PERFORMANCE OF THE IUE SPACECRAFT BATTERIES AFTER 70 MONTHS

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ABSTRACT

The IUE spacecraft was launched on January 26, 1978 into an eccentric synchronous orbit with inclinations of 28.94° to the equator. The IUE power system contains two 6 ampere hour nickel-cadmium batteries designed to provide a beginning life of 145 watts during the eclipse seasons. In addition, battery power is required when the main buss exceeds the solar array output. The spacecraft design life was for three years with a design goal for 5 years. As of November 1983 the batteries have supported the spacecraft requirements for 70 months with excellent performance.

Papers presented at the 1978 and 1979 battery workshops describe the properties of the IUE power system including battery and cell characteristics. The objective of this paper is to update the battery performance since 1979.

CONFIGURATION

The battery in figure 1 is typical of the two flight batteries aboard the IUE spacecraft. Each battery contains 16 regular 6 ampere hour nickel-cadmium cells and 1 signal electrode cell. The batteries are diode coupled to the main buss via a boost regulator that provides 28 volts of regulated power to the spacecraft. Battery telemetry data includes battery voltage, current, signal electrode voltage and battery temperature.

INTRODUCTION

The eccentric synchronous orbit requires the spacecraft to experience 2 eclipse seasons each year, in coincidence with the solar equinox. Shadow period range from 14 to 77 minutes with each eclipse season lasting from 23 to 25 days. During periods when the solar array (spacecraft beta angles less than 0° or greater than 130°) is sufficient to supply the spacecraft power requirements, the batteries are required to augment the spacecraft needs.

FLIGHT PERFORMANCE

Each battery charger was designed to provide charge control as illustrated in figure 2a. This was accomplished by a C/10 (0.6 amp) charge current limit followed by a taper charge to be controlled by the signal electrode. Details of this charging scheme was presented during the 1978 battery workshop. During the early part of the eclipse season 1 it became apparent that the signal electrodes were not performing in accordance with design. Figure 2b represents a typical charge profile as observed in orbit. Because of the operational anomaly, procedures were modified for manual switching of the battery chargers to a trickle charge mode once the signal electrode had exceeded 0.1 volts for 3 hours. The trickle charge rate is 0.1 amps. The IUE cells on life test at the Naval Weapons Support Center (NSWC) at Crane, Indiana did not initially show the anomalous behavior. However after several eclipses there was a progressive loss of signal electrode sensitivity that resulted in the test cells experiencing an increase in overcharge. As a result, the test at Crane was modified to be indicative of the spacecraft recharge scheme for the flight batteries.

During the solstice seasons the spacecraft batteries are maintained in the low rate trickle charge mode except during periods when science activities require battery power to augment spacecraft operations. As a result of normal solar array degradation, the beta angles at which the power system buss remains power positive has decreased. Consequently additional demands have been placed on the batteries to support an increase in the demand for scientific data. These activities have required the batteries to be discharged at low rates while augmenting solar array power. Because of the additional demands being placed on the batteries operational constraints were developed to minimize battery degradation and/or damage. The constraints included a lower limit of battery voltage of 20.9 volts for average spacecraft loads, and 20.5 volts for peak loads. When either of these conditions occur the spacecraft is maneuvered to a more favorable sun angle for battery recharge.

Since the exact relationship between the above stated battery voltage, and battery state of charge was not clear, the life test at Crane was interrupted to evaluate these new conditions. Following an 8 week trickle charge (0.1 amp), the Crane cells were discharged at .05 amps to a 20.5 volt limit. Following the discharge, the cells were recharged and placed on a trickle charge for 7 days prior to repeating the test at a .1 amp discharge rate. Figure 3 depicts the discharge profile for both of these conditions and compares the data with the voltage limits selected for spacecraft operations. Typically the amount of ampere hours experienced from the spacecraft batteries at the normal discharge rates (3 to 4 amps) is 2.3 to 3.8. This is contrasted with the 4.5 to 6 ampere hours obtained at the 0.5 amp and .1 amp discharge rates.

Figure 4 is a summary of the composite of the summer solstice periods using data of 100 day intervals. A deviation from the normal trend is illustrated at approximately day 1150 (Eclipse season 7) when the signal electrode of battery SN 05 increased to an output level observed prior to launch. The reason for this peculiar behavior of the signal electrodes are not known at this time. The low point observed at around 1300 days is attributed to the mode of operations of the spacecraft. This figure also shows the battery temperature history and illustrates the approximate 8 degree battery temperature delta that has been prevalent throughout the mission.

During the early stages of eclipse season 12, the first indication of battery current divergence on discharge is apparent (Figure 5). By day 5 of the season the battery current divergence reached a maximum of .8 amps near end of discharge. By day 16 load sharing between the two batteries was back to near normal. The exact cause of this divergence is not known. However, it is thought to be associated with variation in the plateau voltage between the 2 batteries. Battery current divergence will be further analyzed during the future eclipse seasons.

Figure 6 illustrates a summary of GSFC cell test, spacecraft battery performance, and results of cell life test conducted at Crane as compared to pre-launch predictions. The battery voltage degradation prediction curve shown in this figure, was obtained from data acquired during synchronous orbit testing of older cells of similar design. The available power degradation prediction curve was calculated using the above battery voltage prediction data, solar array degradation and the efficiency factor of the power system boost regulator.

The GSFC test results shown in figure 6 was acquired from inhouse test on flight cells to an 80% peak depth of discharge and using the signal electrode for charge control. The test was accelerated by reducing the solstice periods from 5 months to 1 month. This test result was used as a baseline for prior to launch predictions.

The spacecraft battery voltage shows the trend for the end of eclipse voltage since launch. The first 6 eclipses typically required the battery to experience 60 to 75% depth of discharges. In addition the spacecraft loads required each battery to be discharged in excess of 4 amps during the eclipse operations. In the interest of obtaining maximum battery life (new goal of 10 years life) power conservation measures were implemented to limit the maximum battery discharge to 4 amps per battery. The selection of the 4 amp rate was predicated on life test experience.

The Crane data depicted in figure 6 illustrates the results of real time data from snychronous orbit testing at Crane with cells from the flight lot. The Crane data also follows the voltage prediction curve for eclipse seasons 1 through 7 but at a slightly higher voltage level than the predicted curve. During the early eclipse seasons the signal electrode degraded to a point where the current taper was being controlled by the battery voltage control alone. During eclipse 7 the control was switched to another signal electrode cell in the test pack. During eclipse seasons 8 and 9 no improvement was evident in controlling the battery overcharge. Prior to eclipse season 10 the charge control was modified to duplicate that being used by the spacecraft, as depicted in 2b.

The Crane test also provided for capacity discharge during the peak of the eclipse seasons. Cells were selectively discharged beyond the 80% depth of discharge level to 1.0 volt. For eclipse season 1, cells 9 and 10 were discharged, eclipse season 2, cells 8 and 9 were discharged. For each eclipse season an additional cell was added to each discharge group, until all cells had been capacity discharged. Analysis of the data from these type capacity checks indicated that it was creating a voltage divergence between the cells during discharge. Consequentially, prior to eclipse season 11 the capacity discharges were modified to incorporate all cells being discharged simultaneously. The data as illustrated in figure 6 for eclipse seasons 11 through 14 indicate a progressive increase in the test pack voltage at the 80% depth of discharge level.

Figure 7 illustrates the lowest voltage level that the spacecraft batteries reached at the end of discharge of each eclipse period of seasons 1, 6, and 12. The data give an indication of the rate of battery voltage degradation over the life of the spacecraft. The constraints (limiting the battery discharge rates to 4 amps) were effective in minimizing battery degradation.

Figure 8 illustrates the discharge profile for a day in eclipse season 2 and 12 where shadow period were of equal time. The discharge for day 6 of eclipse season 12 was constrained by the maximum discharge rate of 4 amps.

CONCLUSION

It can be concluded that the changes made in the battery operational procedures have enhanced the operations. The loss of battery signal electrode sensitivity in flight was accommodated by changes in the battery operational procedures. It was anticipated that the battery would start to show some aging effects after several eclipse seasons and that the effects would be somewhat amplified by the 8°C temperature delta that the batteries have experienced during their lifetime. The overall objective has been to adjust battery operations without unduly constraining science activities. Based on the performance of the flight batteries over the first 6 years, it is believed that these batteries will meet the new 10 year design goal.

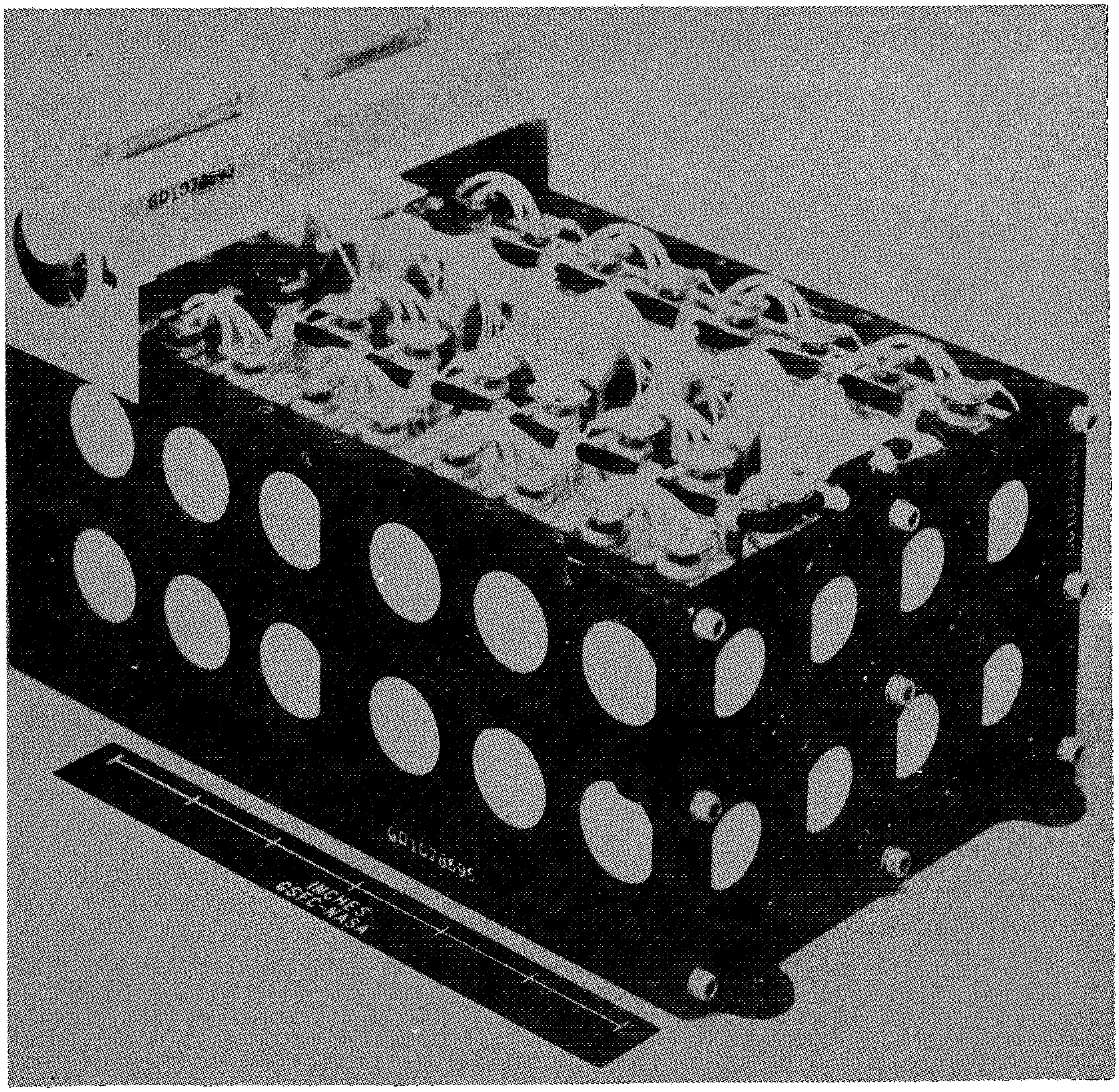


Figure 1.

IUE Spacecraft
Battery Recharge Characteristics
Eclipse Season 12
Day 13

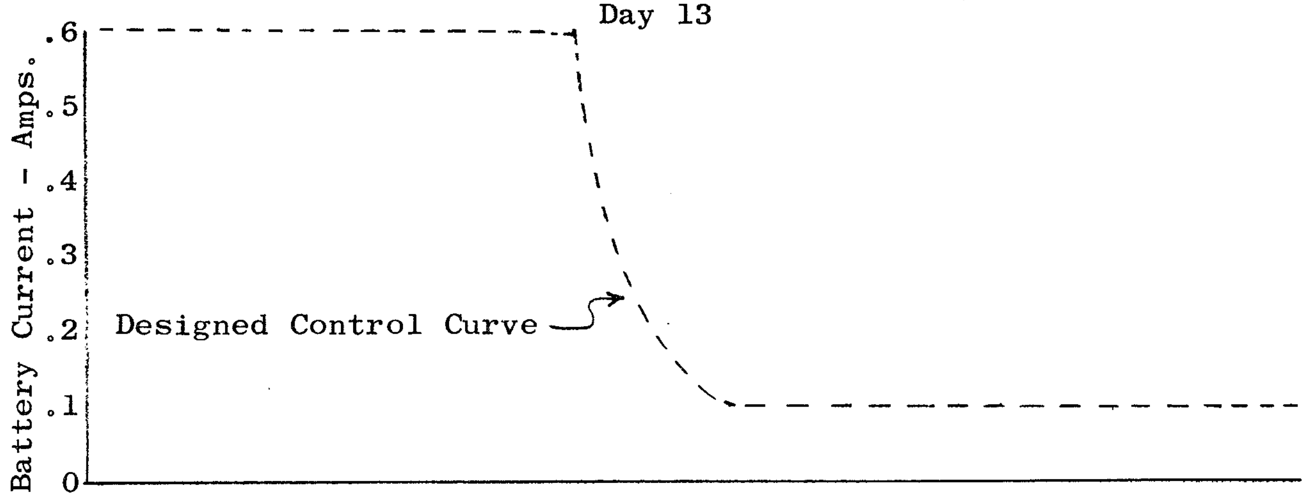


Figure 2a

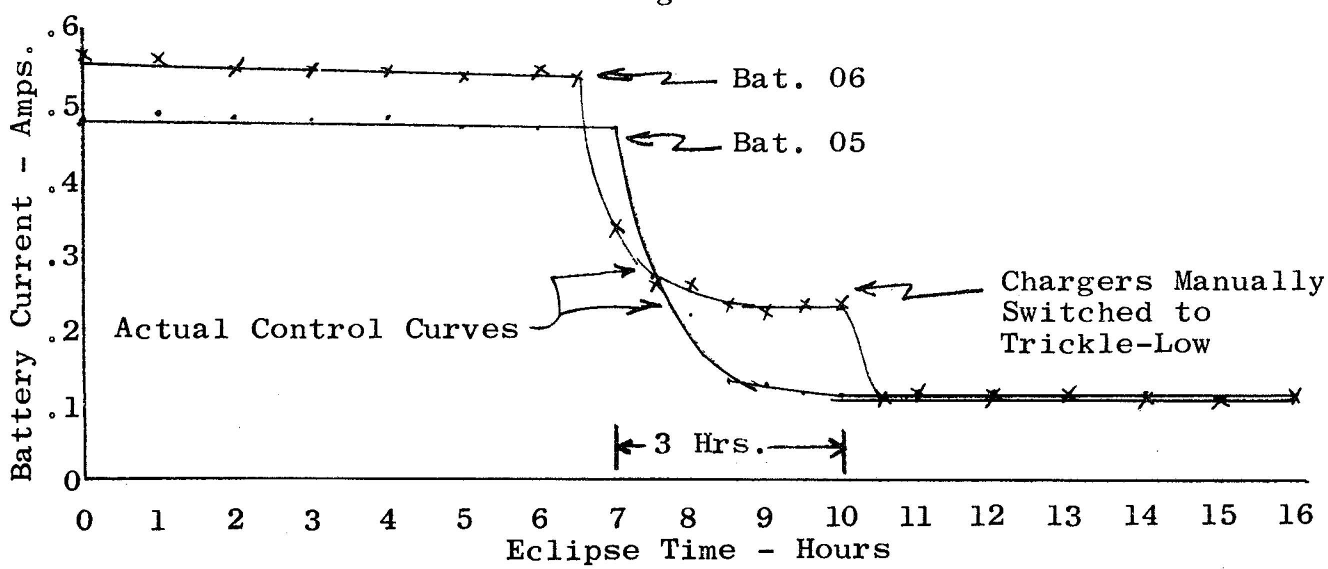


Figure 2b

IUE Test Cells Capacity Vs
Normalized Battery Voltage At
Low Rate Discharge
10°C

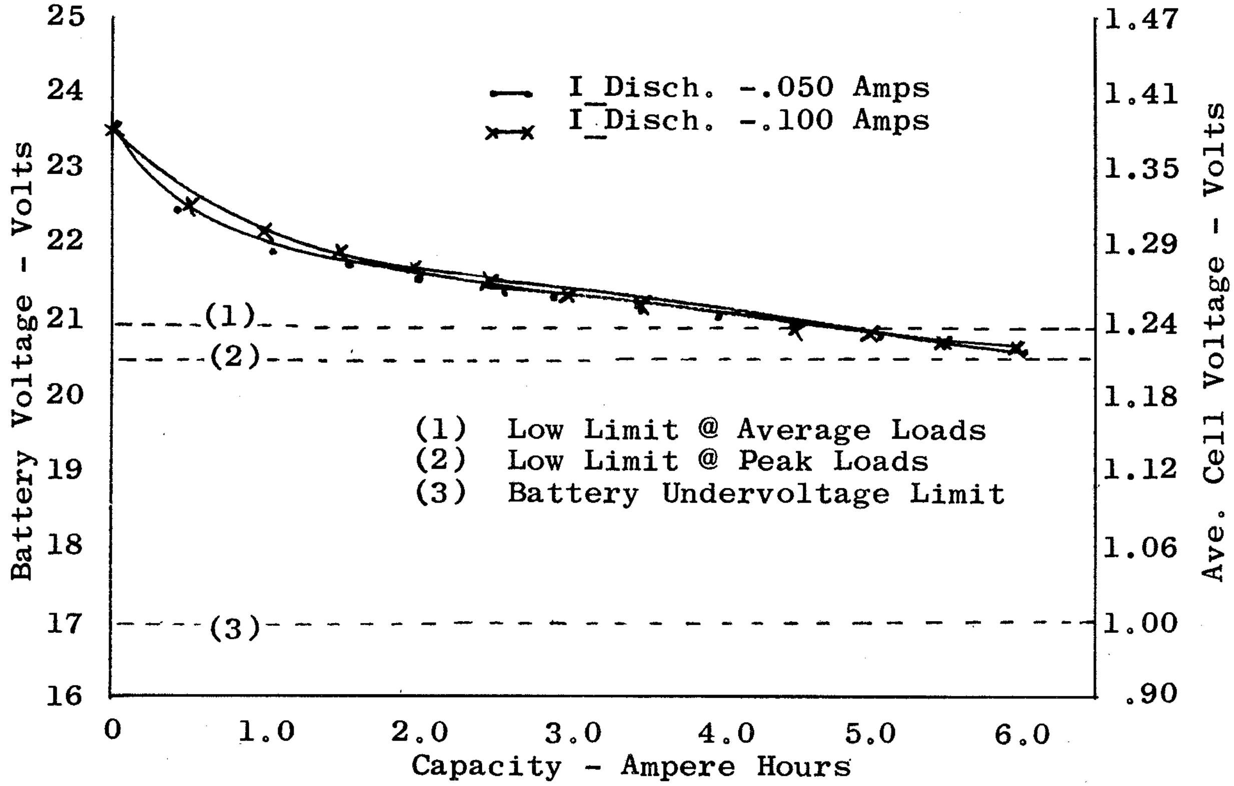


Figure 3

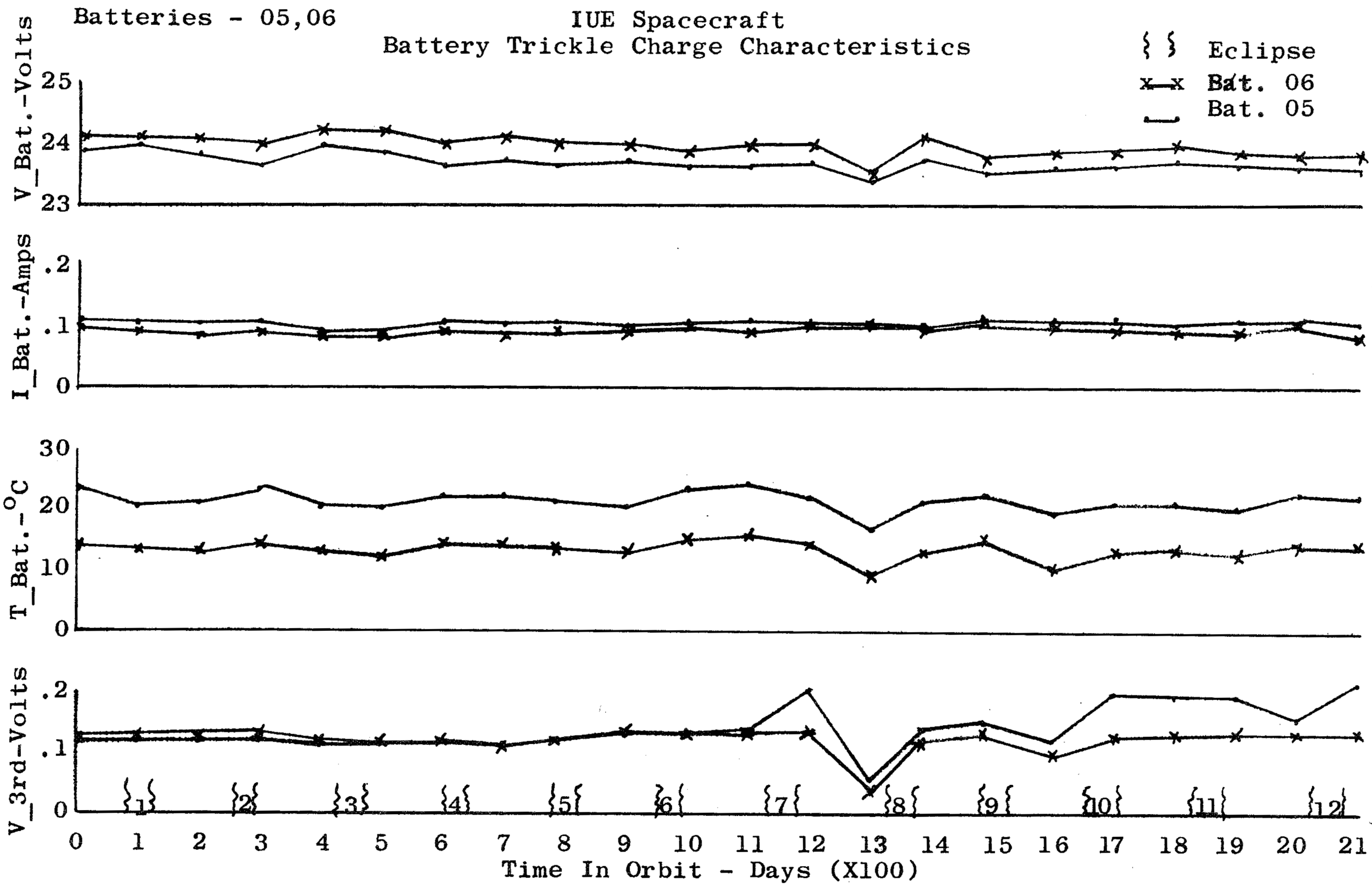

Batteries - 05,06
IUE Spacecraft
Battery Trickle Charge Characteristics
Eclipse
Bat. 06
Bat. 05
V_Bat.-Volts
25
24
23
I_Bat.-Amps
.2
.1
0
T_Bat.-°C
30
20
10
0
V_3rd-Volts
.2
.1
0
1 2 3 4 5 6 7 8 9 10 11 12
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21
Time In Orbit - Days (X100)

Figure 4

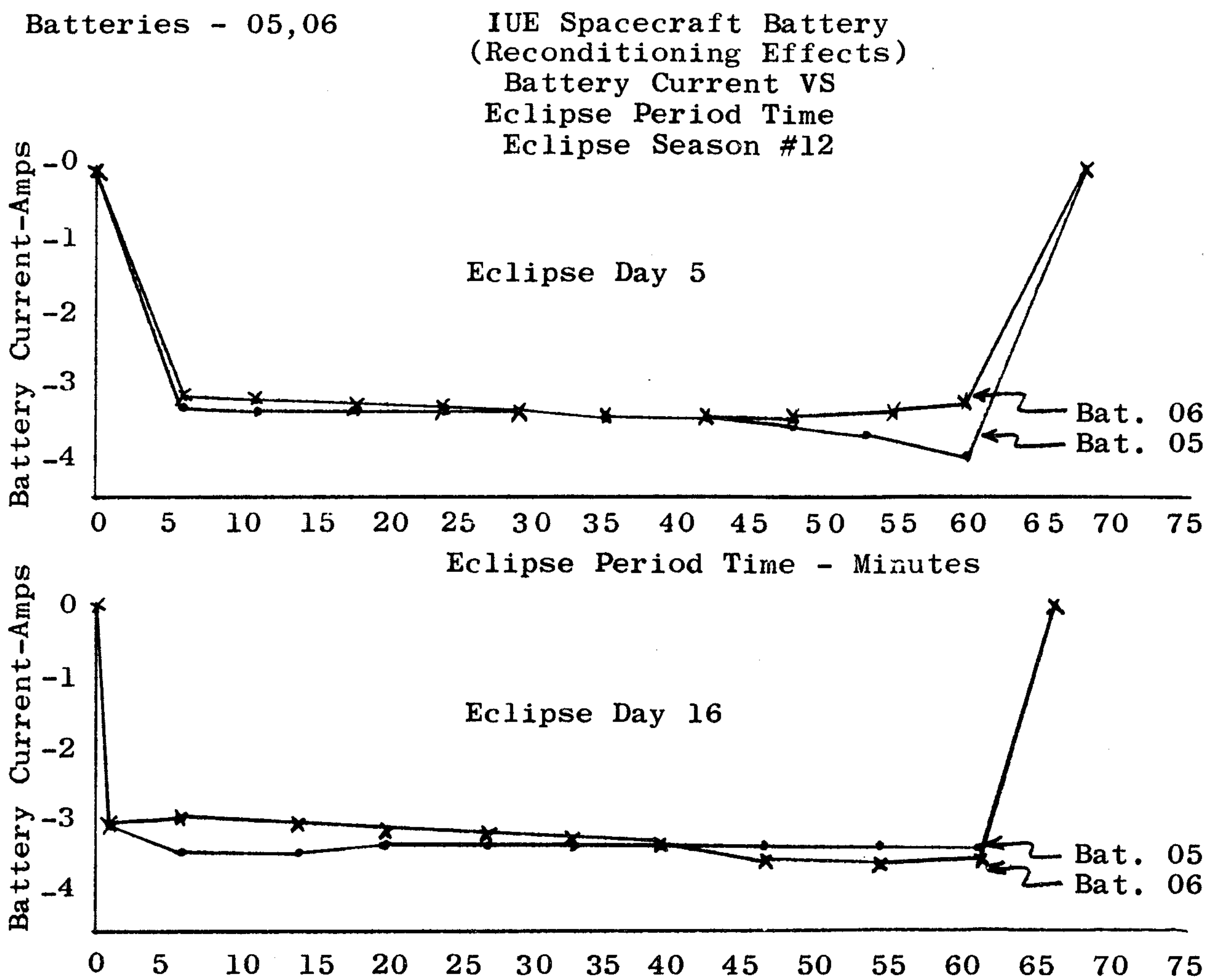

Batteries - 05,06
IUE Spacecraft Battery
(Reconditioning Effects)
Battery Current VS
Eclipse Period Time
Eclipse Season #12
Eclipse Day 5
Battery Current-Amps
-0
-1
-2
-3
-4
Bat. 06
Bat. 05
0 5 10 15 20 25 30 35 40 45 50 55 60 65 70 75
Eclipse Period Time - Minutes
Eclipse Day 16
Battery Current-Amps
0
-1
-2
-3
-4
Bat. 05
Bat. 06
0 5 10 15 20 25 30 35 40 45 50 55 60 65 70 75
Eclipse Period Time - Minutes

Figure 5

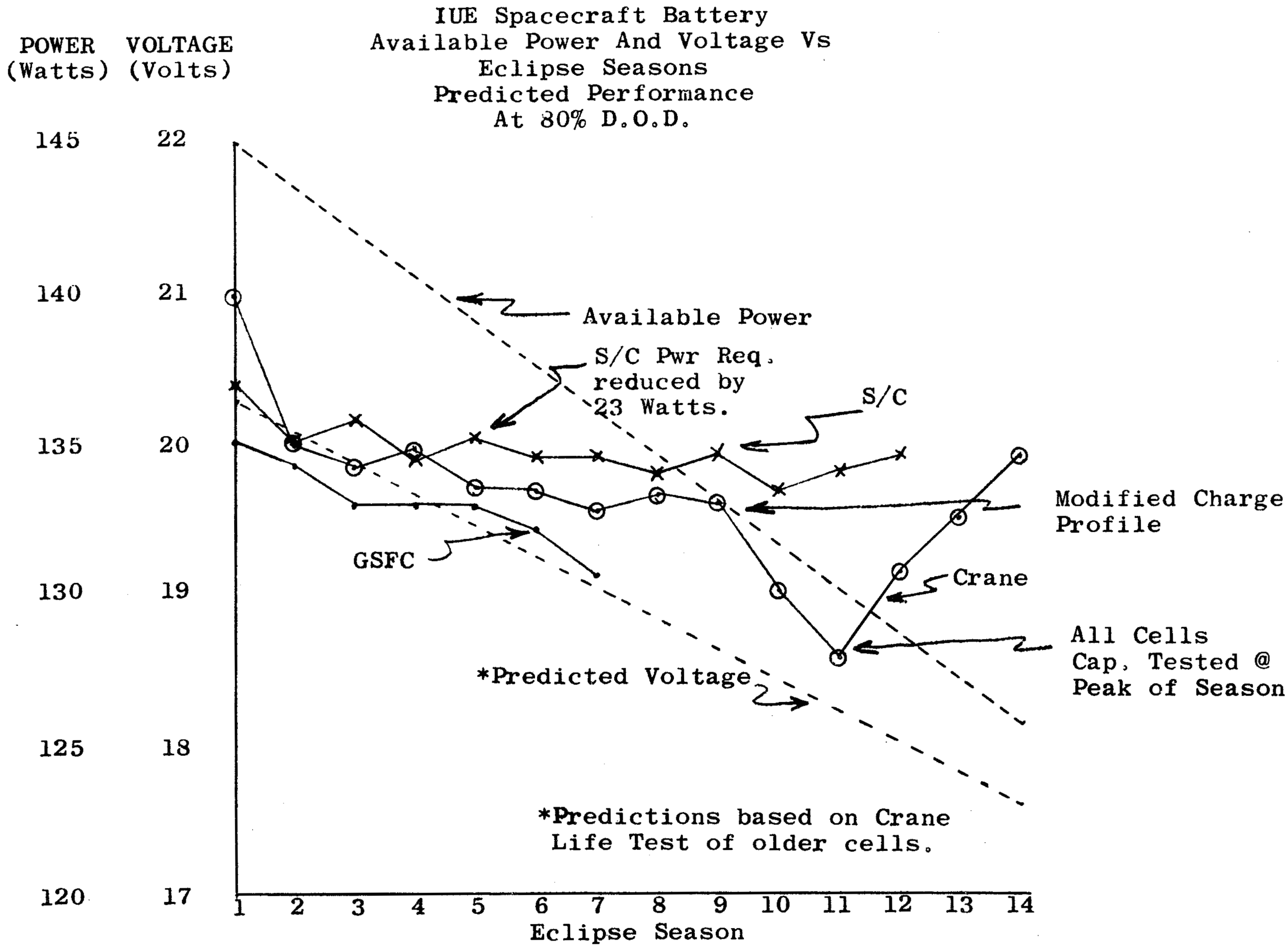

IUE Spacecraft Battery
Available Power And Voltage Vs
Eclipse Seasons
Predicted Performance
At 80% D.O.D.
POWER (Watts)
VOLTAGE (Volts)
145
22
140
21
135
20
130
19
125
18
120
17
Available Power
S/C Pwr Req. reduced by 23 Watts.
S/C
Modified Charge Profile
GSFC
Crane
All Cells Cap. Tested @ Peak of Season
*Predicted Voltage
*Predictions based on Crane Life Test of older cells.
1
2
3
4
5
6
7
8
9
10
11
12
13
14
Eclipse Season

Figure 6

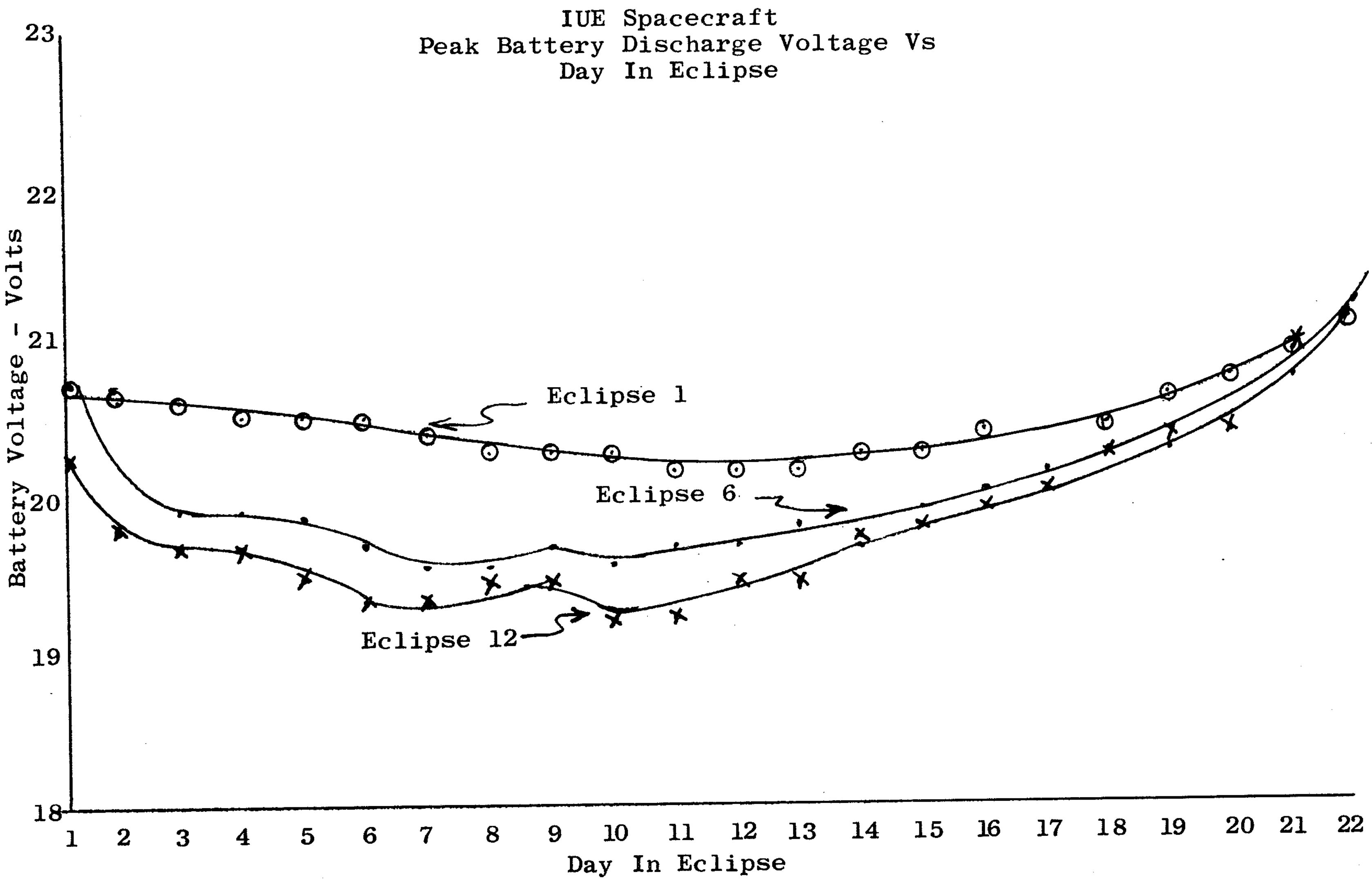
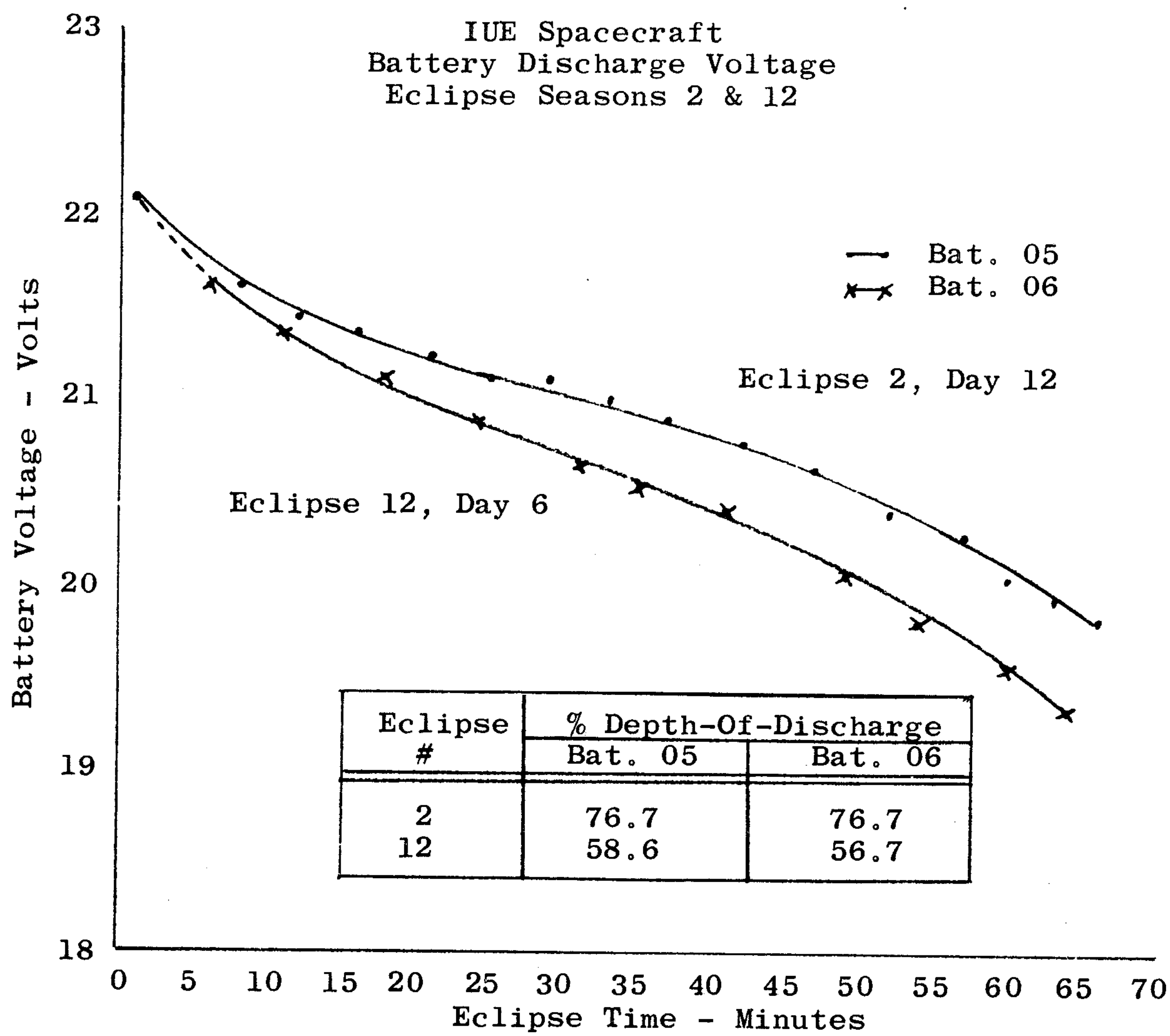

IUE Spacecraft
Peak Battery Discharge Voltage Vs
Day In Eclipse
Battery Voltage - Volts
23
22
21
20
19
18
Eclipse 1
Eclipse 6
Eclipse 12
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
18
19
20
21
22
Day In Eclipse

Figure 7



Eclipse #	% Depth-Of-Discharge Bat. 05	% Depth-Of-Discharge Bat. 06
2	76.7	76.7
12	58.6	56.7

Figure 8

Q. Russell, Space Communications Company: When your batteries are used to supply the spacecraft power do you have to command them into service or does it happen automatically?

A. Tiller, GSFC: It happens automatically. The batteries are on line all the time so it just automatically picks it up if they should slue the spacecraft to an angle that we lose data acquisition the batteries automatically since they are connected to the main bus automatically that go into operation.