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INTERNATIONAL ULTRAVIOLET EXPLORER (IUE) SPACECRAFT BATTERY PERFORMANCE UPDATE

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SUMMARY

January 26, 1987 marks the ninth inflight anniversary of the IUE spacecraft, launched into an eccentric synchronous orbit on January 26, 1978. The orbital path has subjected the spacecraft to 18 solar eclipse seasons sinch launch. Nine years of inflight operations culminate a major milestone for battery support to a spacecraft, which is well in excess of the initial 3-year design life.

Figure 1, provides a brief outline of events, power system characteristics, and papers presented at previous Battery Workshops. In 1978 and 1979, the papers presented describe the IUE battery and cell characteristics and highlight the spacecraft power system design properties. The last paper listed provides an update of battery performance through 1983. Battery cell design characteristics are listed in figure 2 providing pertinent background information relative to the data presented in this paper. It should be especially noted that the battery cells were manufactured utilizing Pellon 2505 separator, and that the negative plates were teflonated to level 1 standards. A second major design characteristic outlined is the light loading of the P.Q. plate with a design goal to reduce plate loading by 10 percent over previous designs. A design goal was also established to increase the quantity of KOH to 4cc/rated ampere-hour. The data listed in figure 3 is the results obtained during cell manufacturing. This data shows the increase in electrolyte (31 percent KOH) and light plate loading resulted in a level of 4.17cc/rated ampere-hour for a 6 ampere-hour nickel-cadmium cell. Figure 4 provides a brief summary of the original battery design parameters. The maximum discharge current level of 4 amps/battery to an 80 percent depth-of-discharge (DOD) limit was the initial design criteria. The DOD limit was decreased to 60-70 percent following eclipse season number 2 to extend battery life as long as possible without unduly limiting spacecraft operations during the eclipse seasons. The objective of this paper is to update battery performance from 1983 through 1986.

CONFIGURATION

The battery photograph presented in figure 5 is typical of the two 6 ampere-hour nickel-cadmium batteries aboard the IUE spacecraft. Each battery contains 16 regular cells and 1 signal electrode cell used to provide charge control in the main battery charger system. The power control system encompasses direct-energy-transfer (DET) of bus power during spacecraft operations. Each battery is diode coupled to the main bus via a boost regulator providing 28 volts of regulated power.

INTRODUCTION

The 6 ampere-hour batteries provide full power for spacecraft operations during the 14 to 77-minute shadow periods of the bi-annual eclipse season which last from 23 to 25 days each. Battery power is also provided wherever the main bus requirement exceed the solar array output during the sun solstice seasons when the spacecraft beta angle is below 0^o or greater than 130^o.

FLIGHT PERFORMANCE

During the eclipse season shadow periods, battery recharging is accomplished utilizing the spacecraft main charger control system augmented by a low rate trickle charge system. Both operations are depicted in figure 6--the main chargers are operating between elapsed time hours 6 through 16--with the low rate chargers operating from hour 16 to the completion of the 24th hour of the depicted eclipse day. It should also be noted that data previously presented including figure 6 show the batteries are being commanded to a low rate charge (approx. 0.1 amps) at hour 16 because the main charger for battery 2 fails to taper the charge current to the 0.1 amp design level. The charge scheme depicted has been used during all previous recharge operations due to the third electrode sensitivity anomaly.

Telemetry data received during eclipse season 2 indicated that the battery discharge voltage recorded at the peak of the eclipse season (day 17) decreased from 20.25 volts during eclipse season 1, to 19.92 volts at the peak of eclipse season 2. Power conservation measures were implemented to limit the maximum battery discharge to the 4 amp per battery design level. Directives were also initiated to turn off non-critical spacecraft loads when either battery exceeded 50 percent DOD. Data plotted for eclipse season 12 and 18 in figure 7 shows that the action taken reduced battery discharge from a 76.7 percent level for eclipse season 2 to approximately 62 percent for eclipse seasons 12 and 18. Figure 8 provides additional support which shows that the reduction in spacecraft power usage is also conducive in reducing battery DOD during the eclipse season shadow periods.

Immediately after launch, the spacecraft telemetry data indicated that battery 05 was approximately $8^{o}C$ warmer than battery 06. Data analyzed during eclipse seasons 1 through 9 gave indications that the operational life of battery 05 may be shortened by the warmer temperature delta. However, data plotted for eclipse seasons 10 through 18 indicate that the battery DOD may be the predominate factor in cell degradation. The temperature delta between the batteries appears to be the controlling factors in load sharing, i.e., battery 06 (approx. $23^{o}C$) provided more power than battery 05 (approx $15^{o}C$) during the peak discharge periods for eclipse seasons 1-9. A switch in load sharing occurred during eclipse season 10 where battery 05 started providing more power than battery 06, supporting the theory that the battery DOD may be the predominate degradation factor. Additional data is shown in figure 10 indicating that battery discharge current is directly proportional to the DOD data previously shown in figure 9.

Figure 11 is a composite data plot of 10 cells on test at NWSC, Crane, Indiana. Discharge cell voltages were plotted versus ampere-hour during a capacity test at the peak of eclipse season 19. It should be noted that the cells are being tested in a simulated synchronous orbit at $10^{o}C$ to 80 percent DOD. The recharge profile was modified prior to eclipse season 13 to simulate the recharge scheme utilized to recharge the spacecraft batteries. The data demonstrates that the test cells discharge voltages track in a close pattern and that cell capacity exceeds 6 ampere-hours after 18-1/2 simulated eclipse seasons.

CONCLUSIONS

The IUE battery cell performance is excellent--with exception of the third electrode anomaly and temperature delta between batteries. Data indicates that battery DOD may be more critical to extend battery life than small operational temperature deltas between batteries. It is predicted that several additional years of battery life may be obtained by a reduction in operational battery DOD.

INTERNATIONAL ULTRAVIOLET EXPLORER

- LAUNCH DATE:..............................JANUARY 26, 1978
- ORBIT:.....................................ECCENTRIC SYNCHRONOUS
- POWER SYSTEM:.............................DIRECT ENERGY TRANSFER
- BATTERIES:................................TWO 6 AMPERE HOUR NICKEL-CADMIUM
- BATTERY CHARGE CONTROL:...................THIRD ELECTRODE
  VOLTAGE TAPER
  CURRENT LIMIT
- CELL MANUFACTURER:........................GENERAL ELECTRIC
- PREVIOUS BATTERY WORKSHOP PAPERS:
  - IUE FLIGHT PERFORMANCE 1978
  - UPDATE OF THE IUE BATTERY..............1979
    IN-FLIGHT PERFORMANCE
  - PERFORMANCE OF THE IUE BATTERIES.......1983
    AFTER 70 MONTHS

Figure 1.

IUE CELL DESIGN (6 Ah NiCd)

- GENERAL ELECTRIC CELL
- DUAL, NICKEL-BRAZE, CERAMIC-TO-METAL SEALS
- PELLON 2505 SEPARATOR
- TEFLONATION OF NEGATIVE PLATE, LEVEL 1
- CARBONATE REDUCTION PROCESS
- P.Q PLATE WITH LIGHT LOADING
  GOAL: 10% REDUCTION IN LOADING
- HIGHER QUANTITY OF KOH
  GOAL: 4cc/RATED Ah

Figure 2.

CELL MANUFACTURING DATA (6 Ah NiCd)

- LOADING-POSITIVE AVERAGE..................12.72 gm/dm^2
  NEGATIVE AVERAGE..................16.2 gm/dm^2
- THEORETICAL CAPACITY-POSITIVE.............10.13 Ah
  NEGATIVE.............18.19 Ah
- FLOODED CELL TESTS-POSITIVE AVERAGE.......7.81 Ah
  (ECT) NEGATIVE AVERAGE.......14.48 Ah
- NEGATIVE/POSITIVE RATIO...................1.85:1
- PRECHARGE SET (BY O_2 VENTING).............2.84 Ah
- ELECTROLYTE (31% KOH).....................4.17 cc/Rated Ah
- SEPARATOR SET OUT TIME (AVERAGE)..........39 Sec

Figure 3.

PERTINENT BATTERY DESIGN PARAMETERS

- AVAILABLE POWER TO SPACECRAFT. . . .82 WATTS/BATTERY
- MAXIMUM DISCHARGE CURRENT. . . . . .4 AMPS/BATTERY
- DEPTH-OF-DISCHARGE . . . . .80 PERCENT
- ECLIPSE PERIOD . . . . .BI-ANNUAL (23-25 DAYS EACH)
- WEIGHT . . . . .5.8 Kg/BATTERY
- SIZE . . . . .280 CUBIC INCHES/BATTERY

Figure 4.

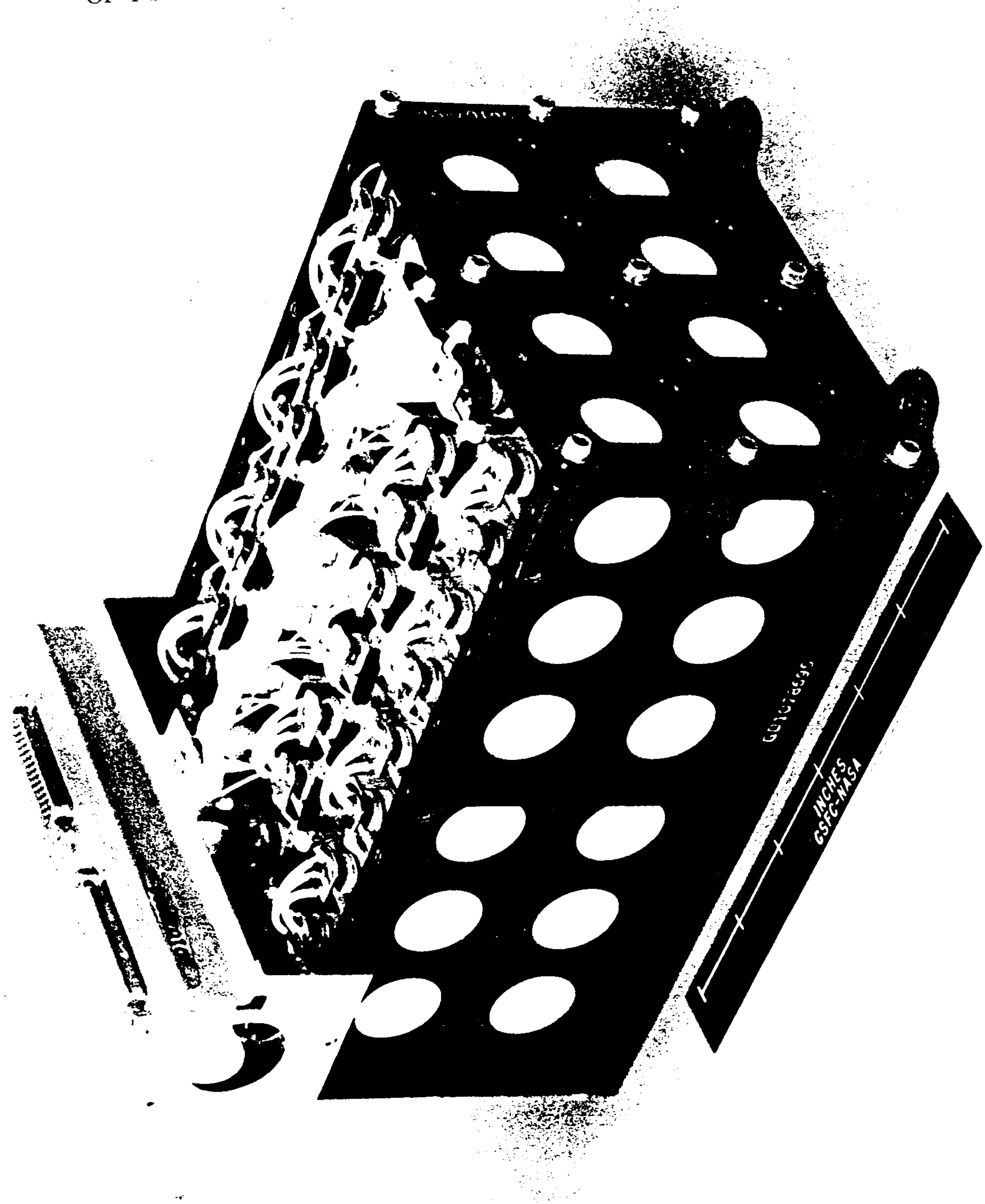

Figure 5.

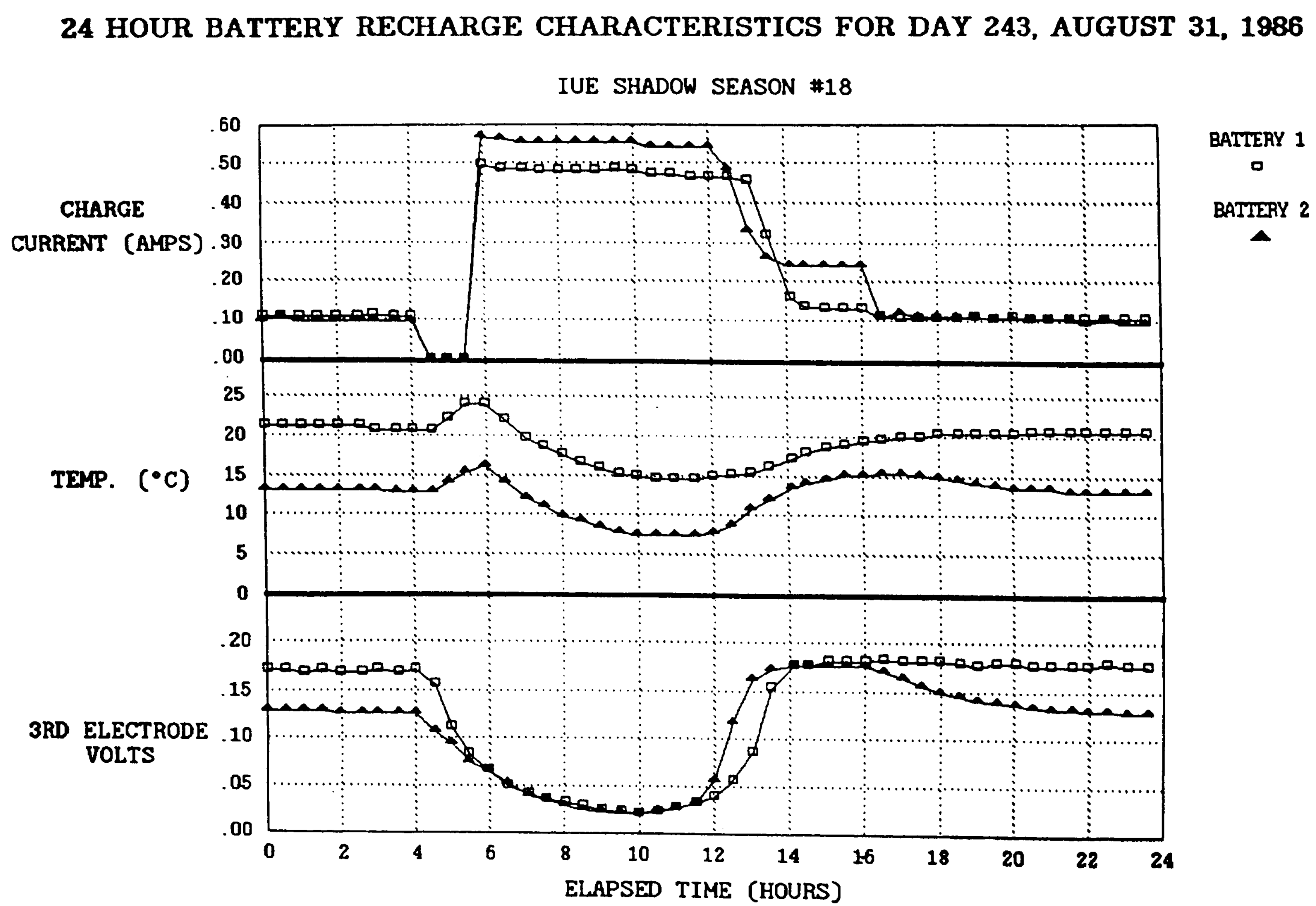
24 HOUR BATTERY RECHARGE CHARACTERISTICS FOR DAY 243, AUGUST 31, 1986
IUE SHADOW SEASON #18
CHARGE
CURRENT (AMPS)
.60
.50
.40
.30
.20
.10
.00
TEMP. (°C)
25
20
15
10
5
0
3RD ELECTRODE
VOLTS
.20
.15
.10
.05
.00
0
2
4
6
8
10
12
14
16
18
20
22
24
ELAPSED TIME (HOURS)
BATTERY 1
BATTERY 2

Figure 6.

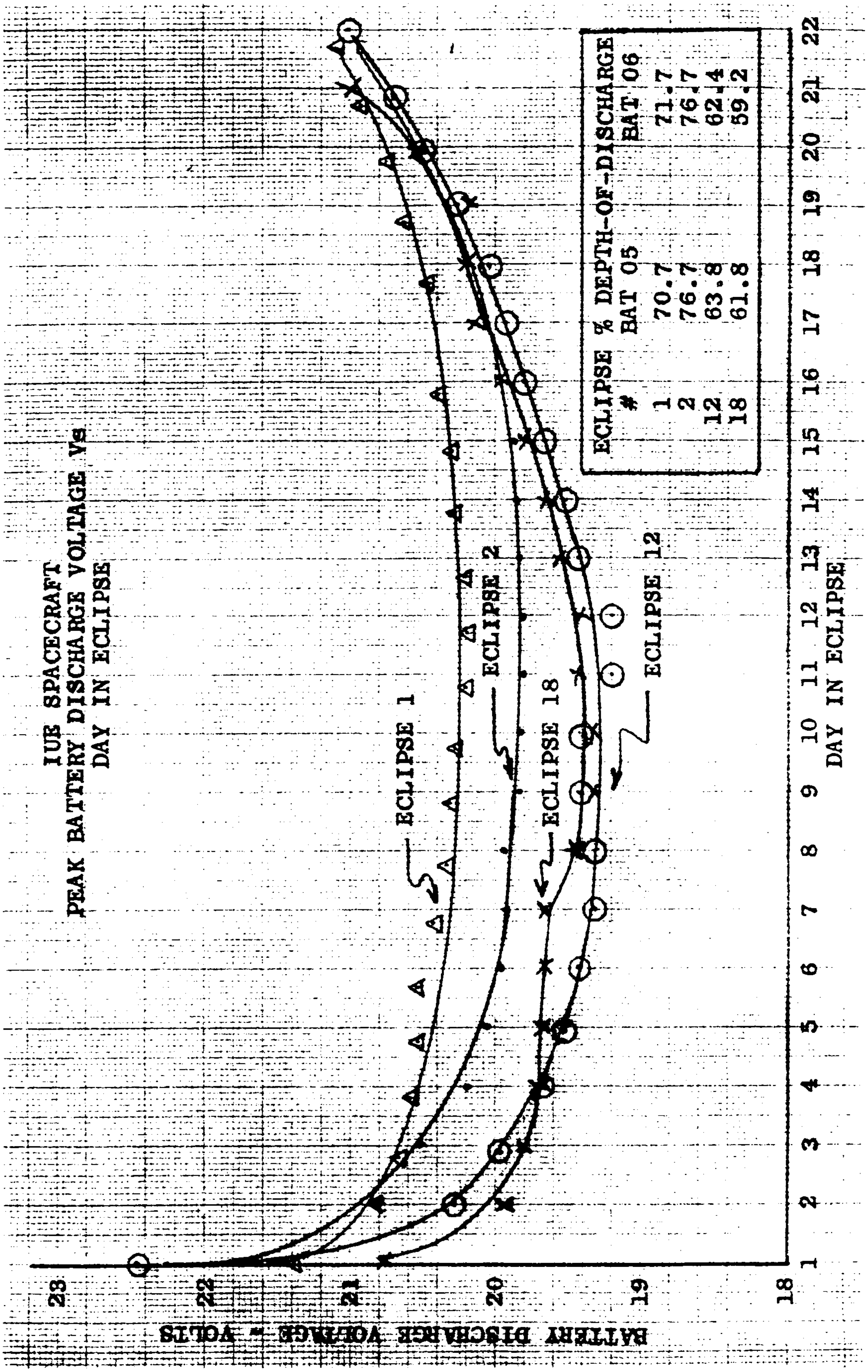
IUE SPACECRAFT
PEAK BATTERY DISCHARGE VOLTAGE Vs
DAY IN ECLIPSE
BATTERY DISCHARGE VOLTAGE - VOLTS
DAY IN ECLIPSE
ECLIPSE 1
ECLIPSE 2
ECLIPSE 18
ECLIPSE 12
ECLIPSE # | % DEPTH-OF-DISCHARGE BAT 05 | BAT 06
1 | 70.7 | 71.7
2 | 76.7 | 76.7
12 | 63.8 | 62.4
18 | 61.8 | 59.2

Figure 7.

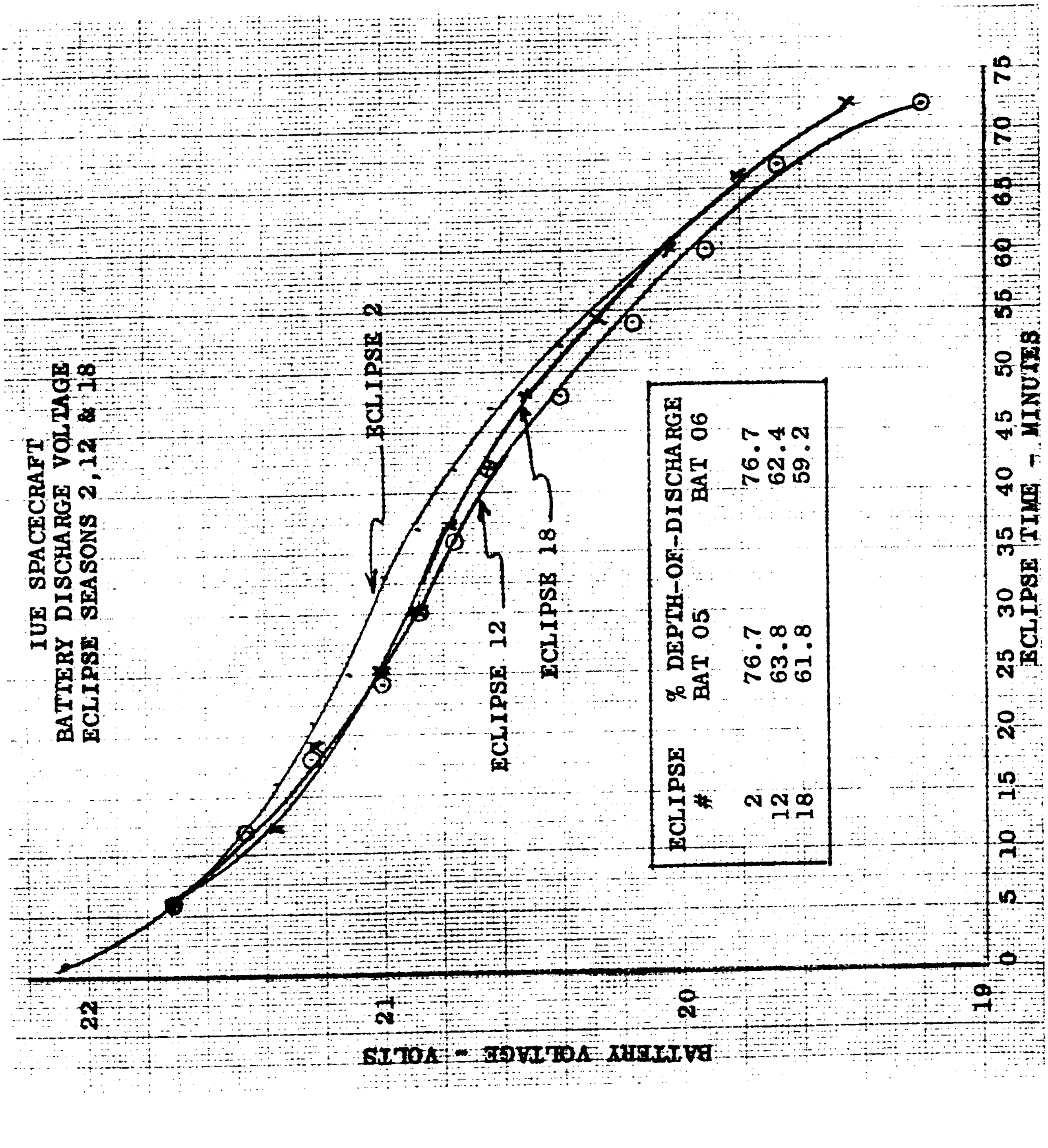
IUE SPACECRAFT
BATTERY DISCHARGE VOLTAGE
ECLIPSE SEASONS 2,12 & 18
ECLIPSE 2
ECLIPSE 12
ECLIPSE 18
ECLIPSE # | % DEPTH-OF-DISCHARGE BAT 05 | BAT 06
2 | 76.7 | 76.7
12 | 63.8 | 62.4
18 | 61.8 | 59.2
BATTERY VOLTAGE - VOLTS
22
21
20
19
0 5 10 15 20 25 30 35 40 45 50 55 60 65 70 75
ECLIPSE TIME - MINUTES

Figure 8.

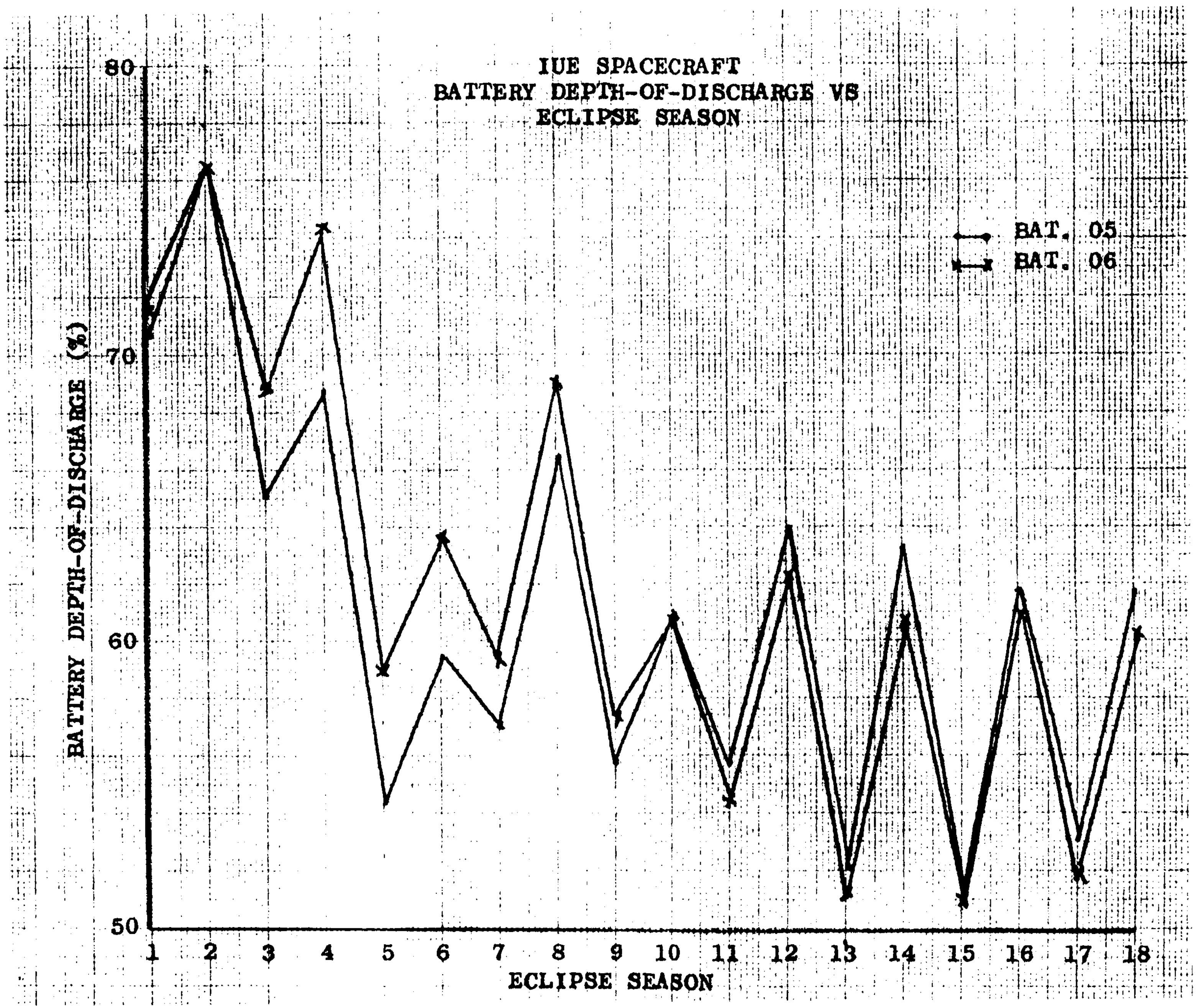
IUE SPACECRAFT
BATTERY DEPTH-OF-DISCHARGE VS
ECLIPSE SEASON
BAT. 05
BAT. 06
BATTERY DEPTH-OF-DISCHARGE (%)
80
70
60
50
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18
ECLIPSE SEASON

Figure 9.

ORIGINAL PAGE IS
OF POOR QUALITY

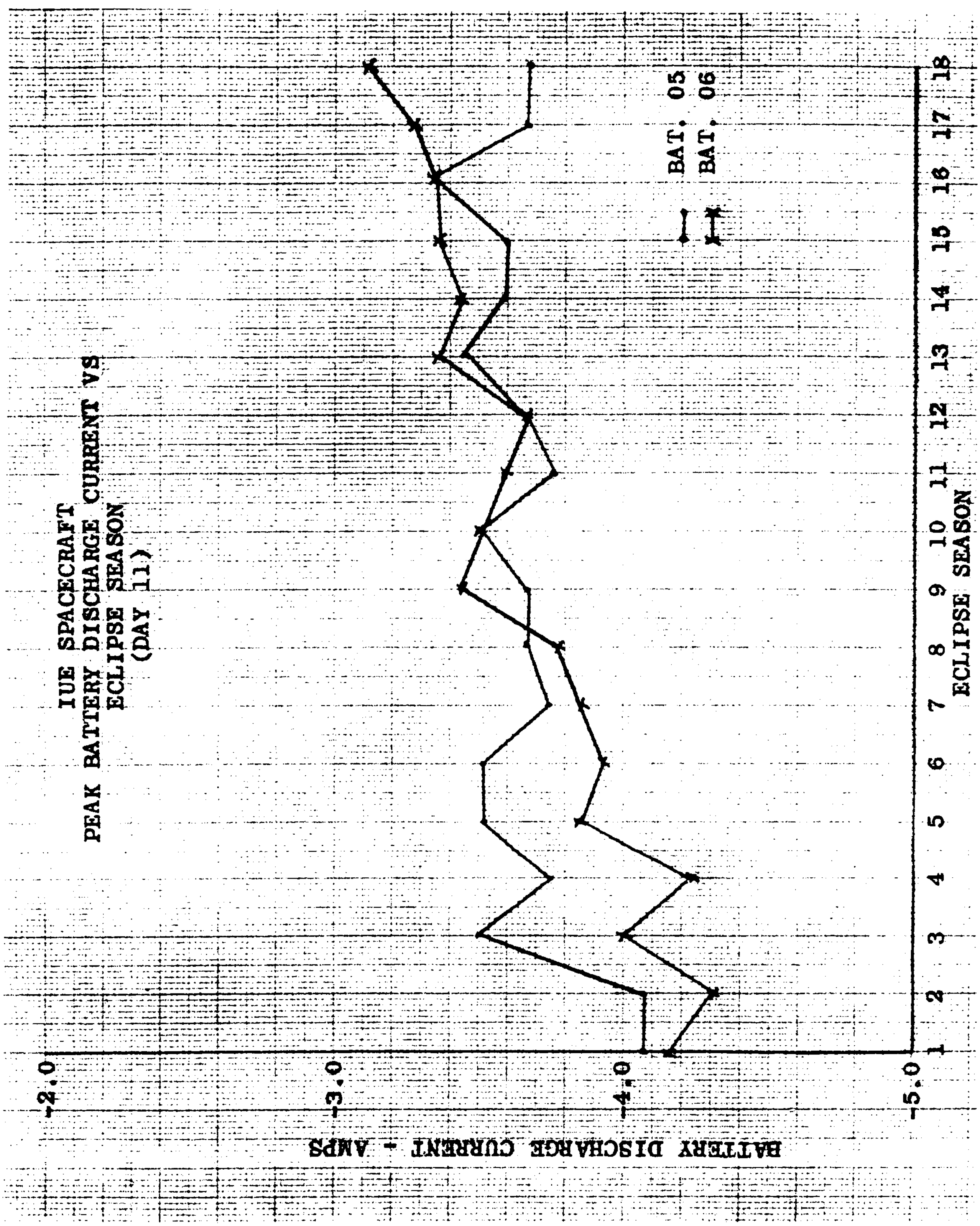

Figure 10.

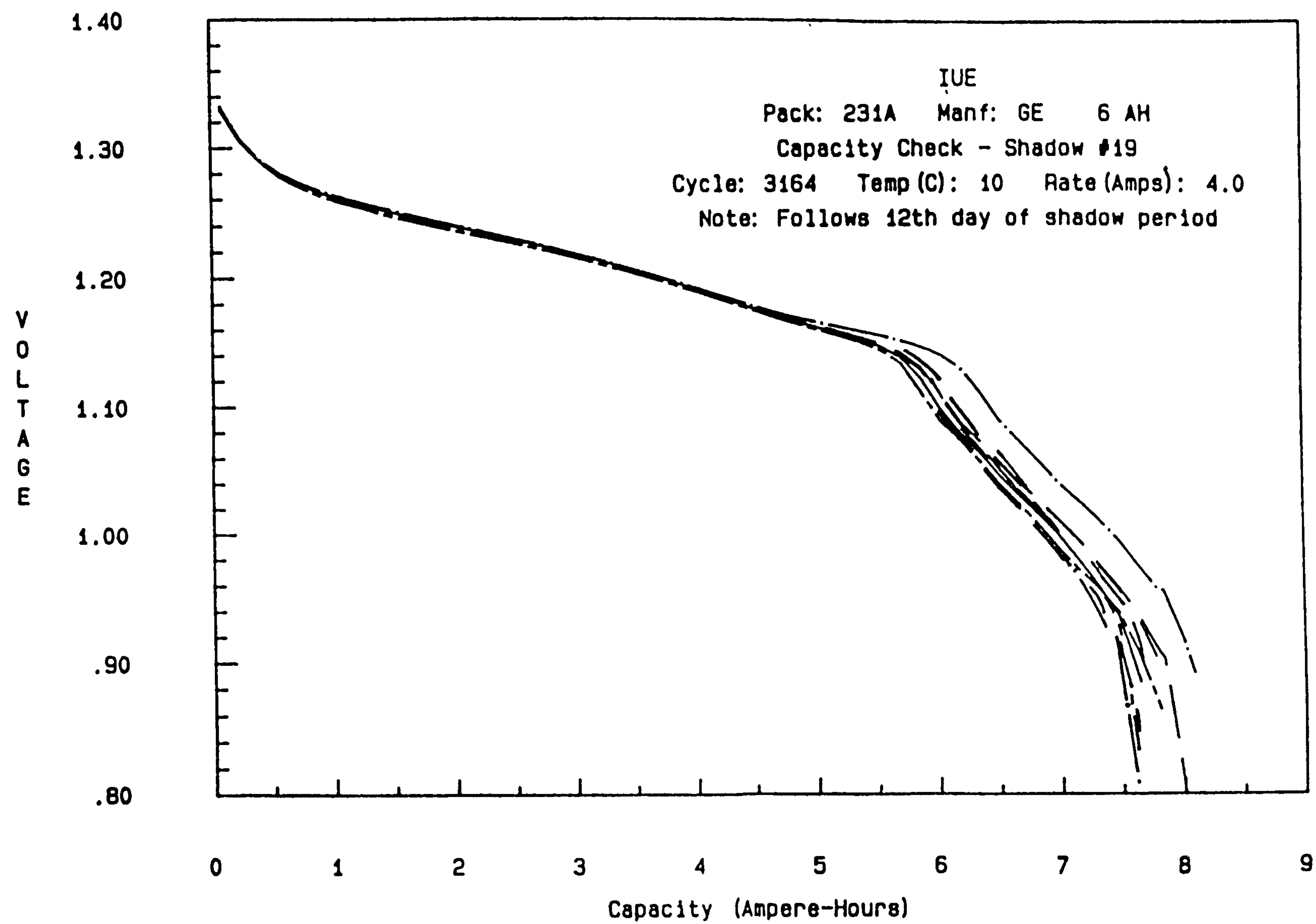
IUE
Pack: 231A Manf: GE 6 AH
Capacity Check - Shadow #19
Cycle: 3164 Temp (C): 10 Rate (Amps): 4.0
Note: Follows 12th day of shadow period
1.40
1.30
1.20
1.10
1.00
.90
.80
VOLTAGE
0
1
2
3
4
5
6
7
8
9
Capacity (Ampere-Hours)

Figure 11.