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 since launch. Nine years of inflight operations culminate in a major milestone for battery support to a spacecraft, which is well in excess of the initial 3-year design life.

Introduction

Table 1 provides a brief outline of events, power system characteristics, and papers presented at previous Battery Workshops. In 1978 and 1979 the papers presented described the IUE battery and cell characteristics and highlighted 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 Table 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% over previous designs. A design goal was also established to increase the quantity of KOH to 4 ml/rated ampere hour. The data listed in Table 3 are the results obtained during cell manufacture. These data show that the increase in electrolyte (31% KOH) and light plate loading resulted in a level of 4.17 ml/rated A h for a 6 A h nickel–cadmium cell.

Table 4 provides a brief summary of the original battery design parameters. The maximum discharge current level of 4 A/battery to an 80% depth-of-discharge (DOD) limit was the initial design criteria. The DOD limit was decreased to 60 - 70% 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.

0378-7753/87/$3.50

TABLE 1

International Ultraviolet Explorer

• Launch date	January 26, 1978
• Orbit	Eccentric synchronous
• Power system	Direct energy transfer
• Batteries	Two 6 A h Ni–Cd
• 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 in-flight performance	1979
— Performance of the IUE batteries after 70 months	1983

TABLE 2

IUE cell design (6 A h Ni–Cd)

- 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: 4 ml/rated A h

TABLE 3

Cell manufacturing data (6 A h Ni–Cd)

• Loading — positive average (g dm^{-2})	12.72
negative average (g dm^{-2})	16.2
• Theoretical capacity — positive (A h)	10.13
negative (A h)	18.19
• Flooded cell tests — positive average (A h)	7.81
(ECT) negative average (A h)	14.48
• Negative/positive ratio	1.85:1
• Precharge set (by O_2 venting) (A h)	2.84
• Electrolyte (31% KOH) (ml/rated A h)	4.17
• Separator set out time (average) (s)	39

Battery configuration

Each battery contains 16 regular cells and 1 signal electrode cell used to provide charge control in the main battery charger system. The power

TABLE 4

Pertinent battery design parameters

• Available power to spacecraft (W/battery)	82
• Maximum discharge current (A/battery)	4
• Depth-of-discharge (%)	80
• Eclipse period	Bi-annual (23 - 25 days each)
• Weight (kg/battery)	5.8
• Size (in.^{3}/battery)	280

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 V of regulated power. The 6 A h batteries provide full power for spacecraft operations during the 14 - 77 min shadow periods of the semi-annual eclipse seasons which last from 23 to 25 days each. Battery power is also provided wherever the main bus requirement exceeds the solar array output during the sun solstice seasons when the spacecraft beta angle is below 0° or greater than 130°.

Flight performance

During the eclipse season, battery recharging is accomplished utilizing the spacecraft main charger control system augmented by a low rate trickle charge system. Both operations are depicted in Fig. 1 — 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 Fig. 1, show that the batteries are being commanded to a low rate charge (approx. 0.1 A) at hour 16 because the main charger for battery 2 fails to taper the charge current to the 0.1 A 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 V during eclipse season 1, to 19.92 V at the peak of eclipse season 2. Power conservation measures were implemented to limit the maximum battery discharge to the 4 A per battery design level. Directives were also initiated to turn off non-critical spacecraft loads when either battery exceeded 50% DOD. Data plotted for eclipse seasons 12 and 18 in Fig. 2 show that the action taken reduced battery discharge from a 76.7% level for eclipse season 2 to approximately 62% for eclipse seasons 12 and 18. Figure 3 provides additional support, showing that the reduction in

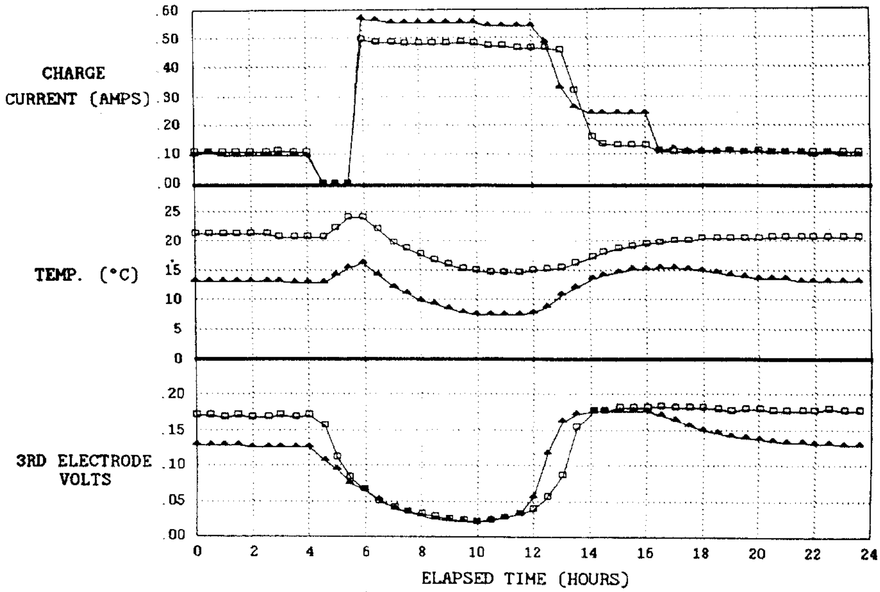

Fig. 1. 24 hour battery recharge characteristics for day 243, August 31, 1986. IUE shadow season #18. □, battery 05; ▲, battery 06.

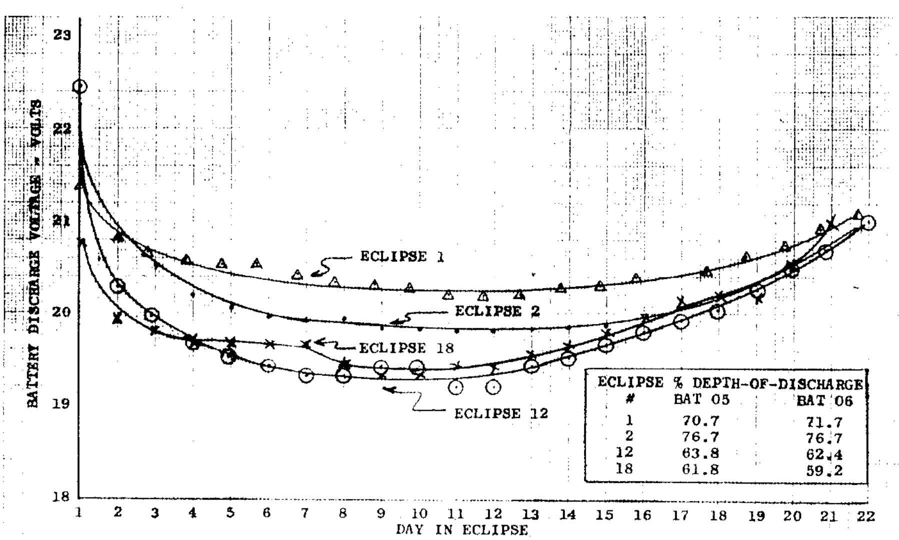

Fig. 2. IUE spacecraft peak battery discharge voltage *vs.* day in eclipse.

spacecraft power usage is also conducive to reducing battery DOD during the eclipse season shadow periods.

Immediately after launch, the spacecraft telemetry data indicated that battery 05 was approximately 8 °C warmer than battery 06. Data analyzed

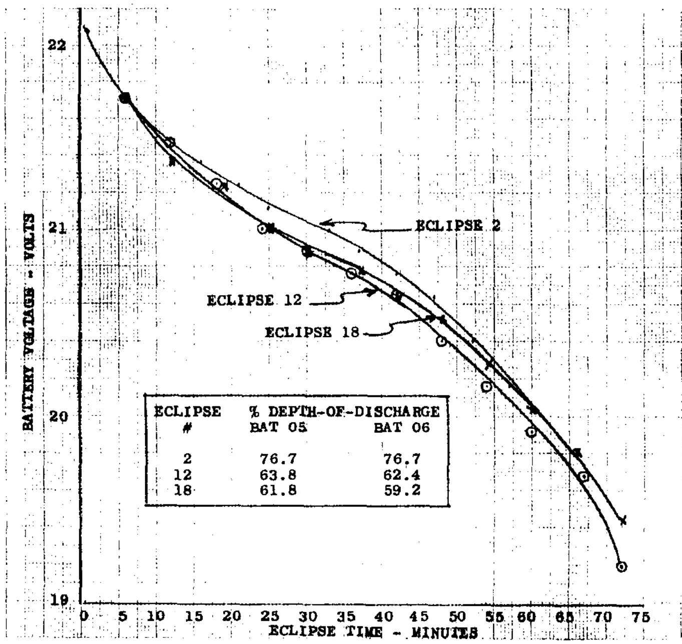

Fig. 3. IUE spacecraft battery discharge voltage eclipse seasons 2, 12 & 18.

during eclipse seasons 1 through 9 indicated that the operational life of battery 05 may be shortened by the warmer temperature. However, data plotted for eclipse seasons 10 through 18 indicate that the battery DOD may be the predominant factor in cell degradation. The temperature difference between the batteries appears to be the controlling factor in load sharing, *i.e.*, battery 06 (approx. 15 °C) provided more power than battery 05 (approx. 23 °C) during the peak discharge periods for eclipse seasons 1 - 9. A switch in load sharing occurred during eclipse season 10 when battery 05 began to provide more power than battery 06, supporting the theory that the battery DOD may be the predominant degradation factor. Additional data are shown in Fig. 5 indicating that battery discharge current is directly proportional to the DOD data previously shown in Fig. 4.

Figure 6 is a composite data plot of 10 cells on test at NWSC, Crane, Indiana. Discharge cell voltages were plotted *versus* ampere hours out 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 °C to 80% DOD. The recharge profile was modified prior to eclipse season 13 to simulate the recharge scheme utilized to recharge the spacecraft batteries. The data demonstrate that the discharge voltages of the test cells track in a close pattern and that cell capacity exceeds 6 A h after 18.5 simulated eclipse seasons.

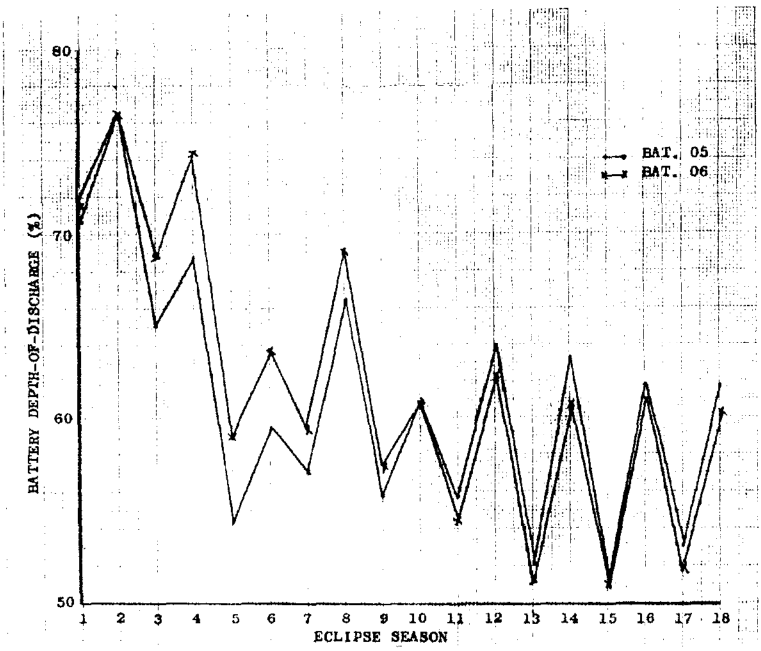

Fig. 4. IUE spacecraft battery depth-of-discharge *vs.* eclipse season.

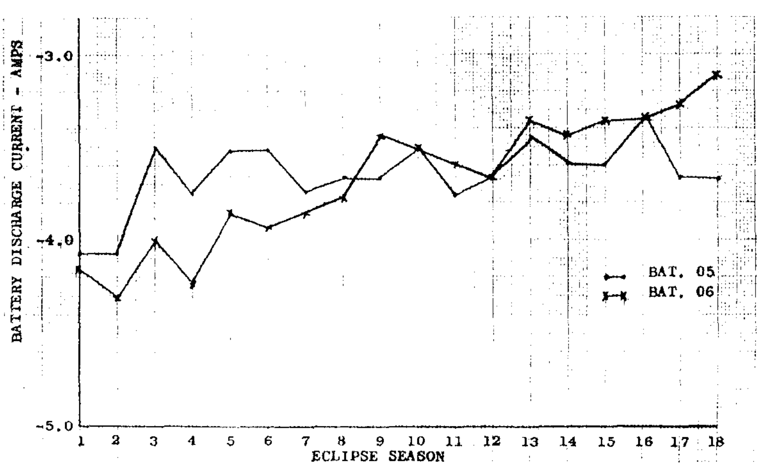

Fig. 5. IUE spacecraft peak battery discharge current *vs.* eclipse season (day 11).

Conclusions

The IUE battery cell performance is excellent — with the exception of the third electrode anomaly and the temperature difference between batteries. Data indicate that battery DOD may be more critical in the exten-

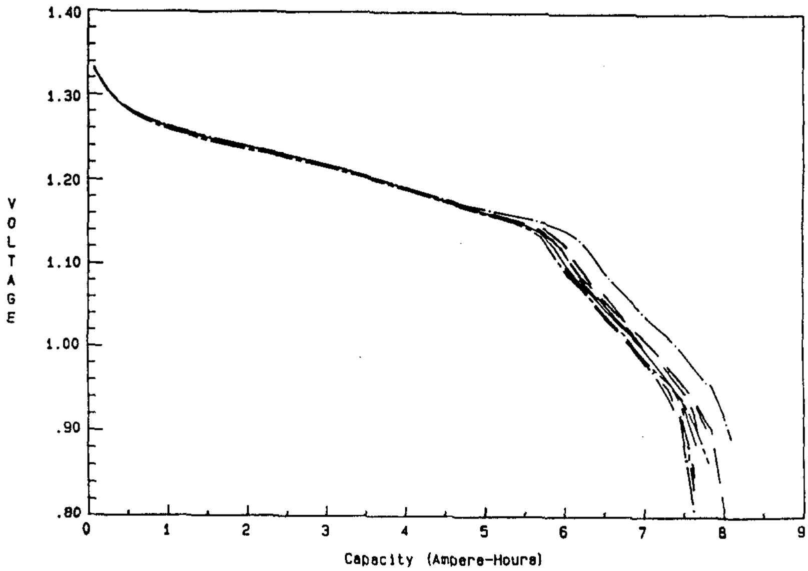

Fig. 6. Average cell voltages of NWSC cells in mid-eclipse at 10 °C to 80% DOD at 4 A discharge.

sion of battery life than small operational temperature differences between batteries. It is predicted that several additional years of battery life may be obtained by a reduction in operational battery DOD.