around the beam emitting platform. The result is consistent with the higher atmospheric density at lower altitudes resulting in greater beam - atmosphere interaction.

### CONCLUSIONS

We draw the following conclusions applicable to the experimental parameters of the CHARGE-2 and SPEAR-1 payloads: 1) the currents collected by HV biased collectors in the ionosphere show strong magnetic limiting and are close to the values predicted by Parker and Murphy /4/; 2) no volume breakdown was observed above 100km altitude by exposing voltages up to 45kV to the ionosphere in the SPEAR-1 payload; 3) the release of gas at flow rates typical of ACS systems can provide sufficient plasma to electrically neutralize space platforms biased at either positive or negative potentials; and, 4) the electron beam-atmosphere interaction at altitudes below about 270km can produce sufficient ionization to allow adequate return current for beams up to 50mA/1keV to operate without excessive vehicle charging.

### ACKNOWLEDGEMENTS

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