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Testing of a Spacecraft Model in a Combined Environment Simulator

J. V. Staskus and J. C. Roche
Lewis Research Center
Cleveland, Ohio

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TESTING OF A SPACECRAFT MODEL IN A COMBINED ENVIRONMENT SIMULATOR

J. V. Staskus and J. C. Roche

National Aeronautics and Space Administration
Lewis Research Center
Cleveland, Ohio 44135

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Abstract

A scale model of a satellite was tested in a large vacuum facility under electron bombardment and vacuum ultraviolet radiation to investigate the charging of dielectric materials on curved surfaces. The model was tested both stationary and rotating relative to the electron sources as well as grounded through one megohm and floating relative to the chamber. Surface potential measurements are presented and compared with the predictions of computer modelling of the stationary tests. Discharge activity observed during the stationary tests is discussed and signals from sensing devices located inside and outside of the model are presented.

Introduction

As part of the continuing effort in the joint NASA/USAF spacecraft charging investigation, electron spraying tests were performed on a model of the SCATHA (P78-2) satellite in one of the large vacuum facilities at NASA-LeRC. Considerable testing at atmospheric pressure had previously been performed on the model.[1] The testing was concerned with measurement and analysis of the model's response to simulated electron induced discharges occurring at various points on the model. The LeRC electron spraying tests were part of a combined experimental and analytical investigation of the charging of dielectric materials in geometric patterns on a curved surface. Previous charging tests had been performed on 30 cm square or smaller samples of single dielectric materials on grounded substrates with normally incident electron beams.

Electron spraying tests of a satellite were conducted by the European Space Agency on the METEOSAT F1 model.[2,3] The tests were an attempt to reproduce anomalies observed on the orbiting spacecraft. During those tests, it was reported that discharges were unexpectedly observed to occur with the satellite floating. In the course of the LeRC testing, it was also observed that discharges occurred with the SCATSAT floating. Furthermore, discharges occurred for electron beam energies well below those required to produce discharges in the tests of small samples on grounded substrates.

The testing, originally planned to investigate charging, was expanded to include investigation of the low level discharges. Sensors were placed in and around the model to determine the nature and location of the discharging. That investigation has only recently been initiated and is still being pursued.

Experiment Description

Facility

The tests were conducted in the 4.6-meter diameter by 18.3-meter long vacuum chamber in the NASA Lewis Research Electric Propulsion Laboratory (Fig. 1). The test object, called SCATSAT,[1] was a 2/3 scale model of the SCATHA satellite launched in January of 1979. The model was suspended on three 0.76-meter long Delrin rods providing DC isolation from the chamber. The support assembly was mounted on a hollow-shaft, rotary vacuum feedthrough with a motorized drive to permit simulation of satellite rotation. The hollow shaft permitted data cables to be brought out of the vacuum chamber before twisting during rotation. The model was centered on the chamber axis. Four electron guns were located about two meters from the model approximately every 90° around the model at the elevation of the chamber axis. Surface voltage probes mounted on vertical arms scanned the cylindrical surface of the model as it rotated. A surface voltage probe mounted beneath the model viewed the stainless steel forward skin to continuously monitor the structure potential. Two vacuum ultraviolet (VUV) sources were mounted near one of the electron guns at elevations above and below the chamber axis (Fig. 2). Electron flux sensors were located between each electron gun and the model at about 15 cm from the model. The chamber was pumped by diffusion pumps and was operated in the mid 10^{-7} torr to low 10^{-6} torr pressure range.

SCATSAT Model

Figure 3 is a detailed view of the SCATSAT. The model is a 1.1-meter long by 1.1-meter diameter, right circular cylinder. The fiberglass cylindrical surface is covered with 2 cm by 4 cm fused silica solar cell cover slides over copper foil to simulate the solar cells of the SCATHA satellite. A small patch of indium-tin-oxide (ITO) coated cover slides is located near the forward end of the model. The conductive ITO surfaces are electrically connected to the SCATSAT structure. The aluminum central band has two areas of silvered Teflon tape about 180 degrees apart around the model. The silver layer on the tape was electrically connected to the model structure through the tape's conductive adhesive. Two square aluminum patches about 180 degrees apart and on opposite sides of the central band represent the spacecraft surface potential monitor (SSPM) simulations for these tests. They are both electrically connected to the model's structure. The forward end of the model is a skin of stainless steel foil. The aft end of the model is an aluminum skin with a nonconductive white paint. Thus the model duplicated the general features of the dielectric surfaces on SCATHA.

Test Results

Material Charging Tests

Testing of the SCATSAT started with an investigation of the charging of the dielectric materials on the curved surface. The first tests were conducted with a one megohm resistive connection between the model and the chamber. A resistive voltage divider was included for structure potential measurement. The stationary model was irradiated by four electron guns for approximately 30 minutes. The guns were then turned off and the model was rotated at 1 rpm to obtain the surface voltage profiles. It is known from repetitive measurements that the surface voltages do not change in the one minute required to obtain the data. Figure 4(a) shows the solar array surface voltage profile resulting from irradiation by four 8-keV, approximately 1 nA/cm^2, electron beams. The four broad peaks were produced by the four electron beams. The narrow peaks correspond to the individual cover slides. The area at zero corresponds to the simulation of the SSPM. The maximum potentials of -6 kV occurred where the electron beam angle of incidence was minimum. The angle was not exactly zero since the path viewed by the probe was not in the plane of the electron guns. The electron guns were turned back on while the model was rotating at 1 rpm and after several minutes equilibrium was reached. The surface voltage profile shown in Fig. 4(b) was the result. The potential peaks were reduced by 700 to 800 volts and the valleys were filled in. Finally, the two VUV sources were turned on and the equilibrium surface voltage profile shown in Fig. 4(c) resulted. During the stationary irradiation tests surface voltage probe and current sensor transients indicated that some low-level, nonvisible discharges were occurring randomly at quite low electron beam energies. The discharge activity was halted or diminished when the model was rotated.

Comparsion to Modelling Predictions

The NASA Charging Analyzer Program (NASCAP)[4-6] was used to generate computer predictions of the surface voltage profiles on a computer simulation of a ground, stationary SCATSAT being irradiated by four electron beams. The SCATSAT was modelled as an octagon (Fig. 5) suspended in a representation of the vacuum chamber. Figure 6 shows the solar array and center band surface voltage profiles recorded on the model following irradiation by the four 1 nA/cm^2 electron beams at 6 keV while the model was stationary. The segmented line connects the potentials predicted for the surface cells of the NASCAP model of the SCATSAT. The values predicted are in good agreement (within 25 percent) with the recorded data. The discrepancy is probably due to the use of an octagonal rather than circular analytical model. It is encouraging to note that the structure seen in the recorded data is also evident in the computer predictions within the constraints of the computer model's spatial resolution. Simulation of the rotating SCATSAT was not attempted at this time.[7]

Discharge Tests

The potential of the floating SCATSAT irradiated by four appromxiately 1 nA/cm^2 electron beams at 2.5 keV is shown in Figure. 7(a). Ignoring the effects of electron gun warm-up, the model's potential rapidly achieved a nearly stable negative value with periodic discharges taking place. The discharges were more frequent than observed during tests with one megohm between the model and ground. The discharge rate increased with increasing electron flux and/or beam energy. Since the model was stationary, the voltage on the model's structure was the only voltage data obtainable. For reasons as yet unknown, the structure potential data underwent periodic step changes in level as indicated at approximately 400, 1000, and 1200 sec. The surface voltage probe transients indicative of discharging are shown between 200 and 400 sec and between 1000 and 1200 sec.

The NASCAP predictions of the material potentials shown in Fig. 7(b) indicate the structure to be the most negative with the surfaces of the solar cell cover slides and Teflon several hundred volts positive relative to the structure. Depsite the large discrepancy between the data and prediction of the time required for the structure to reach equilibrium, the agreement in the equilibrium value is quite good (within 100 volts). The time discrepancy is related to the size of the timesteps used in the computer modelling.

A final observation that requires further investigation is the change in structure potential at turn-off of the electron guns. In the case shown, the structure potential rapidly jumped from -750 to +350 volts. On other occasions, at similar test conditions, the change was much less rapid and on still others there was no observable change. At present the structure potential change at electron gun turn-off does not appear to be chamber pressure dependent.

The evidence of discharging consisted of transients on the surface voltage probe signals and the electron flux sensor electrometer signals. Discharges were not visible to the naked eye and 30 minute time exposure photographs did not show any visible evidence of discharges. When tests were conducted with the model electrically floating, the discharges occurred more frequently for a given electron beam energy and flux. The surface voltage probe mechanism was moved away from the model to eliminate it as a possible discharge site and the discharges continued. The discharge rate was found to increase with increasing electron beam energy and/or flux. The rate was also found to be dependent on the portion of the model being irradiated. When an area of the model with a Teflon-aluminum interface on the central band was being irradiated, the greatest discharge activity was observed. Discharge activity could be diminished by rotating the model to irradiate a different portion of the central band. Each of the electron guns, when operated separately, produced similar variations in discharge activity with variations in the portion of the model being irradiated.

Additional sensing devices were then installed to further investigate the discharging. A device that responds to the time derivative of a magnetic field, a B-dot sensor, was placed in the interior of the model near a Teflon-aluminum interface on the central band. Insulation capable of withstanding over 20 kV was used between the SCATSAT and the sensor and its cables. A 15 cm diameter loop antenna was placed outside of the model and opposite the electron gun being used. Figure 8 shows transient signals from these devices during a 4 keV, 1 to 2 nA/square cm, test of the floating stationary SCATSAT. Both signals were of low amplitude. Though the signals shown were of about the same duration, they were not from the same event. A small fraction of the discharges that were detected by the antenna outside the model produced sufficient signal from the B-dot sensor to trigger its digital waveform recorder. This was probably due to the shielding of the model's interior by the Faraday cage construction representative of the SCATHA satellite. The oscillation frequency of the antenna signal was typically 20 mHz while the calculated vacuum chamber resonant frequency was 50 mHz.

Summary

Electron beam charging tests were conducted on a 2/3 scale spacecraft model in a vacuum chamber using up to four electron guns to irradiate the model's cylindrical surface. The tests were conducted with the model stationary as well as rotating and with the model connected to ground through one megohm as well as floating. Computer modelling of tests of the stationary model, both grounded and floating, produced results in good agreement with the recorded data. The computer model predicted a positive voltage gradient in the insulators on the floating model.

Discharging was noted which occurred for electron beam energies as low as 2.5 keV. The frequency of discharging increased with increasing electron flux and/or beam energy. The discharges were more frequent on the floating model than on the model with one megohm to ground. The discharges were not visible and produced low amplitude signals from sensing devices placed in the vacuum chamber. The rf frequency of the discharges was 20 mHz while the vacuum chamber resonant frequency was calculated to be about 50 mHz.

All of the phenomena that have been observed during the testing are not fully understood and the investigation is continuing.

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7. M. Mandell, I. Katz, and D. E. Parks, "NASCAP Simulation of Laboratory Spacecraft Charging Tests Using Mulitple Electron Guns" late news paper presented at session I of the 18th annual IEEE conference on Nuclear and Space Radiation effects, July 21-24, 1981, Seattle, WA.

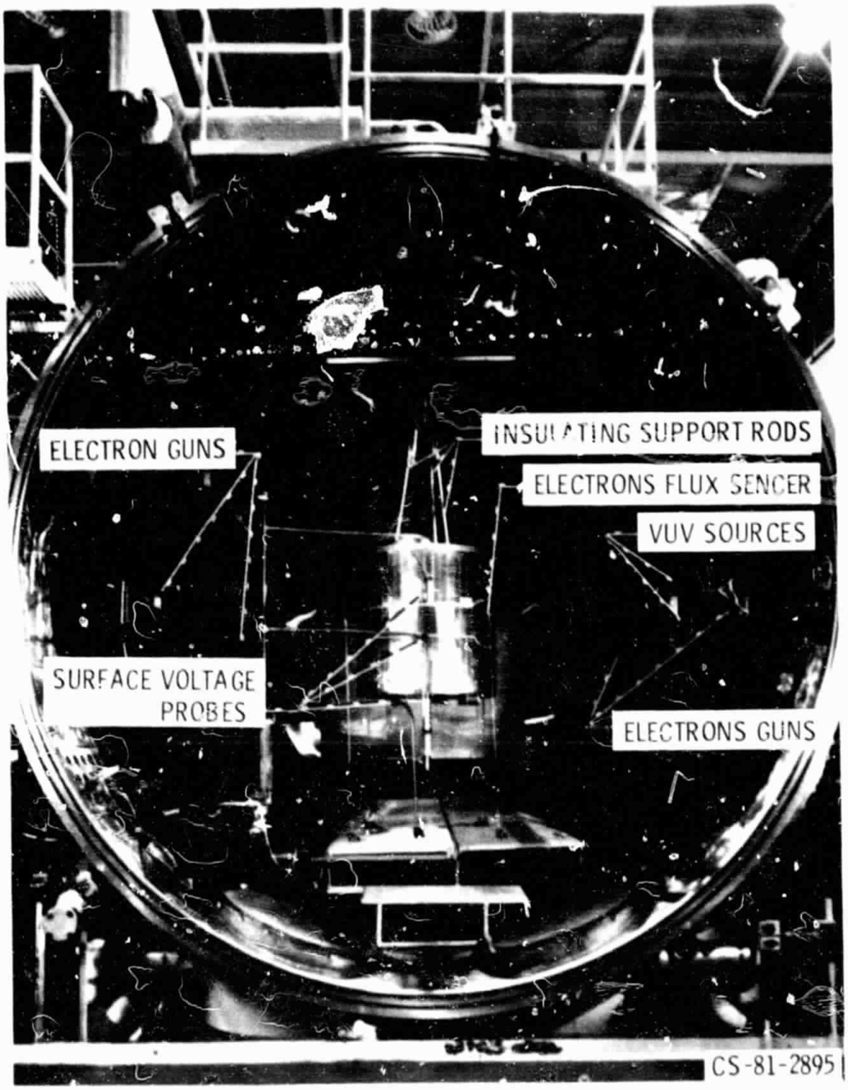

Figure 1. -Model in vacuum chamber.

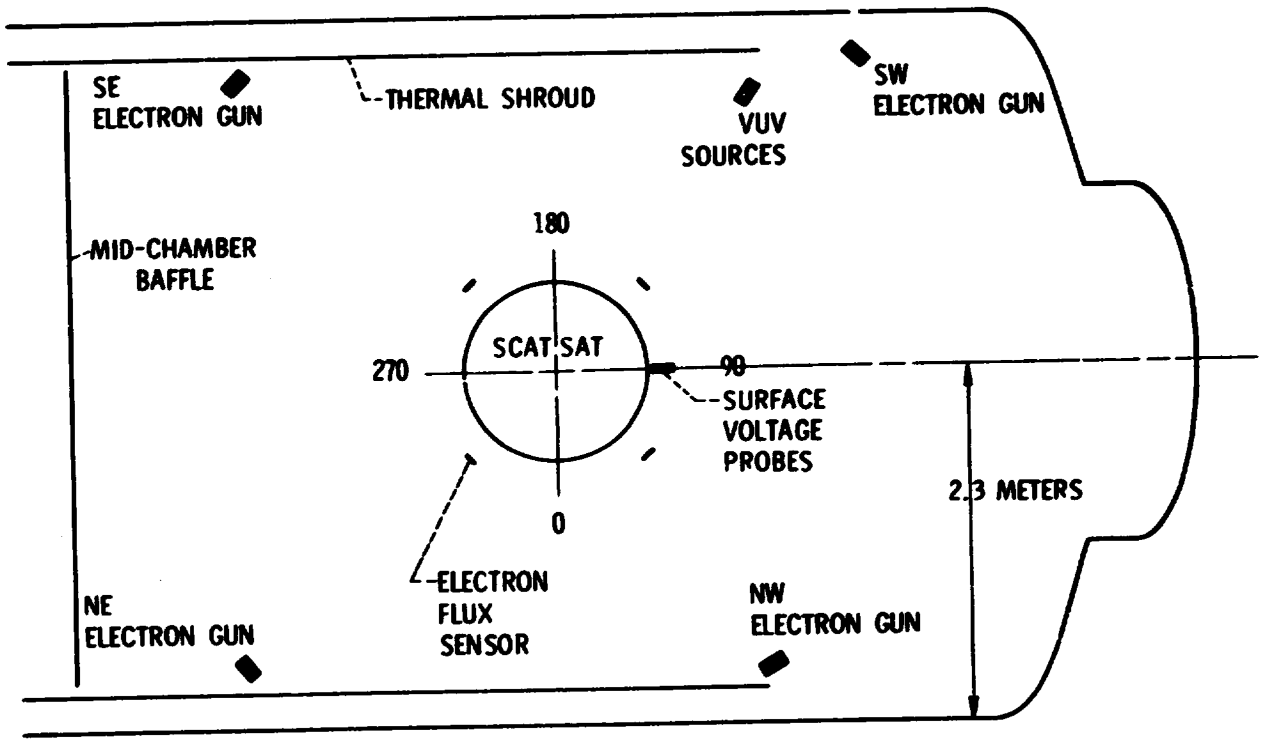

Figure 2. - Layout of experiment in tank 5.

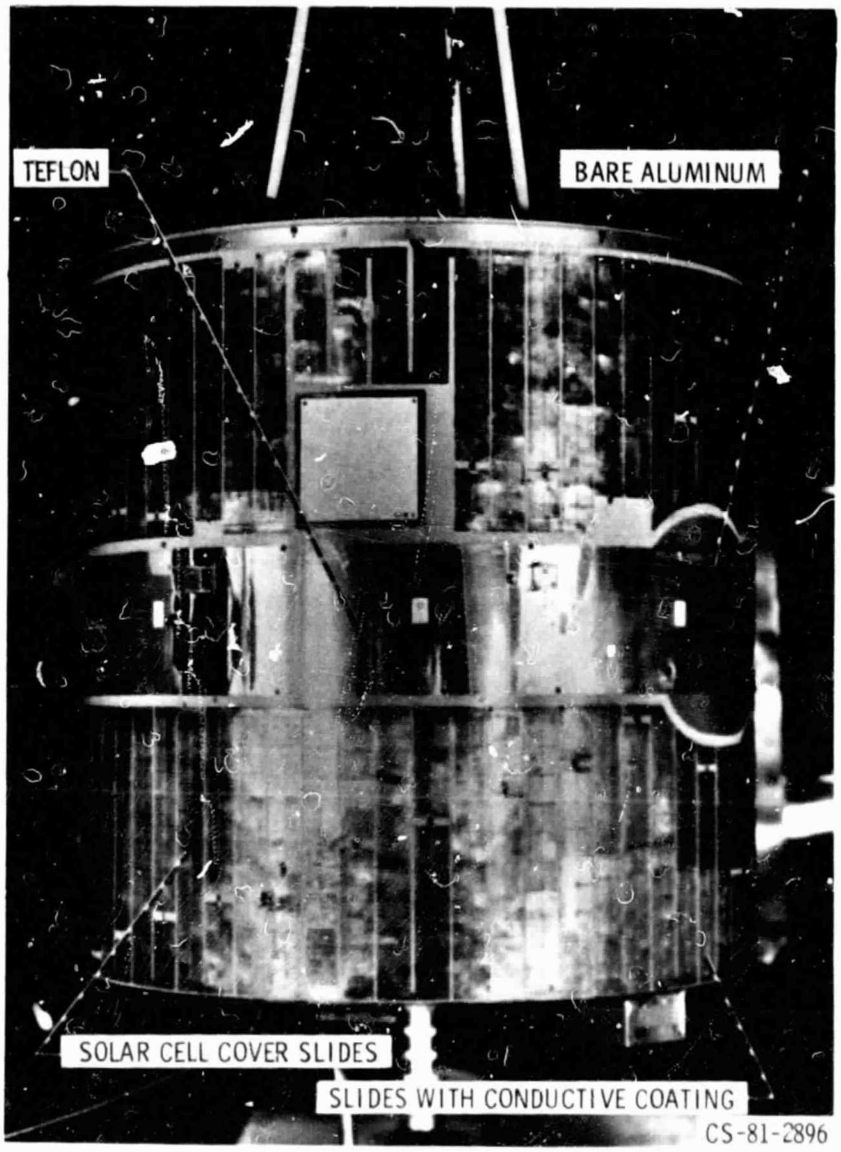

Figure 3. - Close-up of spacecraft model.

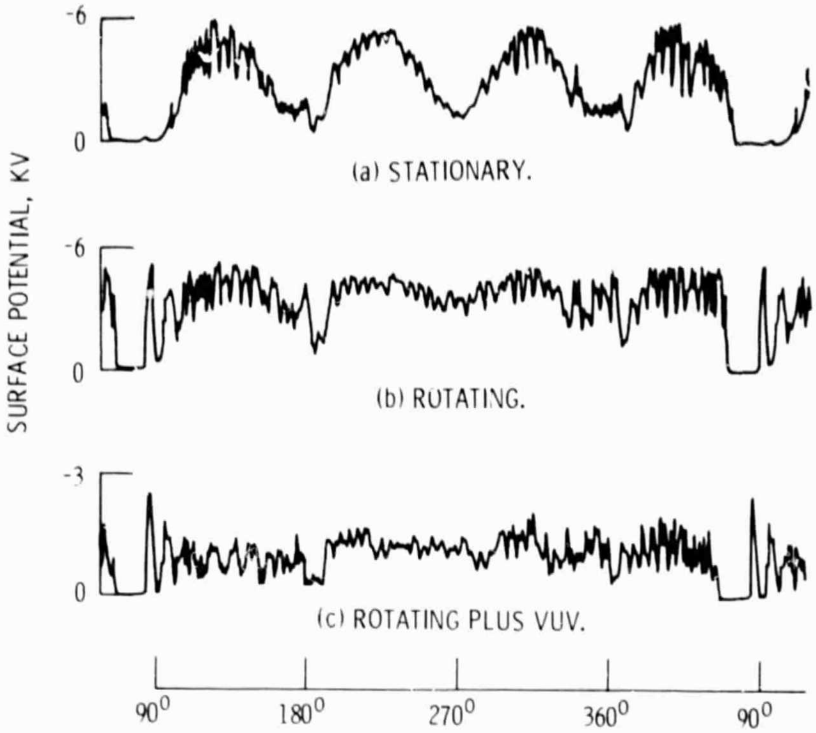

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Figure 4. - Equilibrium surface potential profiles - 8 keV electrons.

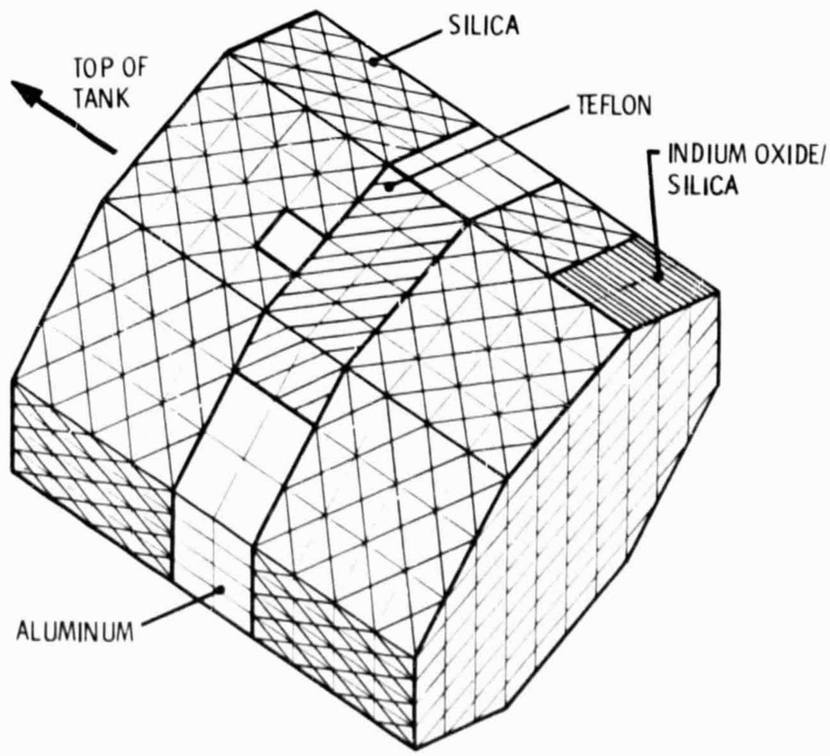

Figure 5. - NASCAP model of SCATSAT.

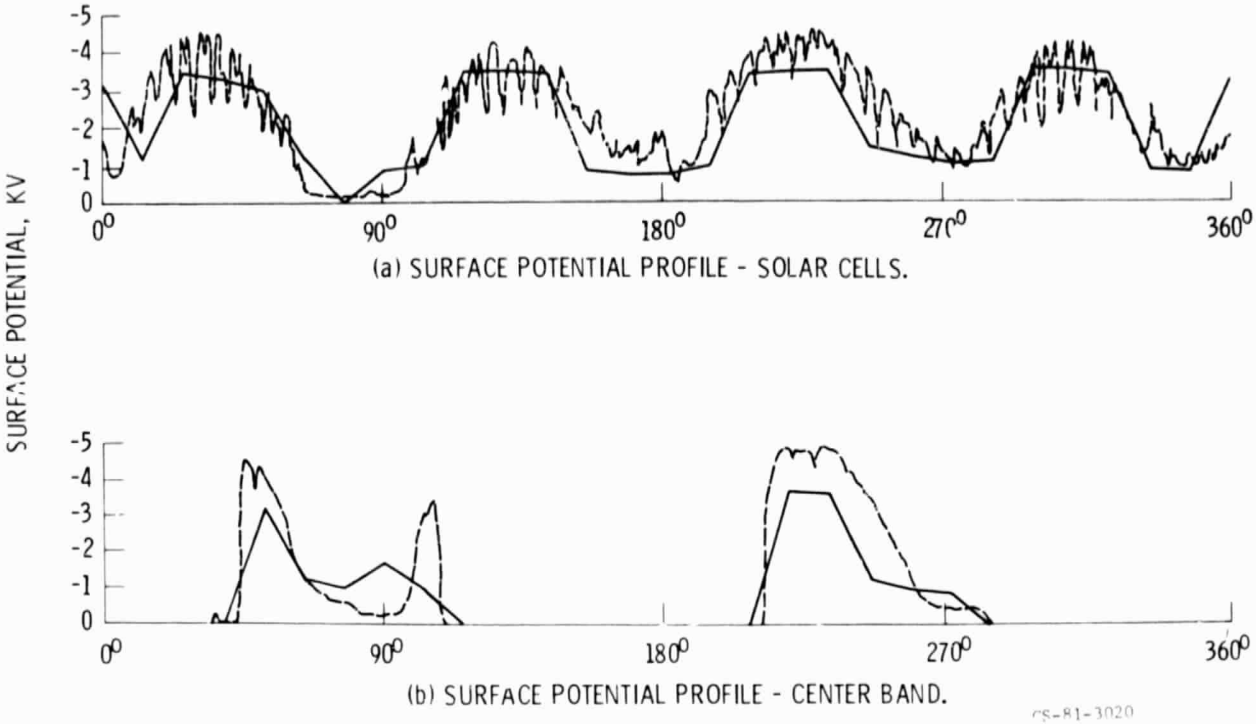

Figure 6. - Comparison of surface potential data to NASCAP predictions.

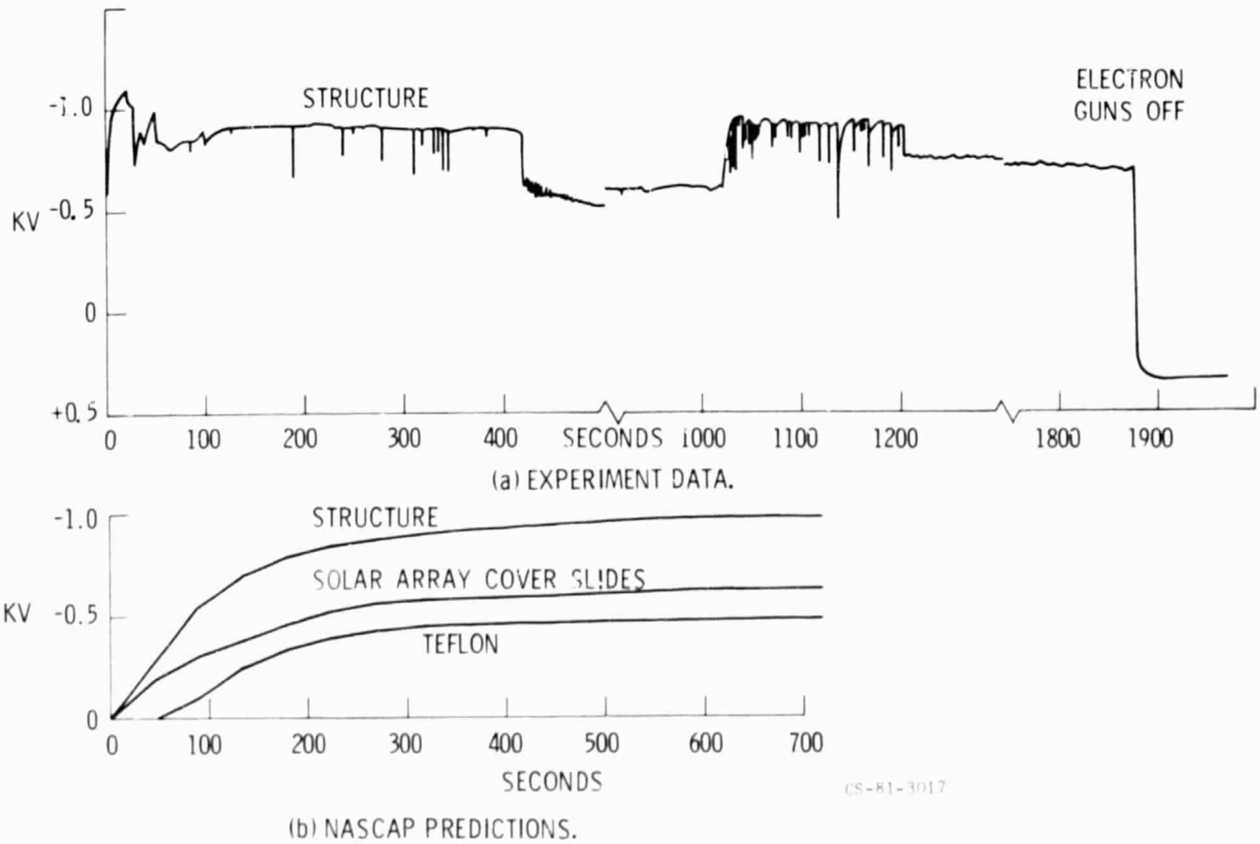

Figure 7. - Spacecraft potentials - model floating - 4 electron guns - 2.5 keV beams.

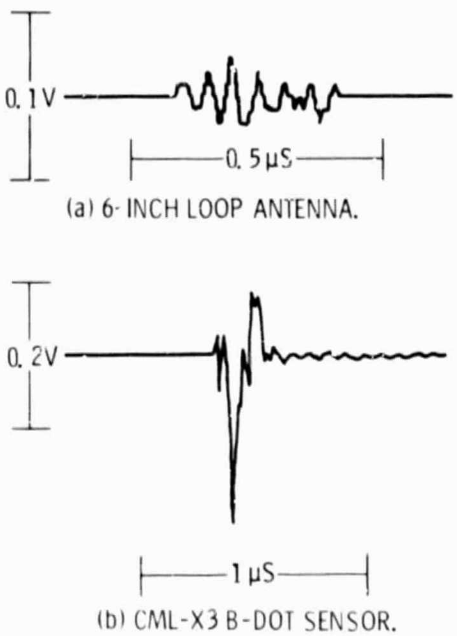

Figure 8. - Responses to discharges.