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The Experiments of LIPS III

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LIPS III is a member of the "Living Plume Shield" series of spacecraft. In each LIPS project the plume shield, a simple sheet metal cone, was structurally stiffened, and an active satellite was then built around it. The original purpose of the plume shield was to prevent the plume from solid propellent engines, which are fired outside the atmosphere after the aerodynamic shroud is jettisoned, from reaching the primary payload. The surface of LIPS III facing the plume also functioned in this manner, but the anterior surfaces were unaffected, and it was there that all solar arrays, sensors, and experiments were mounted.

The purpose of LIPS III was to provide a test bed for new space power sources. With the long delays projected for schedules of the STS and other major launch systems, it appeared that a decade might pass before long term flight data could be obtained on many new and innovative power sources. The fact that a launch scheduled for early in 1987 required a plume shield was seen as a unique opportunity to obtain some of this data in a timely manner. The paragraphs below will describe the LIPS III system, the experiments placed aboard, and the experiment data acquisition subsystem. Various problems were encountered during integration and after launch; those which appear to effect the accuracy of experimental results will be discussed. The paper will conclude with a preliminary description of the accuracy of the flight experiment data.

The LIPS III System

LIPS III was injected into a nearly circular orbit of 1100 kilometer altitude with inclination slightly in excess of 60° late in the spring of 1987. The planned mission life of LIPS III is 3 years, with hopes of attaining 5 years. As shown in Figure 1, the structure is very shallow, with an outside diameter of 74 inches and a height of only 4 inches. The paddles shown were folded over the annular spacecraft body during launch and subsequently deployed as shown. The spacecraft is spin stabilized with the spin axis pointed toward the sun so that all experiments receive constant illumination. The concentrator experiments on LIPS require both accurate alignment to the sun and the means to optimally radiate waste heat to space. To meet the sun pointing requirement the error between the spin vector and the sun vector was limited to ±0.5°. These sun pointing needs also required careful alignment of the paddles, on which the concentrators were mounted, so that in their deployed configuration they would remain perpendicular to the spin vector. The waste heat rejection requirement was met by mounting the concentrator experiments over holes cut in the paddles for this purpose, allowing a clear view of space for radiation from the back (nonilluminated) surfaces. The shallowness of the LIPS structure was a distinct advantage here, since it eliminated any radiative interaction between the spacecraft body and the concentrator waste heat radiators.

The spacecraft EPS is powered by five silicon solar panels generating 25 watts (BOL). This solar array drives an unregulated bus operating at 14.5v ±2v with a 6 A-H NiCd battery for storage. The telemetry system encodes an analog voltage of 0.0 - 5.1 volts into an 8-bit word. This data is transmitted via an L band downlink at a rate of 2441 bits/second, and includes both housekeeping information and experimental data. The telemetry frame rate, the time required for every quantity in the telemetry list to be sampled once, is 0.2228 seconds. No provision was made for on-board data storage, so data can only be obtained in real time when the spacecraft is in view of a tracking station.

The thermal control system is an all passive design, with multilayer thermal blankets covering most of the satellite surface. The paddles were not blanketed, but were coated with silver-teflon tape. The blanket on the non-illuminated side of LIPS provided freedom for thermal properties of the outer blanket surface to change markedly during impingement of the plume without affecting subsequent thermal performance. A number of experiments were mounted on standoffs over the blanket on the illuminated (clean) body surface, thus limiting their ability to radiate thermally from their back surfaces. For this reason, many of the body mounted panels are operating at higher temperatures in sunlight (80° - 100°C), compared to those on the paddles which operate at lower temperatures ; i.e., 20° - 50°C.

The operation of the attitude control system (ACS) will now be sketched. For a detailed survey of the design and operation of the ACS, see Ref. 1. This system was designed to operate in two modes. At orbit injection, the spacecraft was expected to be spinning at 30 RPM with its spin vector pointed 120° from the sun vector. A hydrazine thruster was designed to be pulsed each time the spacecraft rotation put it in the appropriate position to reduce the angle between sun and spin vectors. The pulse timing is determined from a wide angle sun sensor with a "fan shaped"field of view (FOV=4° x 180°). This sun sensor was mounted on the outer edge of the spacecraft with the plane of the "fan" containing the spin axis. As LIPS rotates the fan sweeps across the entire celestial sphere and when the sun crosses the field of view, the angle between the spin and sun vectors is measured. From the time between consecutive measurements, the next hydrazine pulse time is calculated. Once the spin vector was brought within five degrees or less of the sun, the second mode of operation began which relies on a magnetic interaction to control attitude. A solenoid [ref. 2] was mounted in the spacecraft so that when a pulse of current flowed through its windings the resultant dipole moment was perpendicular to the spin axis. This dipole couples to the earth's magnetic field to generate a torque on the spacecraft which will change the spin rate if the torque is parallel to the spin vector, or change the spin vector direction if the torque and spin vector are perpendicular. Thus, depending upon the instantaneous direction of the earth's field, either spin rate or direction (or both) can be changed, and thus controlled. To implement this magnetic control system, a three axis fluxgate magnetometer and a fine angle sun sensor were placed aboard the spacecraft. The design ensured that measurements of the earth's magnetic field are accepted from the magnetometer only when the solenoid is not energized. The fine angle sun sensor has a useful field of view of 5° with a resolution 0.05° . Since this magnetic control system is currently operating with errors $\leq 0.1°$, we plan to rely on this mode of operation for the remainder of the mission.

The Experiments

With the exception of a study of material properties of selected thin films submitted by Martin Marietta Company, all of the experiments aboard LIPS III were photovoltaic in nature. It is unfortunate that the small size of the spacecraft and very tight schedule precluded integration of other types of energy conversion experiments, such as solar dynamic systems. As can be seen from Table 1, experiments were submitted by 18 laboratories involving cells of silicon (both crystalline and amorphous), GaAs, AlGaAs, InGaAs, and $CuInSe_2$. One of the primary goals of the LIPS III effort was to realistically test photovoltaic concentrators in space; there are three concentrator concepts represented on LIPS III. In all, 140 separate I-V characteristics are measured. These span short circuit current values of 1.2×10^{-3} amps up to 2.0 amps, with open circuit voltages varying from 0.35 volts to 6.0 volts. Temperatures are sensed by measuring the resistance of a sensor, and including resistance values of the non-photovoltaic thin film experiment from the Martin Company, resistances from 40 ohms to 24 megohms are measured. These experiments are housed on some 30 panels or fixtures, nearly all manufactured by the experimenters and integrated by NRL.

It should be pointed out that the LIPS experimenters met an extremely tight schedule, building and testing their experiments in a time so short that many had no chance to obtain official support for their efforts from their respective managers before starting work. Integration meetings were usually held by telephone and telecopier. Throughout this hectic time, high standards of workmanship were adhered to as evidenced by the almost complete success (to date) of the experiments.

Data Acquisition Plan

Provision was made for measuring the current-voltage (I-V) characteristics of each experiment both in sunlight, and the forward characteristic in darkness for those experimenters requesting it. A four terminal measurement was planned so that only very small currents would flow in the pair of wires monitoring voltage. Due to the large number of experiments, the grounding scheme became quite complex, so that one half of the experiment current is inadvertently permitted to flow in the voltage ground lead. Since this is a short (length ≤ 2 ft.) AWG#22 wire, the resulting underestimation of cell voltage was deemed unimportant. A given I-V curve is measured by varying a dynamic load through 24 points, measuring current and voltage values of each point. One value each of voltage, current, and temperature sensor resistance are measured simultaneously during each telemetry frame. The illuminated measurements were made in the following way:

a. First, the open circuit voltage of the cell is measured and the value is stored.

b. Next, the short circuit current is measured by driving the dynamic load to zero. The cell is slightly back biased to compensate for line losses between the cell and dynamic load.

c. Once I_{sc} is measured, values of voltage are selected at which the current is to be measured. The voltage points were planned to form an ascending array of values which steps out across the I-V curve from short circuit to open circuit. The target voltages are chosen in the following way: V_{oc} is divided into three parts, as shown in Figure 3, corresponding to three regions of the I-V curve; region one runs from 0.0 volts to 0.4 V_{oc}, and corresponds to the low voltage region of approximate constant current operation. Region two runs from 0.4 V_{oc} to 0.65 V_{oc}, well into the "knee" of the curve. The third region, running from 0.65 V_{oc} to V_{oc}, represents the region of rapidly falling current as the open circuit condition is approached. Region I is divided into four equal segments, region II into five equal segments, and region III into fourteen. The ends of these segments are the voltage values targeted for measurement. After each desired voltage value is calculated, the dynamic load is varied until the experiment operating voltage is equal to the calculated value. To improve resolution of the voltage measurement, two possible gain settings are provided, and the most appropriate setting is automatically selected for each measurement.

d. With the voltage value set, the current is measured. Since the experiment currents span such a wide range, there are seven possible gain settings for current measurement. An autorange circuit selects the gain giving the best resolution, and this gain setting with the analog values of current, voltage, and voltage gain are then available for telemetry.

e. The resistance of the appropriate temperature sensor is measured for every current-voltage point. This much temperature data is overkill, but it was quite inconvenient to do this any other way. In this way, 24 points (including I_{sc}) are measured for each I-V curve, the last point being V_{oc}, according to plan at least. Actual operation in orbit will be described in the next section.

The dark forward I-V characteristic is measured in a very similar way, except that the maximum voltage was chosen by the experimenter and stored in a ROM on the spacecraft. The 24 points are evenly spaced between V=0 and V_{max}

There are three data channels each of which make the above measurements independently. These can each be turned on or off by ground command. Each channel has a compliment of up to 64 experiments through which it steps and a counter to indicate which experiment is being measured at any given time. Unfortunately, the values of these three counters were not included in the telemetry list. A master counter is included however, which can indicate the current status of each multiplexer. When this master counter runs through its complete sequence, it resets and issues a reset pulse that forces all of the data channel counters to reset, so thereafter, they are all in sync with the master counter. This causes some operational complexity since when a data channel is commanded on, the master counter must then be reset before any of the data is meaningful. As discussed in the next section, considerably more serious problems result from unreliable master counter readings.

Problems Encountered With LIPS III

Several problems effecting the collection of experimental data appeared during final integration and after launch. Some of the more serious difficulties which have not yet been completely resolved will be discussed below:

a. Dust Buildup: During final integration LIPS was mechanically attached to the primary payload with the axis of symmetry vertical, LIPS on the bottom, and the body mounted experiments looking upward. This configuration was maintained throughout transport to the launch site, mating with the launch vehicle, and subsequent launch. Now after complete assembly at the launch pad, the finished vehicle waited for a number of weeks before launch, and during this time a robust stream of cooled and filtered air flowed down over the primary payload and LIPS. LIPS was below a very complex spacecraft structure so that gravity, assisted by the air flow, would bring any loose particles to the LIPS surface on which experiments were mounted. A considerable buildup of dust was observed on this surface shortly before launch, but a comprehensive cleaning would have required removal of the aerodynamic shroud, causing an intolerable launch delay. Samples of the dust were collected through a small access door and studied. The particle size varied widely from a few up to several hundred micrometers, and because of this wide variation, obtaining reliable particle counts was complicated. The samples were studied under a low power microscope producing counts of particles 10 micrometers and up. Densities of these larger particles were between $5/cm^2$ and $100/cm^2$. Among the debris there were bits of thread, particles of a red substance resembling RTV, and a few metallic appearing species which might have been chips of solder. The difficulty of sample collection precludes making a meaningful quantitative estimate of density, but observers reported that the dust layer appeared thick enough to allow "writing a name in it with one's forefinger." The effects of this dust coverage might well be partially mitigated by several factors. First, the paddles were folded during accumulation so that dust would have collected on the paddle surface not illuminated after deployment. During launch, the entire spacecraft is subjected to vibration. After the aerodynamic shroud is jettisoned, the entire assembly is spinning at approximately 30 RPM when the third propulsion stage is fired. After separation, the paddles are deployed producing a mild shock, once again while the spacecraft is spinning. Since the dust did not appear oily and was seen to brush off easily in the small areas available through the access doors, it is hoped that centrifugal force, in conjunction with vibration, removed many of the particles. Those experiments which were mounted on the LIPS body (instead of one of the paddles), and which were not covered by a paddle in the folded, pre-launch position are the most likely to be affected by the dust. Some of these experiments do show low short circuit currents which might be attributed to this problem. However, several other experiments mounted in this way show no adverse effects.

b. Voltage Offset Problem: Twenty-four hours before final integration of the LIPS spacecraft with the primary payload, it was discovered that voltages as reported by telemetry occasionally varied by up to 10%, as if a very low frequency signal of unknown origin was present. This effect was unmistakable during a test of experiments with all three data channels turned on simultaneously. The data taken during this test was essentially gibberish. This effect is greatly reduced when only one data channel is turned on, so it is in that mode that experimental data has been gathered ever since. The effect can be seen from Figure 4 where bus voltage (which is equal to solar array voltage) is plotted with solar array current. It is seen that both the current and the voltage fall simultaneously, which cannot happen for a photovoltaic device. At the same time, temperatures of large components such as the battery vary with identical time dependence. All this could be explained if a ground potential were varying, but considerable analysis has not produced a plausible explanation for such a variation.

Though the effect on housekeeping data can be severe, it is most fortunate that the effect on the quality of experimental data is small or zero when only one data channel is on. The measurement of small resistance values does seem to be effected occasionally, but overall the values returned for currents and voltages do not seem to drift when the effect is evident in housekeeping data. Recall, however, that only a small amount of flight data has been studied to date.

c. Spacecraft Attitude Determination: A primary requirement was the collection of as much experimental data as possible during the first week after launch, especially in the first 24 hours, for the purpose of firmly establishing an initial operating point for each experiment. Now when the spacecraft first came in view of the tracking station shortly after launch, we expected to see an attitude error of about ten degrees and the ACS operating in mode 1 with the hydrazine thruster continuing to reduce that error. Instead, we observed a nutation of the spin vector in excess of twenty degrees which made the hydrazine thruster ineffective or occasionally detrimental in reducing the error. It required almost two weeks to solve this problem and achieve stable, high accuracy sun pointing of the spin vector. During the first week of operation considerable experimental data was gathered, but to sensibly reduce it, accurate knowledge of the rapidly varying spacecraft attitude was needed. Much effort has been expended to achieve this, without, as yet, producing suitable results. We have two sun sensors aboard, neither of which are useful for attitude determination with a large nutation angle. The small angle sun sensor saturates at approximately 5°, as shown in Figure 5. The wide angle sensor with the "fan" shaped field of view records the sun angle, but the time of that measurement is not known, and as the following paragraph shows, ignorance of the time of measurement makes this data nearly useless.

The solar array was designed to operate at voltages considerably less than that for maximum power at BOL. In fact, the array closely approximated a constant current source during the first week in orbit. With knowledge of the array temperature (which was measured and included in telemetry), variations of the current due to changes in sun angle can be isolated. In short, we have a crude sun angle sensor in the solar array, the current being proportional to the cosine of the desired error angle. The period of the LIPS spin rotation is denoted by T_{spin} in Figure 6, which shows solar array current as a function of time. The nutation of the spacecraft is obvious, and turns out to have a period almost exactly 1/2 that of the spinning motion. The information from telemetry will determine that some time during T_{spin} a measurement of sun angle was made by the wide angle sensor, and it will report the value of that angle. It is clear from Figure 6 that the spacecraft motion is far too rapid for the wide angle sensor to be of use. It should be noted that no evidence of the voltage offset phenomenon was seen in the data of Figure 6. What is seen there is due only to the complexity of the LIPS motion. The solar array current itself could provide an estimate of the angle, except that this variable is susceptible to the voltage offset problem (see Figure 4). There are numerous statistical means for detecting a variation of this type, a number of which were tried. The difficulty in isolating (and hopefully algebraically removing) the offset signal results from the fact that we have only four data points per nutation period. This is close to the nyquist limit, making data recovery uncertain. The magnetic field measurement could be included with the solar array current to improve an estimate, but these measurements of the earth's field are themselves affected by the offset problem, though to a smaller degree than the solar array current. The combination of solar array and magnetic data still offer some hope of satisfactory attitude determination.

Taking a different approach, the data was searched for points during the spacecraft gyrations at which the fine angle sensor was not saturated. If these occurred often enough, they might well be used to recalibrate the solar array current to provide useful data. The fine angle sensor gives no indication when it is in saturation, however, as shown from the high angle "wings" in Figure 5. A telemetry voltage of, say, three volts could indicate an angle of -2° , or -10° or less. Upon discovery of this fact from study of the telemetered data, the effort to reduce experimental data from the first week of operation was postponed.

Several other problems have occurred but have been suitably resolved. The most worrisome of these was the occasional unreliability of the master telemetry counter. Recall that, after the experiment counters in the data channels are forced into synchronization with the master, it is the value of this master counter from which we infer the identity of the experiment currently being measured. If the master counter "jumps" rather than incrementing its count by one at each reading, identification of all subsequent data in that run can be confused. It is most fortunate that the types of errors experienced are not too numerous, so that a program can be written to test for all of them. This has been satisfactorily implemented without the loss of great amounts of data.

Preliminary Assessment of Data Quality

Approximately fifteen percent of the data gathered to this point has been analyzed, but already some generalizations can be made. First, the goal of measuring the entire I-V curve from short circuit to open circuit conditions was not achieved, since a measurement of V_{oc} is almost never made and I_{sc} is rarely obtained. It seems that the data acquisition system has stability problems when either the voltage or current of the cell operating point is driven to zero. Secondly, the accuracy of current and voltage measurements seem to be more accurate for those experiments with larger short circuit currents. Short circuit and open circuit conditions are also more nearly approached for the larger current experiments. A method has been devised by G.F. Virshup [ref. 3] for estimating V_{oc} from the raw data. Recall that target voltage values for measurement were calculated from V_{oc}. By observing the differences between actual voltages measured and comparing them with the scheme described in Figure 3, the starting value of V_{oc} can be estimated. As pointed out in the next paragraph, caution should be exercised since the process of target voltage selection is often unstable. Shown in Figures 7-10 are results for the silicon witness cells of LIPS. These figures depict early flight data adjusted to 135.3 mw/cm^2 and 27°C compared to the results of preflight measurements made with an X-25 solar simulator before the experiments were integrated with the spacecraft. These figures show a fair representation of the data quality and its variation among experiments.

If the voltage offset problem were seriously affecting the current vs voltage data, it would be of much lower quality than what is shown here. The offset problem, along with other noise sources does appear to have a serious effect on the selection of target voltages at which current is to be measured. Recall from Figure 3 that the target voltages should have started at 0.0 and increased monatonically up to V_{oc}. The values actually selected by the data acquisition system are often out of order, and do not show the regular progression of values as planned. We believe, however, that once a voltage is selected, the resulting current measurement is not effected by this noisy environment, and that the values reported are of reasonably high quality.

The measurement of temperature is, unfortunately, not as accurate in some cases. First, the digital quantization noise is quite high for some experiments, and disastrously high for one, indicating a failure in integration of the experiment with LIPS. This effect can be seen in Figure 8, where there is a considerable difference in voltage between the flight and preflight data. A change of the least significant bit here amounts to a temperature difference of 15°C. Thus, our knowledge of that temperature is imprecise and the adjustment of flight data back to 27°C is inaccurate. This is the most likely reason for the voltage discrepancy in Figure 8. It also appears that the offset problem does occasionally effect the measurement of resistances, especially the small values. This is most pronounced whenever the current or the voltage that is simultaneously being measured is zero. Figure 9 shows what may be evidence of the dust problem. Observe that flight values of current at lower voltages are uniformly low, but the flight data and preflight measurements approach each other as we approach V_{oc}.

Conclusion

The discussion above has dealt in some detail with the problems of LIPS III. Although mistakes were made and satellite operation is not according to plan, the quality of the flight data is, in general, quite good. Almost all photovoltaic technologies for space (circa 1987) are represented on LIPS and, with the exception of four temperature sensors and two cells, the large number of experiments here survived integration, launch, and the first six months of flight operation. Thus, a preliminary assessment can be made that, overall, LIPS III with its compliment of experiments, is a success.

The effort to design, fabricate, and test LIPS III was made difficult by the short time available for the task. Many people made outstanding efforts under the most trying of circumstances, without which success would have been impossible. All of the coauthors of this paper played essential roles in this project and are due much credit. The long list of those who contributed experiments is one of true distinction. Of particular importance to the spacecraft in general were the contributions of experimenters Ted Stern, Micky Cornwall, Allan Dollery, Christopher Goodbody, and especially

Gary Virshup. Members of the NRL staff whose efforts were exemplary are far too numerous to be listed here, but, aside from the coauthors, this paper would be incomplete without expressing special thanks to Robert Burdett, command system design and flight computer "Guru", Christopher Herndon, AGE design, Mark Johnson, telemetry design, David Hastman, thermal design, George Gregory, mechanical layout and design, Robert Morris, RCS design, Christopher Garner and Wilbert Barnes, NiCd Battery, Charles Morgan, ordinance design, William Webster, RF design, Joseph Valsi, wiring layout, Eric Eisler, RCS valve control design, Michael Mook, ACS system, Robert Conway, tracking station operations, Robert Grant and James Mills, system test conductors, and Joseph Delpino, launch integration specialist.

References

[1] Robert H. Towsley, David A. Hastman, and Michael Mook, "LIPS III: An Effective and Existing 'Lightsat' ", AIAA/DARPA Meeting on Lightweight Satellite Systems, August 4-6, 1987, Monterey, CA.

[2] The solenoid used was a "TORQROD", a lightweight, flight qualified unit manufactured by Ithaca Corporation, Ithaca, NY.

[3] G.F. Virshup, and J. Werthen, To be published in the proceedings of the Twentieth IEEE Photovoltaic Specialists Conference.

Table 1

GaAs, AlGaAs, InGaAs	
Applied Solar Energy Corp	2cm x 2cm and 4cm x 4cm GaAs Cells: GaAs cells on Ge substrate - four cells in series
AFWAL/POOC-2	CRRES Ambient Panel (Backup) - 10 four-cell strings comparing coverslips, coatings, and adhesive
Boeing	Small Area "Concentrator" Cells: LPE (Spectrolab); MOCVD (ASEC); MOCVD (Kopin)
CNRS (France)	MBE GaAs - two cells; LPE InGaAs - two cells
MBB (Munich, FRG)	Two cells (MELCO)
Royal Aircraft Estab. (Farnborough, Hants, UK)	Four cells in series (MARCONI)
Spectrolab	Two GaAs (Spectrolab) and two AlGaAs/GaAs (HRL)
VARIAN	GaAs, AlGaAs - nineteen cells in all: InGaAs under inactive AlGaAs; AlGaAs grown on inactive InGaAs
Martin Marietta Astronautics Group	MOCVD GaAs - compares welded and soldered interconnects
Single Crystal Silicon	
AEG (Wedel, FRG)	Bifacial Cell Array - four 5cm x 5cm cells; Two very light weight support structures tested
Applied Solar Energy Corp	2 mil Cells (2cm x 4cm)
AFWAL/POOC-2	Integral Coverslip covering eight cells; Gallium Doped Silicon Cells
Boeing Co.	Four cells with high temperature contacts ("Burst" Annealable)
MBB (Munich, FRG)	Five advanced design cells
NRL/Solarex	Six Vertical Junction Cells (Comparing various coverslips & adhesives); Advanced Design Planar Cells
Royal Aircraft Estab. (Farnborough, Hants, UK)	Four cells comparing coverslips & coatings; Two designs for high radiation resistance
Spectrolab	Two advanced design cells
InP	
Royal Aircraft Estab. (Farnborough, Hants, UK)	Four cells fabricated by Newcastle University
NASA-LeRC	Four cells fabricated by Rensselaer Polytechnic
Thin Film Cells - CuInSe$_2$ and Si	
Boeing Co.	Three series strings of four CuInSe$_2$ cells each
Sovonics	Two α Si Cells
Solarex	Two α Si Cells
Concentrators	
Boeing Co.	Six light funnels
General Dynamics	Three Slats Modules, Six I-V curves
TRW MiniCassegrainian	Three Lightweight Modules (NASA); Two Hardened Modules (AFWAL)

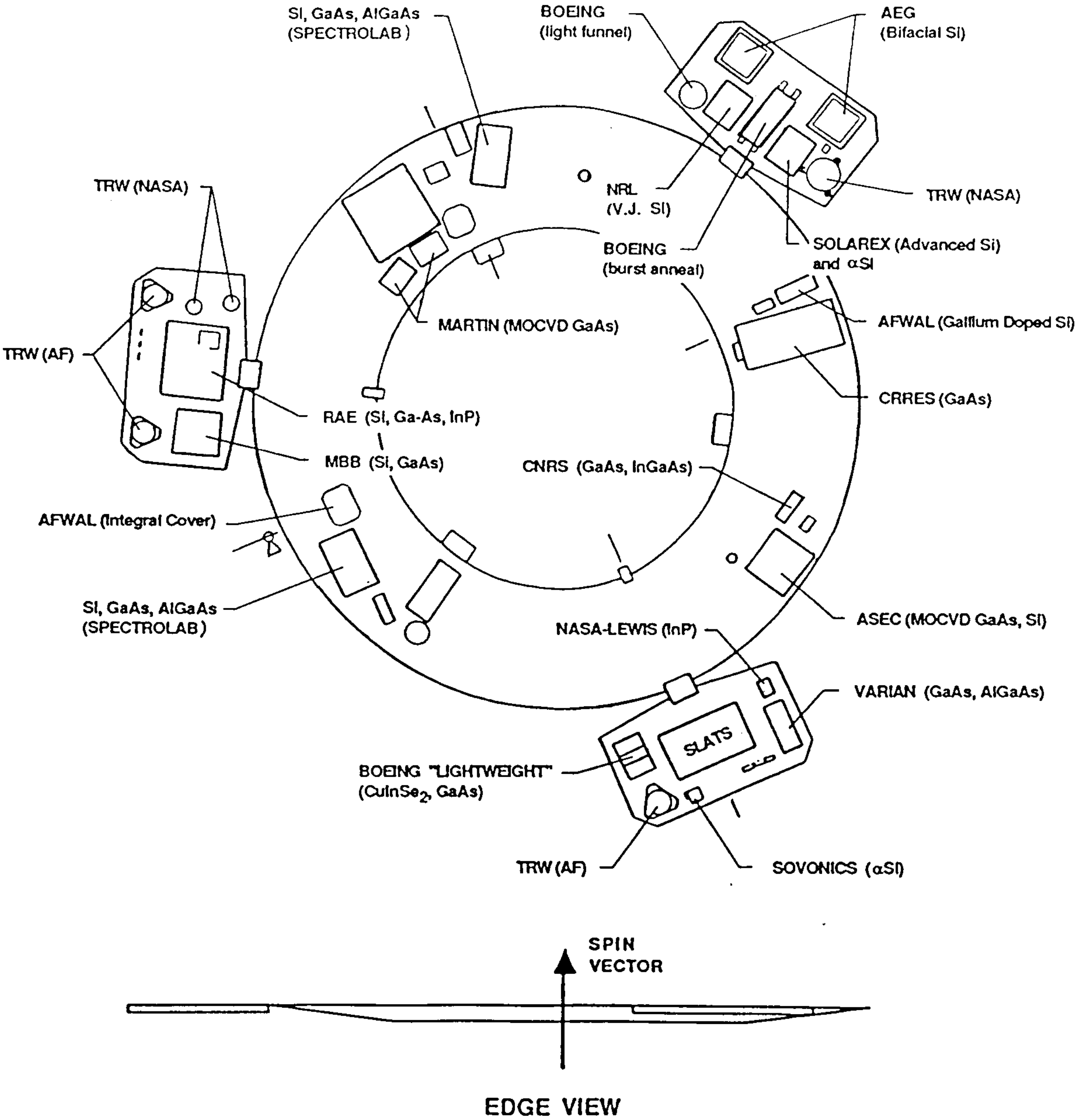

FIGURE 1
LIPS III EXPERIMENT LAYOUT

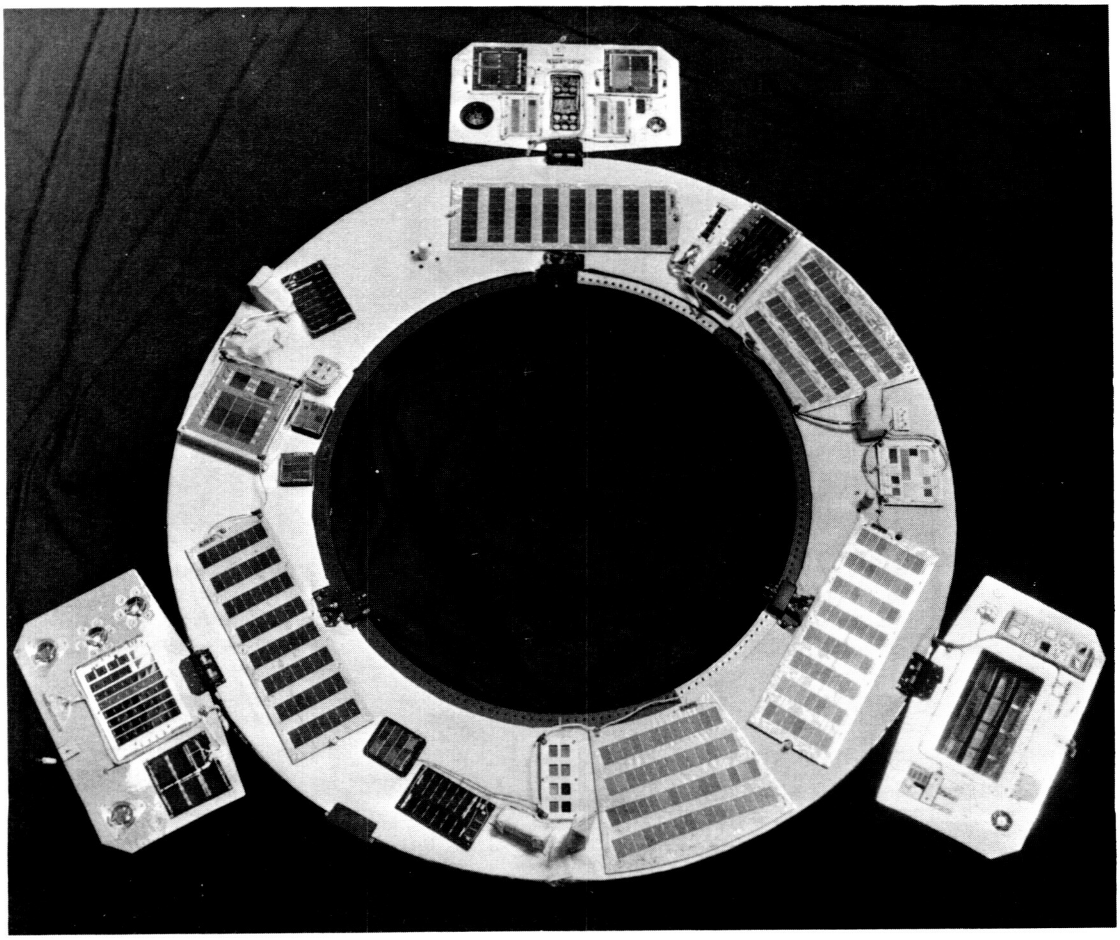

FIGURE 2
LIPS III PADDLES IN FLIGHT CONFIGURATION

ORIGINAL PAGE
BLACK AND WHITE PHOTOGRAPH

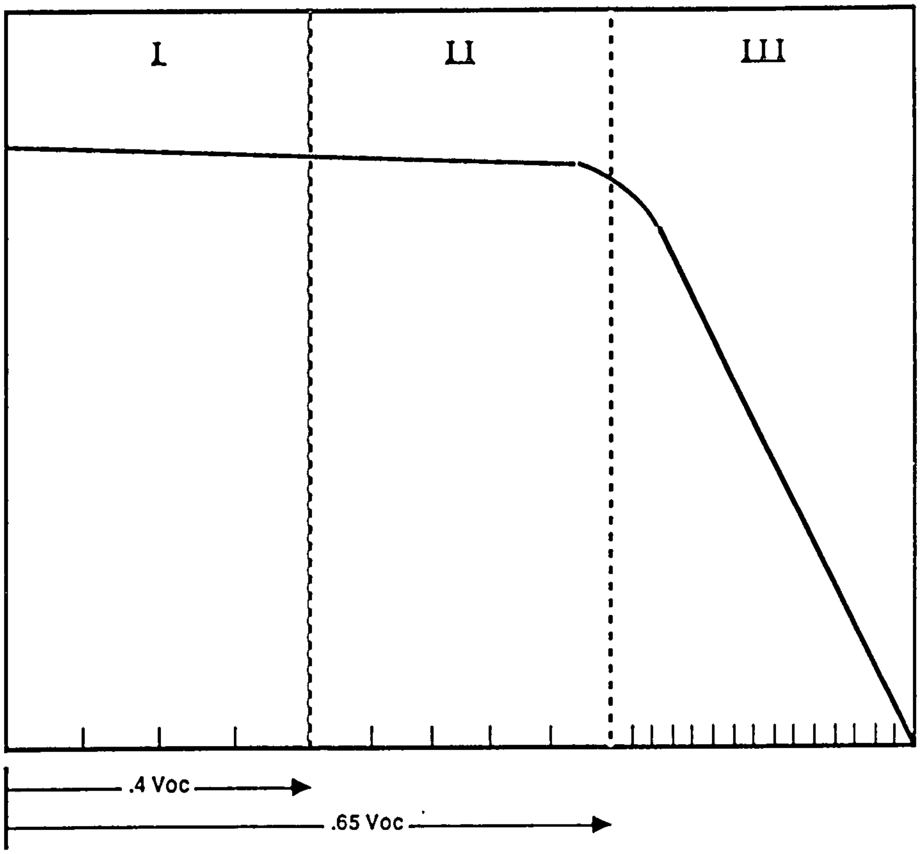

FIGURE 3
TARGET VOLTAGE POINT SELECTION

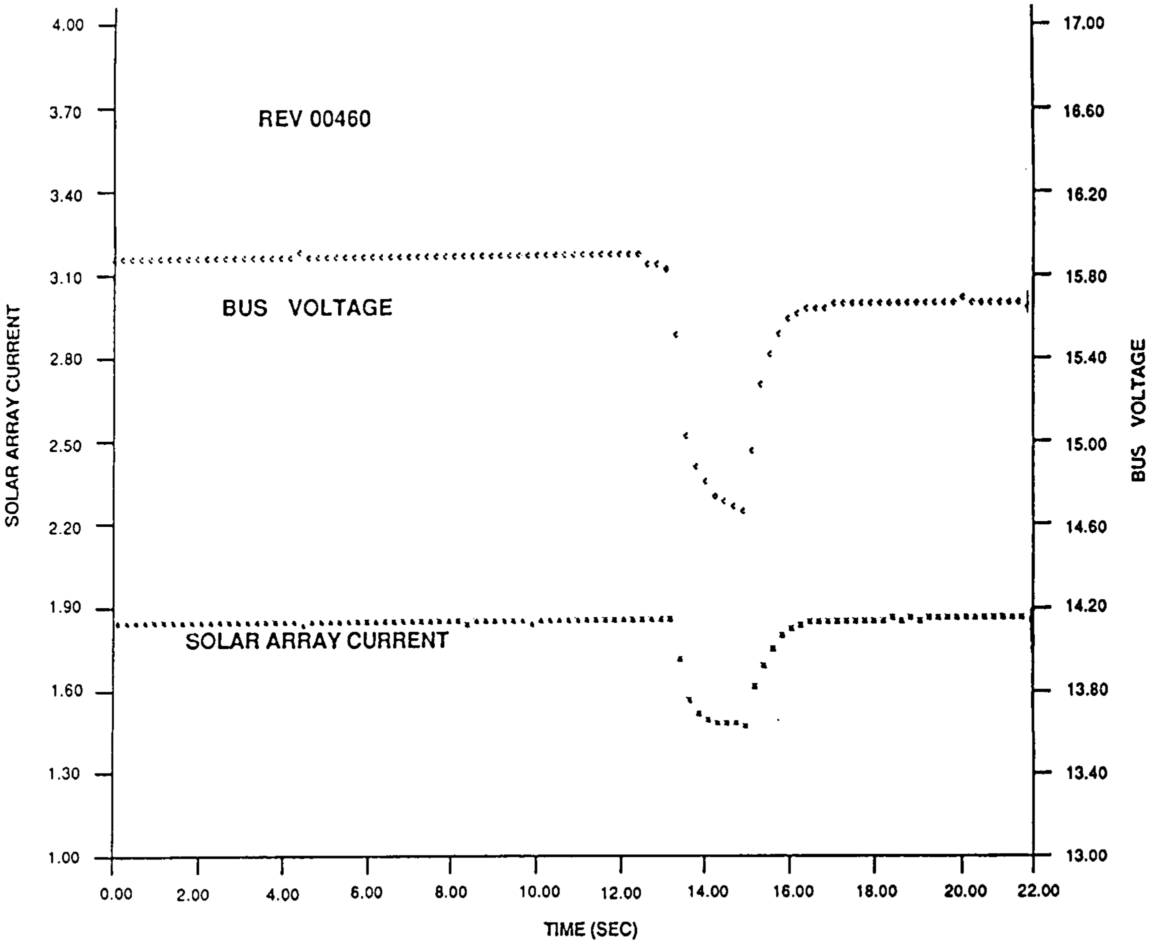

FIGURE 4
BUS VOLTAGE and SOLAR ARRAY CURRENT SHOWING VOLTAGE OFFSET
SPACECRAFT ATTITUDE VERY STABLE

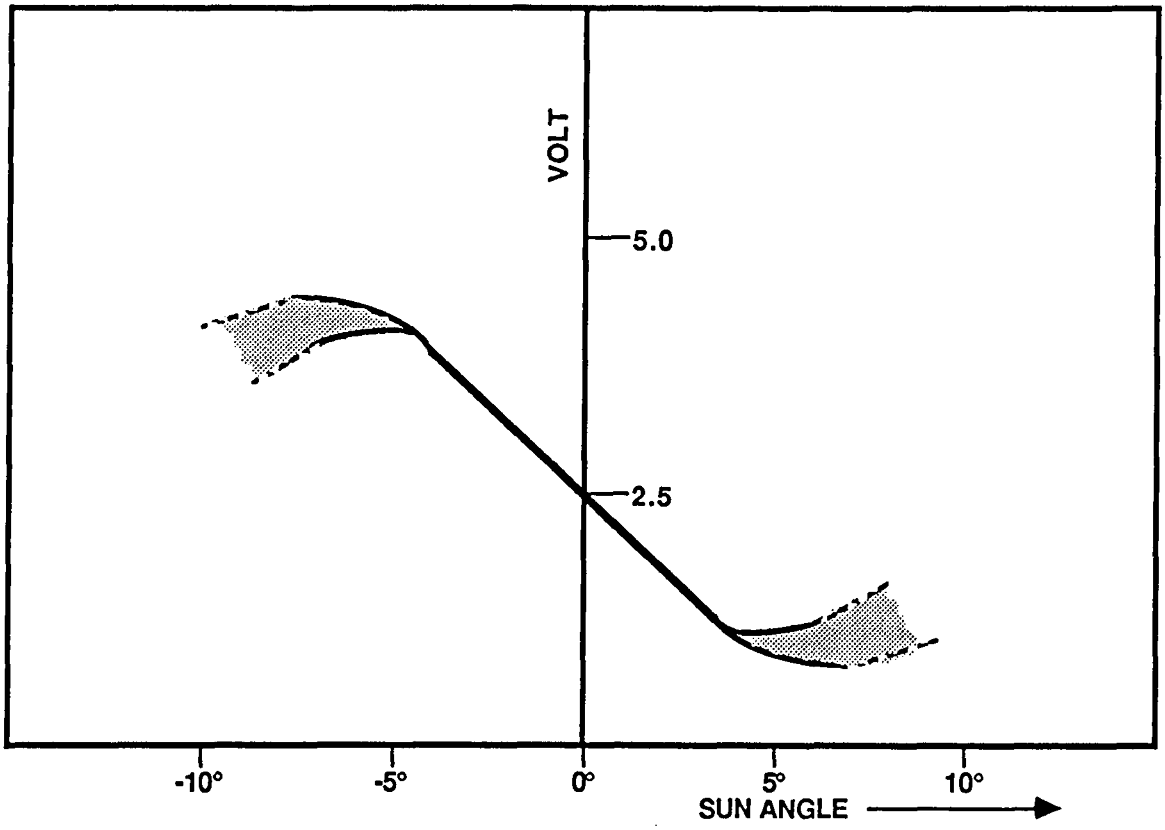

FIGURE 5
FINE ANGLE SUN SENSOR RESPONSE

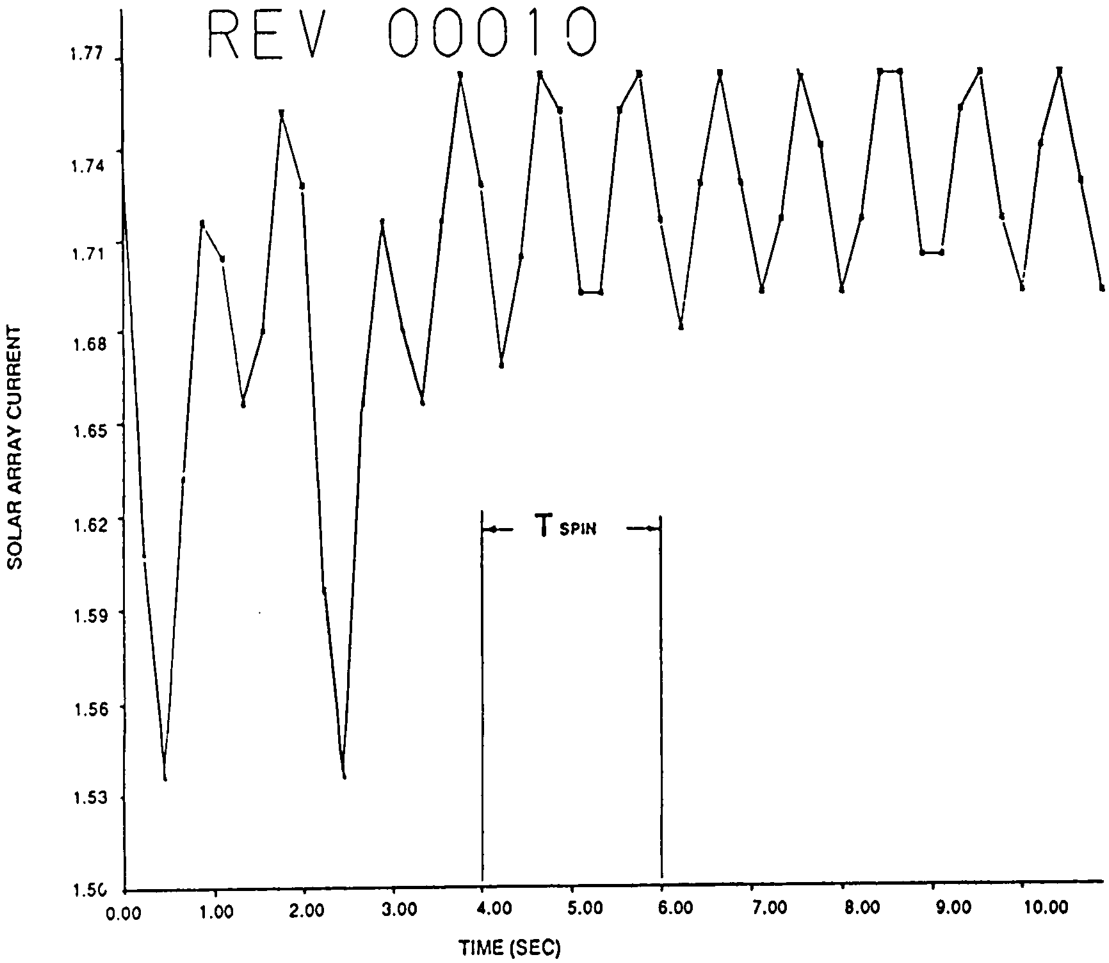

FIGURE 6
SOLAR ARRAY CURRENT WHEN NUTATION IS HIGH

LIPS III FLIGHT DATA

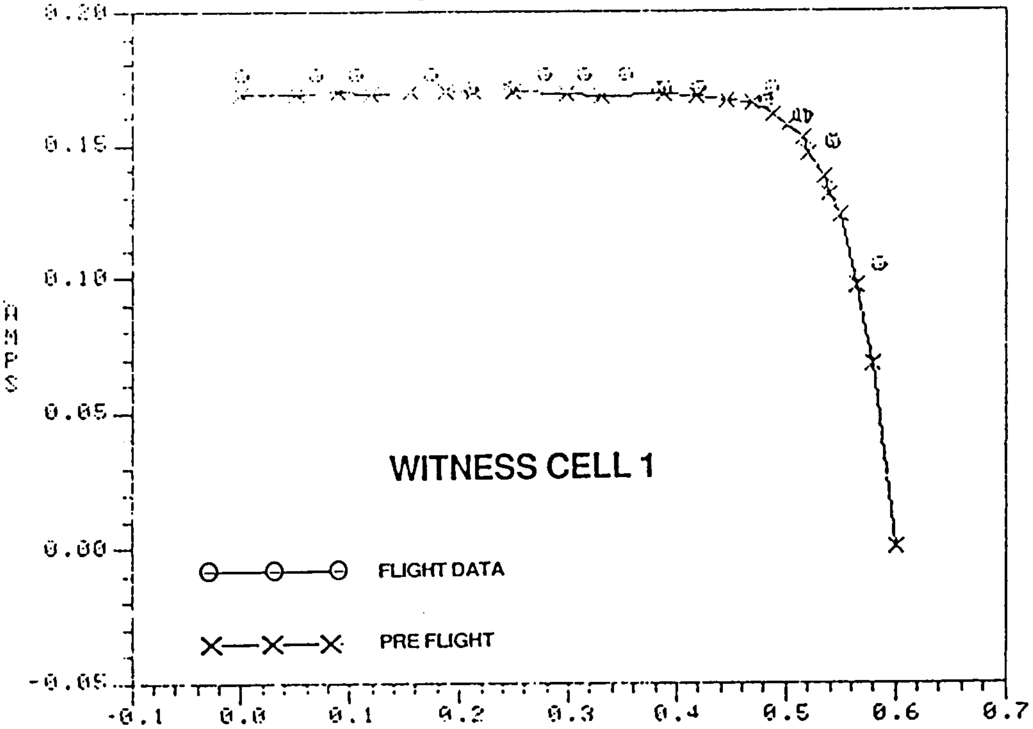

FIGURE 7

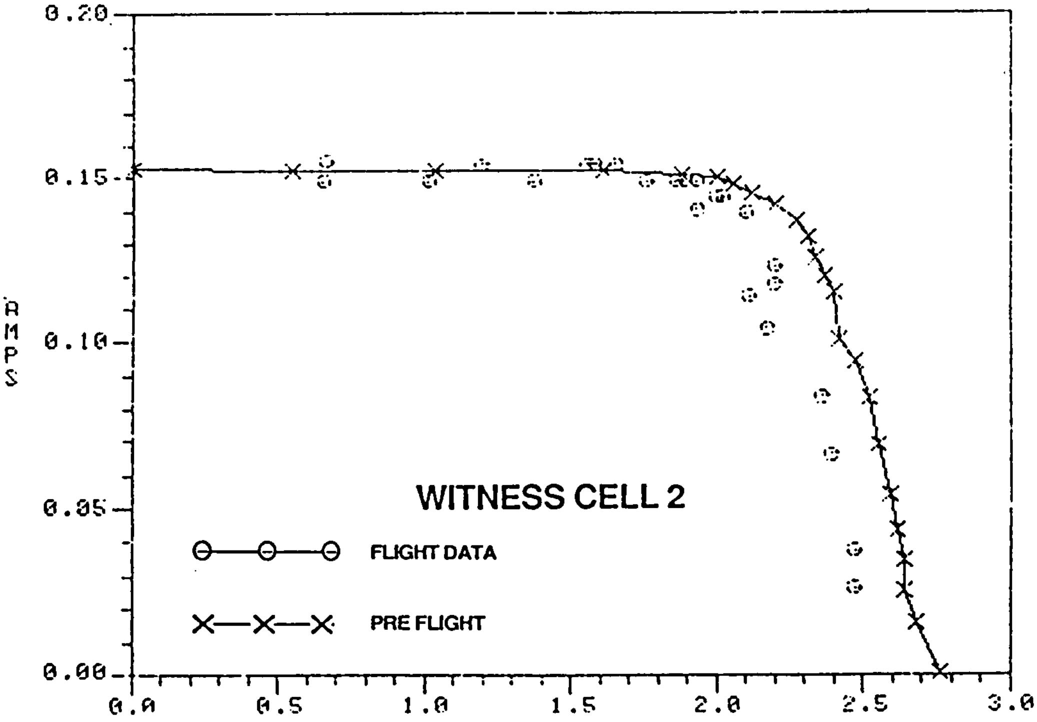

FIGURE 8

LIPS III FLIGHT DATA

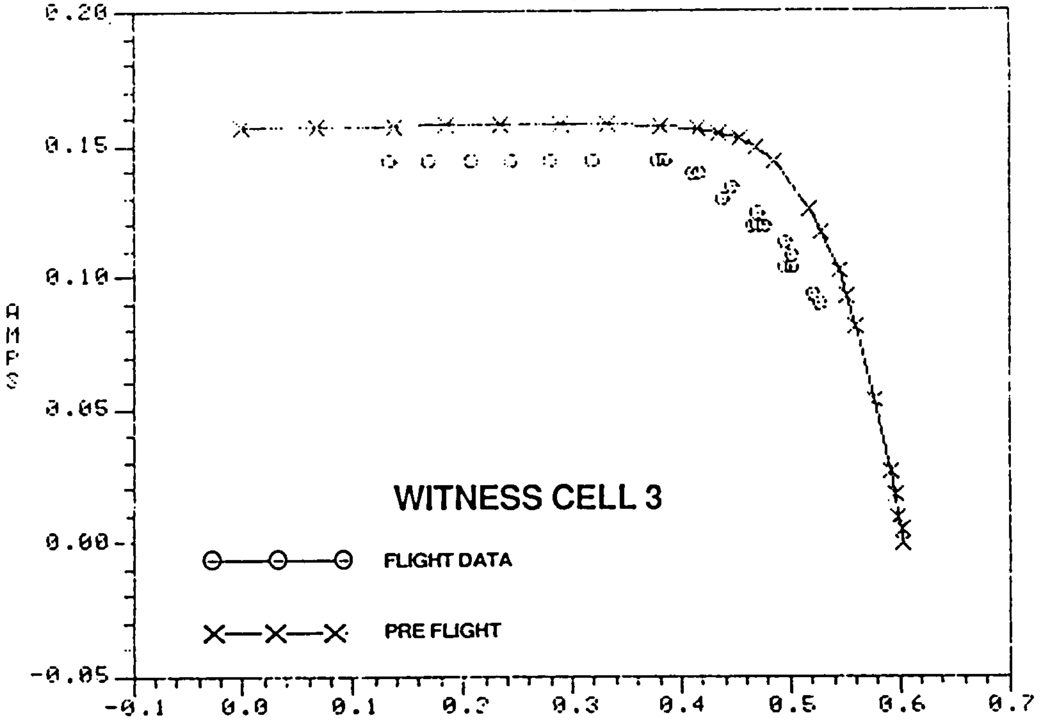

FIGURE 9

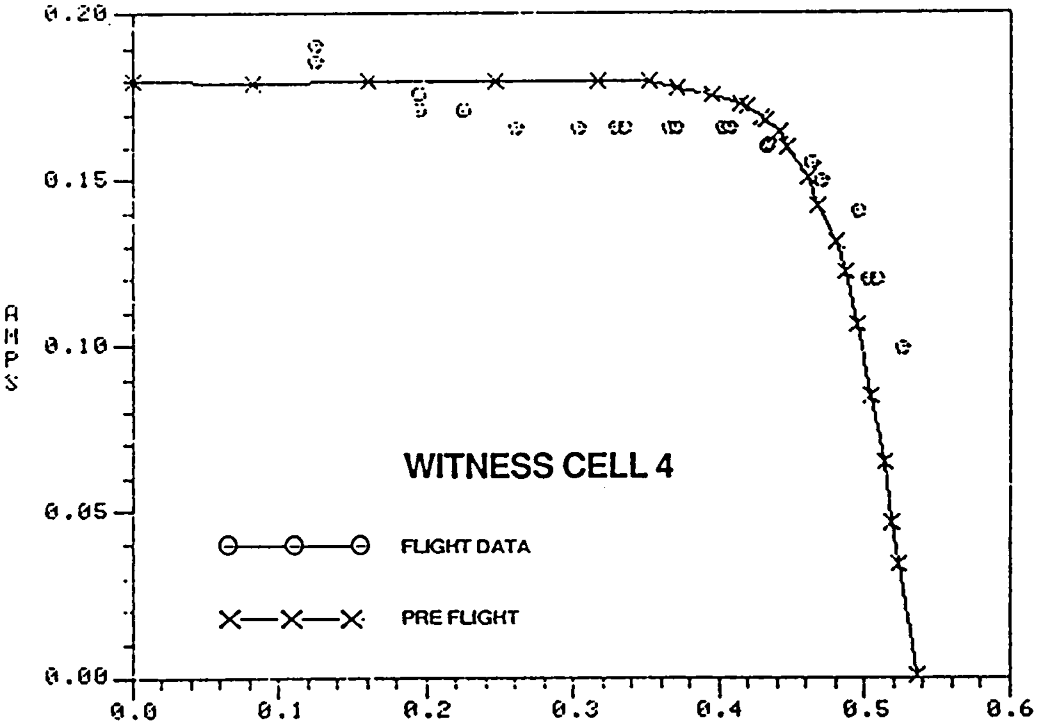

FIGURE 10