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6. Active Control of Potential of the Geosynchronous Satellites ATS-5 and ATS-6

Raymond Goldstein
Jet Propulsion Laboratory
Pasadena, California

Abstract

The ATS-6 geosynchronous satellite carries two cesium ion thrusters as part of the technology experiment package. Their effectiveness in controlling the spacecraft potential has been shown during normal operation of the thrusters. The University of California at San Diego auroral particles detectors were used to estimate spacecraft potential, amount of cesium propellant backflow to the spacecraft, and "electron signature" of the thruster. Operation of the thruster clamps the spacecraft to about -10 v in the presence of a wide range of ambient particle flux. Some positive ions from the thruster are returned to the spacecraft during this period. The plasma bridge neutralizer of the thruster is also effective in controlling the spacecraft potential. Laboratory simulation tests of the ATS-5 ion thruster thermionic emitter neutralizer showed that negative differential charging on the spacecraft surface probably prevents the emitter from completely discharging the spacecraft in flight.

This paper presents the results of one phase of research carried out at the Jet Propulsion Laboratory, California Institute of Technology, under Contract NAS7-100, sponsored by the National Aeronautics and Space Administration.

1. INTRODUCTION

The effectiveness of the cesium ion thrusters and their neutralizers carried on the geosynchronous satellites ATS-5 and ATS-6 to control the spacecraft potential under a wide range of environmental conditions has recently been reported.[1, 2, 3] Some variation of these devices is a likely candidate to be used on a spacecraft explicitly for active potential control. It is therefore important to understand details of the operation of these devices and their effects on the spacecraft. For spacecraft conducting scientific measurements, for example, of particles and fields, the question arises as to the direct effect of the discharge device on the measurements. That is, it is desirable to know in what way, if any, the device will contaminate the measurement with spurious contributions. In the following, an analysis of some of the data from the University of California at San Diego auroral particles detectors on ATS-6, taken during operation of a thruster, is described and discussed. It is shown that operation of the discharge device has a marked effect on the character of the measured data.

While the plasma devices on ATS-6 appear capable of clamping the spacecraft potential even during severe environmental conditions, the ATS-5 thermionic emitter has not been entirely successful. The spacecraft usually can only be partially discharged, and even then, the potential generally does not remain constant. In order to understand the cause of these effects, some laboratory simulation studies were performed using a flight spare ATS-5 thruster. The tests and results are described below.

2. ATS-6 PLASMA EMITTER FLIGHT TESTS

2.1 Ion Measurements

The configuration of ATS-6 is shown in Figure 1. The features of interest here include the two ion thrusters, one of which is located on the north and the other on the south facing surfaces on the Earth Viewing Module (EVM). The UCSD detectors are located on the Environmental Measuring Experiment (EME) at the top of the spacecraft. The detector of concern in the investigation discussed here is capable of rotating so as to accept electrons or ions in a N-S almost vertically oriented plane. A 10-m diameter mesh antenna lies between the EVM and EME (approximately 13 m apart). Each of the solar array booms is approximately 17-m long.

During the flight operation of the north-facing thruster in 1974, it was observed that higher than normal count rates were observed in the low energy ion detector channels.[2] Furthermore, during the period of time in which the detector was

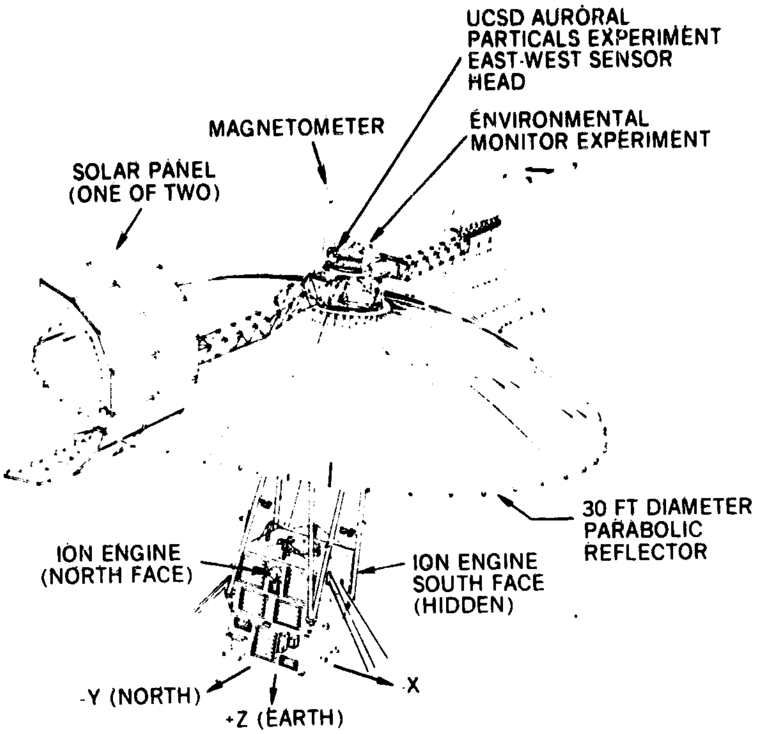

Figure 1. ATS-6 Spacecraft Configuration

rotated, a strong angular dependence of the counts was also observed. In Figure 2, this angular dependence is shown for ions in the 11.8 eV channel, corresponding to the peak in the low energy counts. A strong maximum is seen near the due north (0°) direction, with a weaker maximum near the "straight up" (90°) direction.

The thruster beam was directed downward at an angle of 60° with an energy of 550 eV. Hence, the primary beam ions would not likely travel to the detector, particularly since the local magnetic field was roughly along the beam direction. A more likely source of the ions detected is the cloud of thermal energy charge exchange ions formed near the beam boundary, especially near the thruster exit. These low energy ions are greatly influenced by the electric fields resulting from differential charging on spacecraft surfaces. Whipple[4] has shown in fact, that the solar array surfaces of ATS-6 can often be the order of one or two hundred volts negative with respect to the rest of the spacecraft. In addition, the differential charging also appears to produce a negative potential "well" in the vicinity of the solar panels. Such potentials would be sufficient to attract ions to the upper portion of the spacecraft. In fact, the 0° angle of Figure 2 corresponds to the detector looking approximately at the north solar panel. The data of Figure 2 therefore

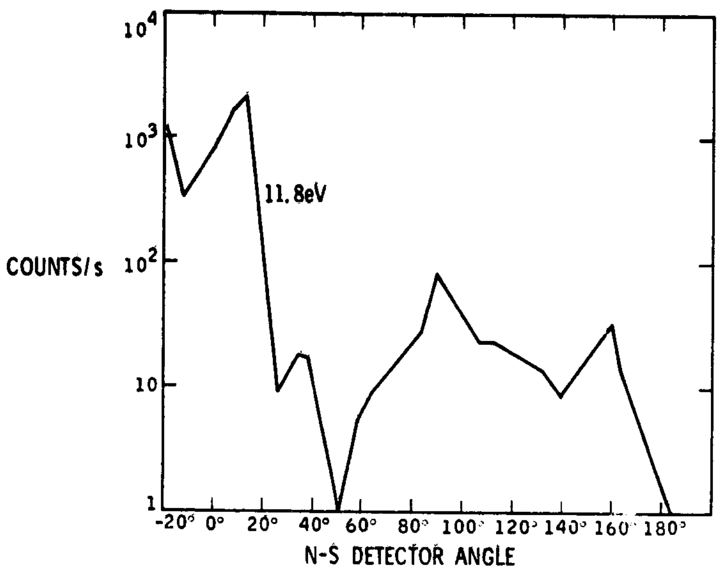

Figure 2. Angular Dependence of 11.8 ev Ion Count Rate During N Ion Thruster Operation on ATS

probably corresponds to low energy ions produced in the thrust beam and then bent around the EME by the negative differential charging and potential well in the vicinity of the solar panels.

Analysis of the energy distribution shows that the low energy ions observed during thruster operation have a peak around 10 eV but have a very nonMaxwellian distribution. Such characteristics are normally not seen in the environmental plasma. This is further evidence that these ions are introduced by the thruster and are not truly environmental in origin. Since the thruster couples the spacecraft to about -10 V with respect to plasma potential, thermal thruster ions reach the spacecraft with energy of 10 eV, explaining the peak measured at that energy. Of course, any low energy environmental ions present would also appear at that potential. However, no low energy environmental ions were seen prior to thruster operation.

Operation of the plasma bridge neutralizer alone is sometimes but not always accompanied by a similar low energy ion peak. These data have not been analyzed in great detail, and it is not understood why this variability exists.

2.2 Electron Measurements

The electron detector normally shows a group of low energy electrons to be present under almost all conditions. These electrons, which peak around 10 eV, correspond to secondaries and photoelectrons produced at the spacecraft and trapped by the negative potential well surrounding it. These low energy electrons persist even during daylight charging events of a few hundred volts negative.[4] During operation of the ion thruster the count rate for these electrons drastically decreases, indicating their ability to escape from the spacecraft vicinity.[2] The character of the remaining low energy electrons is quite different, however, from those without thruster operation.

This difference is shown in Figure 3, where the phase space density (effectively the count rate divided by the square of the energy) is plotted for the low

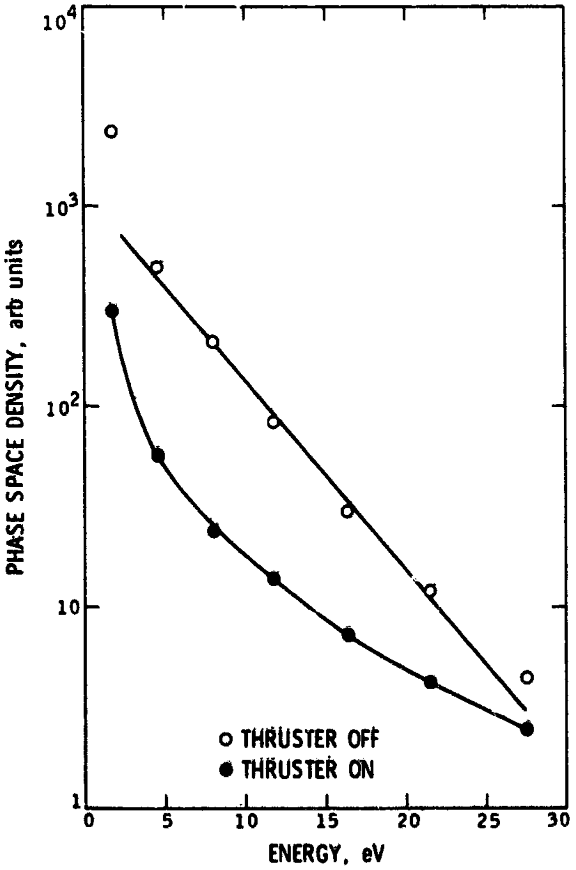

Figure 3. Phase Space Density of Low Energy Electrons Before and During Ion Thruster Operation on ATS-6

energy electrons before and during thruster operation. Note that a Maxwellian distribution should give a straight line, the effective temperature determining the slope. The thruster-off electrons follow a straight line quite closely, indicating a near Maxwellian distribution (temperature ≈ 5 eV). It should be noted that the lowest energy point is subject to relatively large error because of energy scale calibration difficulties. The thruster-on electrons, aside from being fewer in number, show a distinctly different distribution. They are no longer Maxwellian.

It is not likely that electrons from the thruster plasma have arrived at the detector, because of the adverse potential gradients. A more probable explanation is that modification of the potential barrier by the thruster plasma has allowed low energy environmental electrons to reach the detector. Normally these electrons are repelled by the negative potential barrier and do not reach the spacecraft. The electrons detected with the thruster on are thus probably a mixture of spacecraft generated secondaries and true environmental electrons. Since the spacecraft was clamped at -10 V by the thruster, the environmental electrons were retarded in energy by that amount.

Operation of the neutralizer alone has a similar but less drastic effect on measured electrons as does full thruster operation. The neutralizer does not have as significant an effect on the potential barrier.

The thruster operation does not have a clear effect on the angular dependence of the low energy electron counts. Since most of these electrons originate at the spacecraft, this is not surprising.

3. ATS-5 NEUTRALIZER EMITTER LABORATORY SIMULATION TESTS

A series of tests were performed in the Xerox-Electro Optics Systems 2 ft × 5 ft long vacuum chamber to study the characteristics of the ATS-5 thermionic emitter under conditions simulating differential charging on the spacecraft. A schematic diagram of the test setup is shown in Figure 4. A flight spare ATS-5 ion thruster was mounted along the centerline near one end of the vacuum chamber. The end of the thruster protruded through a hole in an electrically isolated metal plate simulating the spacecraft surface. This arrangement resembled closely the actual mounting of the thruster on the (cylindrical) spacecraft. A second metal plate, 2 ft from the first, was used to simulate a plasma sheath or potential barrier. Power supplies were provided to bias the two metal plates as shown. Currents were measured as indicated in the figure.

Power was applied to the thermionic emitter neutralizer appropriate to give 1760^{o}C, the flight nominal temperature of the emitter. With no biasing about 4.25 μa emission was obtained. It was then noted that up to 200 v negative on the

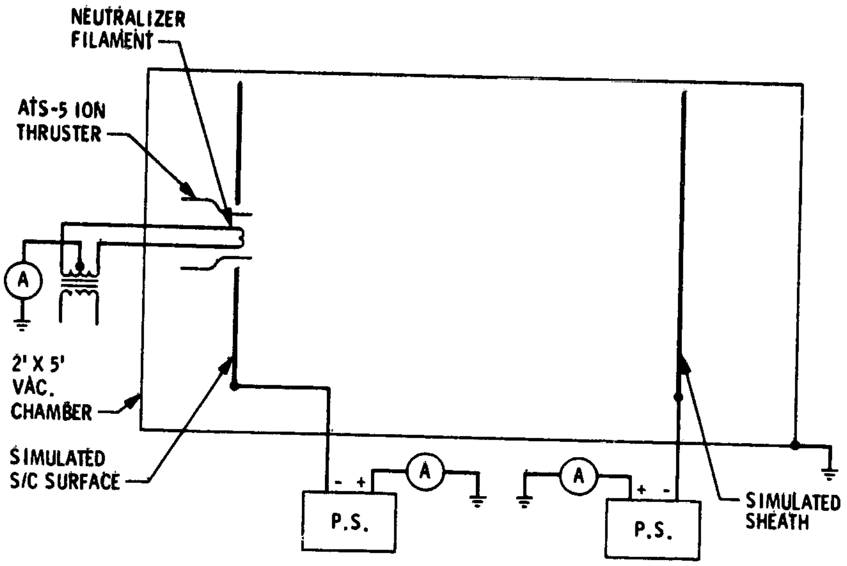

Figure 4. Schematic Diagram of ATS-5 Emitter Laboratory Test

simulated sheath had little (< a few percent) effect on the emission current. However, even a small negative bias on the spacecraft surface produced a marked reduction in the emission current. This effect is shown in Figure 5, which is taken from an X-Y plotter output. The total emission is the total current leaving the filament. For comparison, the current intercepted by the thruster shell (identified as ATS-5 Ion Thruster in Figure 4) is also shown. Note that almost all of the current escapes the thruster and little is returned directly to the thruster body even though the filament is recessed a few inches from the opening.

Differential charging on the spacecraft surface is thus very effective in suppressing emission from the filament. In the case of the flight tests described in References 1 and 2, the spacecraft was charged to a high negative potential in eclipse. Both the surface of the spacecraft (largely covered with solar cells and hence is dielectric) and the frame should be at about the same potential. However, if the filament is turned on the spacecraft frame becomes less negative while the surface remains at the original potential. The filament then experiences a negative differential potential which suppresses the emission, as in Figure 5. The filament is not able to reduce the potential further and the potential may remain approximately constant or increase in magnitude. The details of the environment particle fluxes and energy distribution, as well as the geometry of the spacecraft determine the actual voltage history of the spacecraft during this process.

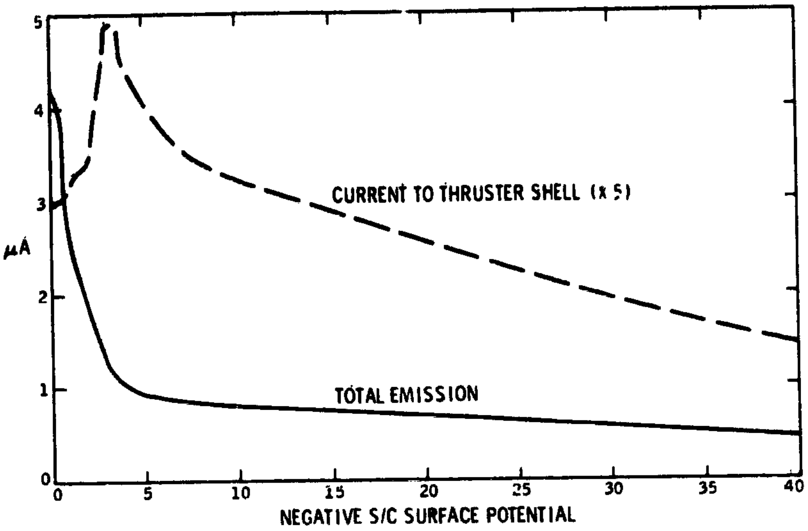

Figure 5. Emission Suppression by Negative Surface Potential

4. SUMMARY AND CONCLUSIONS

The change in character of low energy electrons and ions detected at the spacecraft during ion thruster operation has been examined. The result indicates that use of a plasma device for spacecraft potential control produces a signature at on-board particle detectors. In order to minimize or understand contamination effects a careful calibration, in the laboratory or in flight, would be necessary. In addition, mounting of the discharge device on a boom well away from the spacecraft is probably desirable. Dielectric surfaces, which can cause differential charging, aggravate the contamination problem and should be avoided on the spacecraft.

Laboratory simulation studies have shown that differential charging on spacecraft surfaces is very effective in inhibiting electron emission from the ATS-5 neutralizer filament. This effect prevents the emitter from completely discharging the spacecraft under those conditions, and explains poor results of attempts to control the spacecraft potential in flight. Dielectric surfaces should be avoided for electron emitters to be effective potential controllers. Mounting on a boom away from the spacecraft would also minimize interactive effects.

Acknowledgment

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