IN FLIGHT PERFORMANCE OF A SIX AMPERE-HOUR NICKEL-CADMIUM BATTERY IN LOW EARTH ORBIT

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ABSTRACT

A low earth orbit (LEO) spacecraft has successfully completed over 17,000 orbital cycles. The energy storage system for this spacecraft supplies eclipse power and power for peak loads, and is a 28 volt, 6 ampere-hour Nickel-Cadmium battery system. There are two batteries per spacecraft, and each battery consists of 21 series connected, hermetically sealed Nickel-Cadmium cells. The cells utilize a pellon separator, a standard positive plate and a silver-treated negative plate.

This paper reviews and summarizes flight data for 17,000 orbital cycles. Discussion focuses on battery trend analysis used in determining the feasibility of extending mission life.

SYSTEM DESCRIPTION

The battery function on this spacecraft is power production during eclipse periods and power provision for power conditions in which the required load exceeds the solar array power. The average bus load for the completed 17,000 orbital cycles was 40 watts. The batteries equally share the bus load, although the system was designed so that either battery could support the load during eclipse periods. A simplified electrical power system (EPS) block diagram, Figure 1, shows that each battery has its own battery charger comprised of a primary (A) and backup (B) charger. The primary charger utilizes the Voltage/Temperature (V/T) charge curves shown in Figure 2. The lower V/T curve (A) is approximately equivalent to level 4 of the NASA Modular Power System V/T curves. The backup charger operates at a constant C/10 charge rate or a commandable C/60 trickle charge rate. Only the primary charger has been employed for the completed 17,000 cycles with all operations at level A.

The spacecraft solar array system comprises three body-mounted solar panels and four deployable solar paddles. There are a total of 53 solar cell strings. Thirty-five strings are permanently wired to the power bus while 18 strings can be ground commanded IN or OUT. The power control and distribution unit routes and controls power to the battery chargers and from the solar arrays or batteries. Excess power is controlled with the 18 switchable solar cell strings. When the bus voltage rises above 32 volts, a shunt control unit switches shunt resistor banks ON to dispense excess power.

CELL/BATTERY DESCRIPTION

Nickel-Cadmium cell design parameters are summarized in Figure 3. Plate loading and the negative-to-positive capacity ratio are standard for sealed spacecraft cells (ref. 1). The material for the positive and negative terminals is Nickel 200, the separator is Pellon 2505 and the cell case is 304L stainless steel. The cell height, including terminals, is 3.63 inches. Width is 2.13 inches and thickness 0.82 inches. The cell weight averages 285 grams.

The six ampere-hour, 28 volt Nickel-Cadmium battery, depicted in Figure 4, consists of 21 series connected cells. Battery dimensions are provided in Figure 4, and the battery weight is 16.3 pounds. Three thermistor temperature sensors are strategically placed on each battery. Data from the two thermistors mounted to the top surfaces of cells number six and eleven are included in telemetry data. A third thermistor is mounted between cells number 16 and 17, and is used for the V/T charge control. The battery is mounted to an aluminum honeycombed deck in the spacecraft with an RTV-60 compound for improved heat transfer.

FLIGHT DATA

The battery data base for this spacecraft includes battery temperature, recharge fraction (charge/discharge ratio), average daily depth-of-discharge (DOD), minimum battery voltage and the bus load. Battery performance is directly related to solar array performance, which is influenced by percent illumination, alpha angle (complement of beta) and solar flux. The solar flux is normalized to a standard 135.3 milli-watts per square centimeter. These parameters are provided in Figure 5 as a function of orbit number.

The average battery temperature for the 17,000 cycles was approximately 20°C. Battery temperature versus revolution (orbit) is plotted in Figure 6. Comparison of Figures 5 and 6 illustrates battery temperature is largely a function of the alpha angle, although percent illumination and solar flux also influence battery temperature. The temperature plot, Figure 6, indicates spacecraft battery temperature is high compared to other aerospace LEO vehicles (ref. 2). High battery temperatures occurred only on this spacecraft, the first of a series. Several subsequent spacecraft have maintained battery temperatures to less than 10°C.

The average daily DOD for both batteries has been consistently below 10 percent. The low average DOD results from the conservative design approach; i.e., sizing the power system for operation with one battery failure. The DOD largely depends on the eclipse period, with larger DOD during an eclipse greater than 22 percent of the orbit period. This condition is illustrated, Figure 7, for DOD and recharge fraction, which are closely related. The recharge fraction for eclipse periods greater than 22 percent of the orbit is from 110% to 120%. This recharge fraction is considered normal for a temperature of 20°C and for the V/T charging level used for this spacecraft.

The minimum battery voltage is the most easily observed cell degradation characteristic (ref. 3 and 4). Figure 8 shows minimum battery voltage as a function of orbit number. As seen in the figure, minimal cell voltage degradation has occurred during the 17,000 orbits. Minimum battery voltage for seven percent DOD as a function of revolution is shown in Figure 9. Data for the first 7000 cycles was for an Alpha 90° condition, thus was not plotted due to its particularity. The end-of-discharge voltage has remained reasonably stable during the past 10,000 orbits, ranging from 26.1 to 26.3 volts. This corresponds to cell voltages of 1.24 to 1.25 volts. This is substantially above the minimum acceptable bus voltage of 23.8 volts. Barring any sudden changes in performance, the batteries will almost certainly meet and exceed the mission requirement.

LIFE TEST DATA

Life testing on a flight type battery has been conducted in parallel with the mission. Over 16,000 LEO cycles at 20 percent DOD and 25°C have been completed to date. The minimum battery voltage degradation for 20 percent DOD is shown in Figure 9. The end-of-discharge battery voltage was stabilized around 25.7 volts up to orbit 11,500. An appreciable battery voltage degradation of 0.5 volts has occurred during the last 4,000 cycles. The same V/T charge level as the flight battery is utilized. The discharge regime consists of a 2.0 amperes constant current discharge. A capacity check prior to the start of the life test yielded 7.80 ampere-hours. The capacity check was performed at a C/2 discharge rate to a battery voltage of 23.8 volts.

Similar capacity checks at cycles 308 and 1264 yielded 7.35 ampere-hours and 5.55 ampere-hours respectively. The charge and discharge regimes for cycles 2200 and 15465 are compared in Figures 10 and 11. The end-of-charge voltage curves for cycles 2200 and 15465 are basically identical, thus only one charge voltage curve is present in Figure 10. The charge current increase from cycles 2200 to 15465 is considered normal and has been previously reported (ref. 5 and 6). The end-of-discharge battery voltage degradation, depicted in Figure 11, from cycles 2200 to 15465 is analogous to the life test minimum battery voltage degradation depicted in Figure 9. This voltage degradation is inherent to Nickel-Cadmium and is considered acceptable.

SUMMARY

The Nickel-Cadmium battery system on this spacecraft has successfully completed 17,000 low earth orbit cycles without a failure or an abnormality. The in-house life test data for 20 percent depth-of-discharge, Figure 9, indicate design life requirements would be reached, even at a deeper depth-of-discharge. The relatively simple, predictable and repetitive load profiles for this spacecraft, in conjuntion with the conservative power system design approach, will result in the capability to extend mission life.

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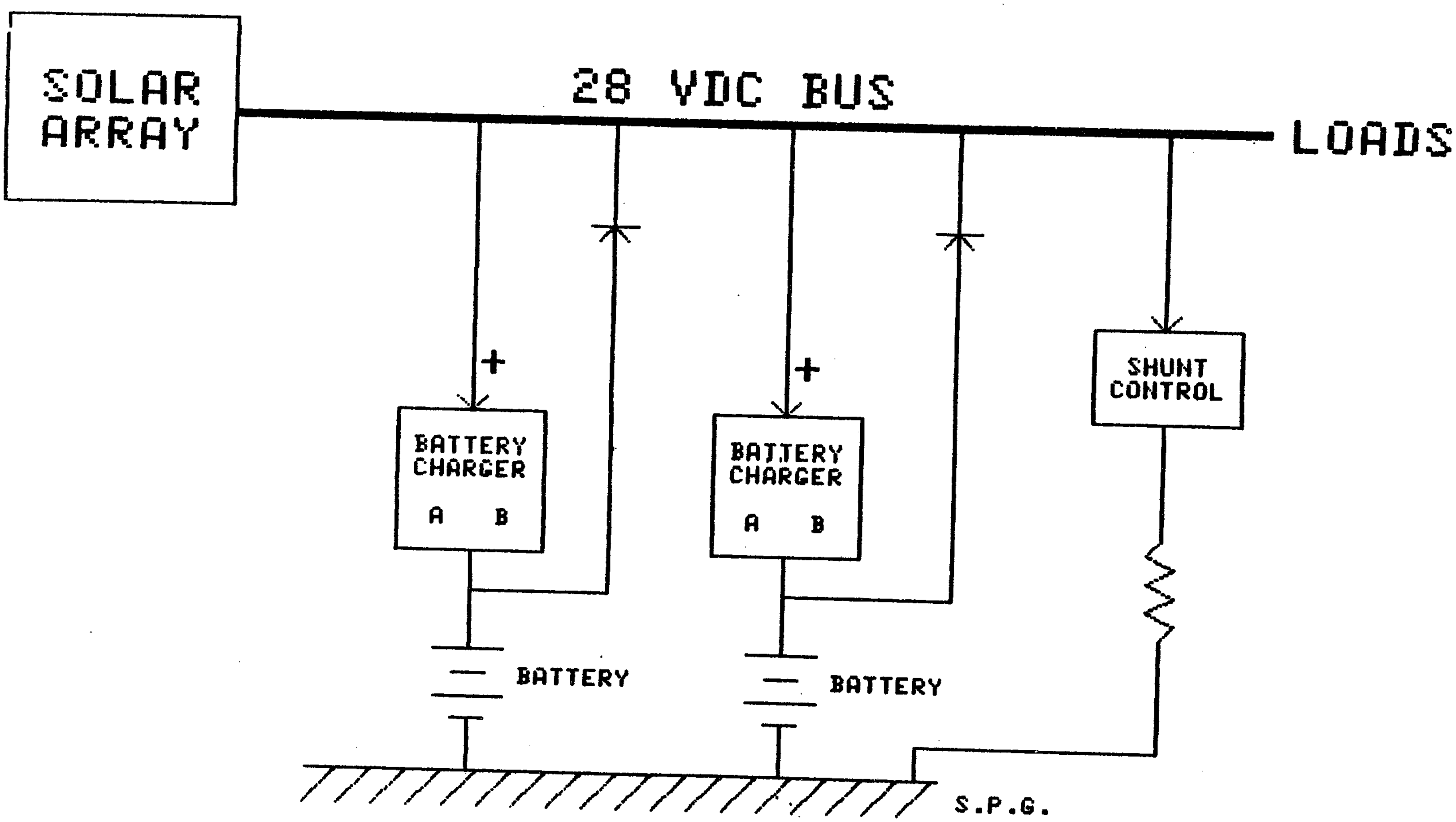

Figure 1. Electrical power system block diagram.

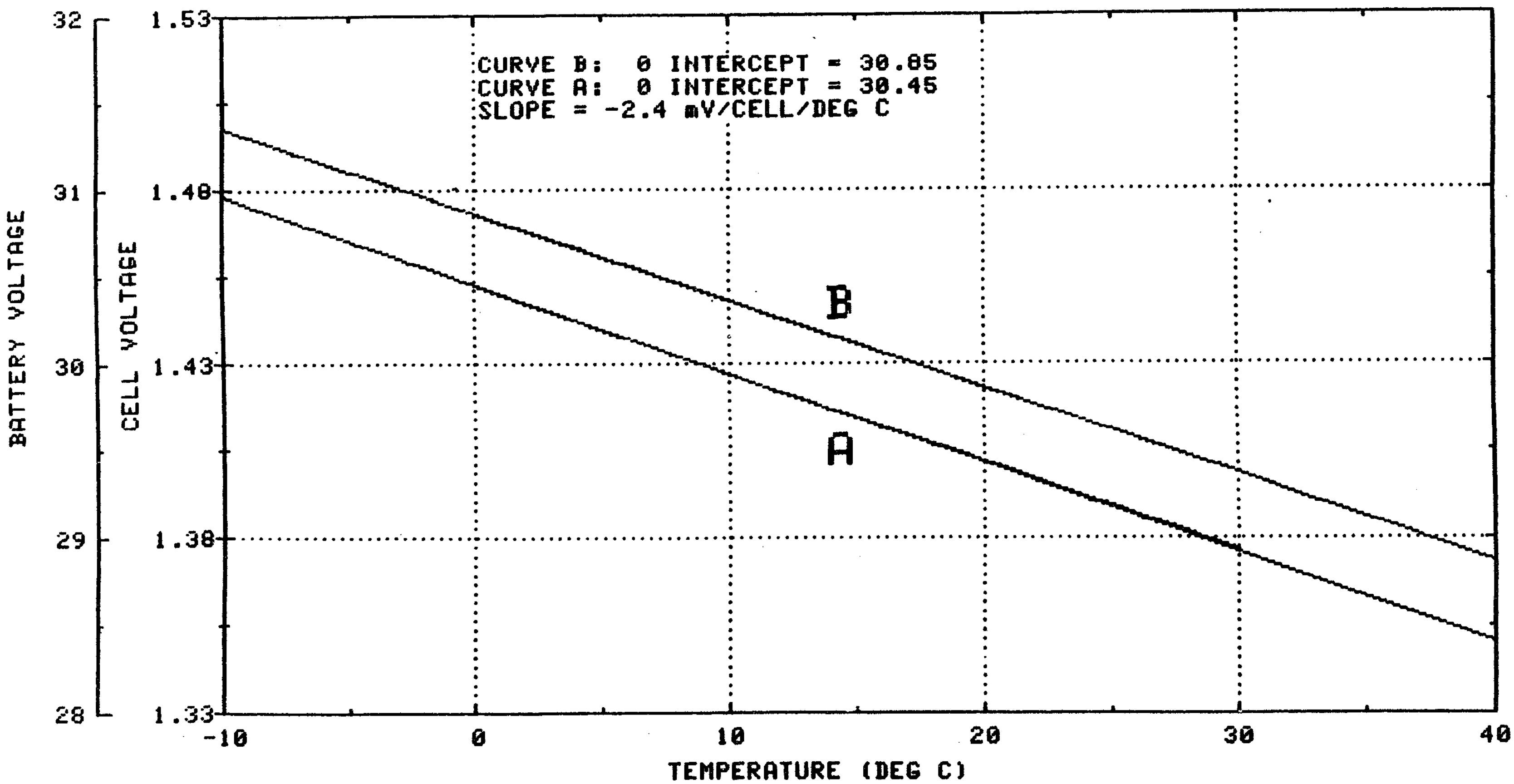

Figure 2. Cell/battery voltage limit versus temperature.

PART NUMBER	6AB67
NAMEPLATE CAPACITY (AH)	6.0
SHIPPING WEIGHT (GRAMS)	285
NO. OF PLATES (+/-)	10/11
POSITIVE LOADING (G/DM^2)	12.51
POSITIVE AREA (CM^2)	275.5
NEGATIVE LOADING (G/DM^2)	15.50
NEGATIVE AREA (CM^2)	303.1
NEGATIVE TREATMENT	SILVER
NEGATIVE/POSITIVE RATIO	1.73
OVERCHARGE PROTECTION (AH)	3.3
KOH LOADING (CC)	21.0

Figure 3. Cell design parameters.

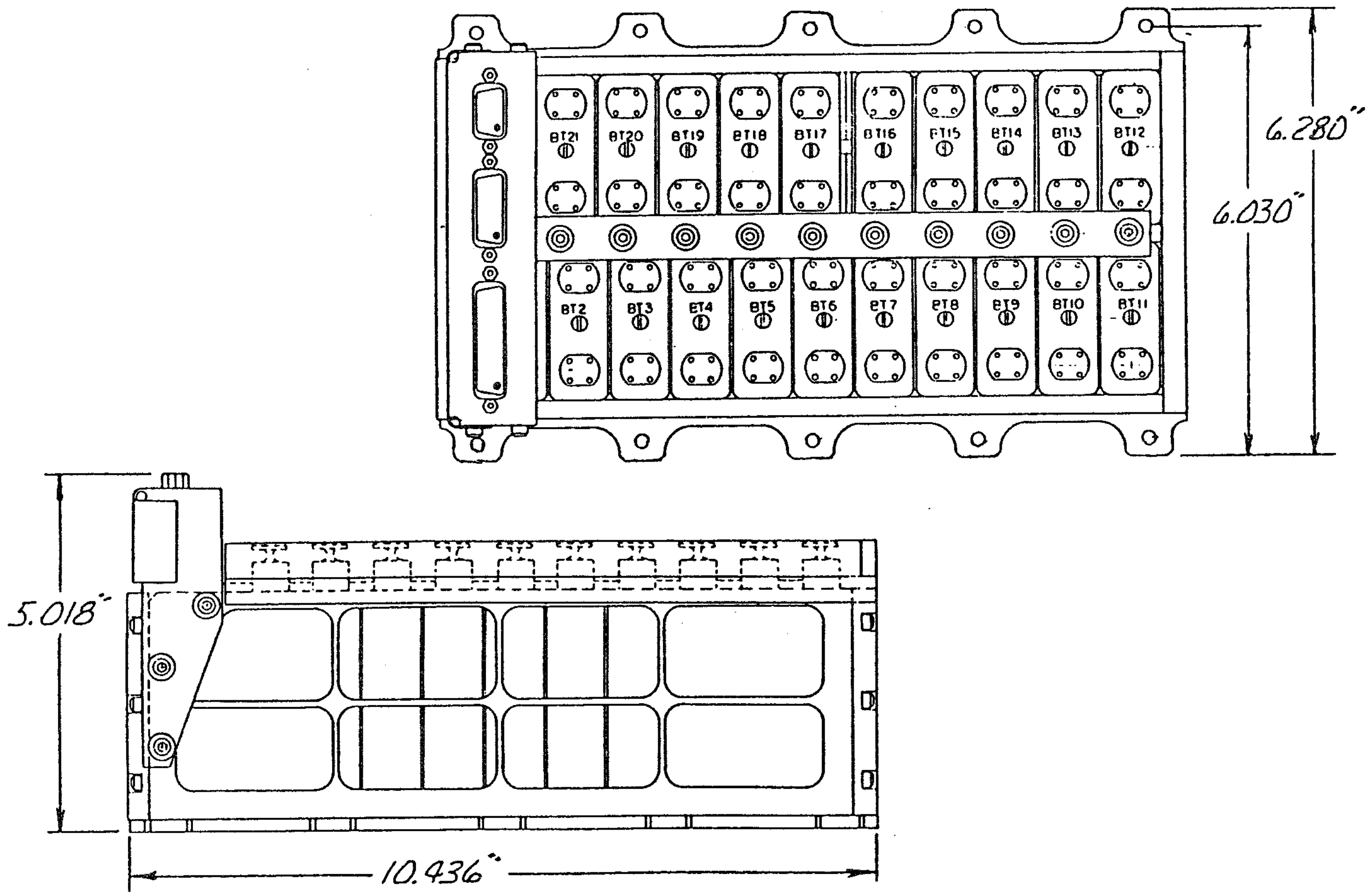

Figure 4. 28 volt, 6 AH battery configuration.

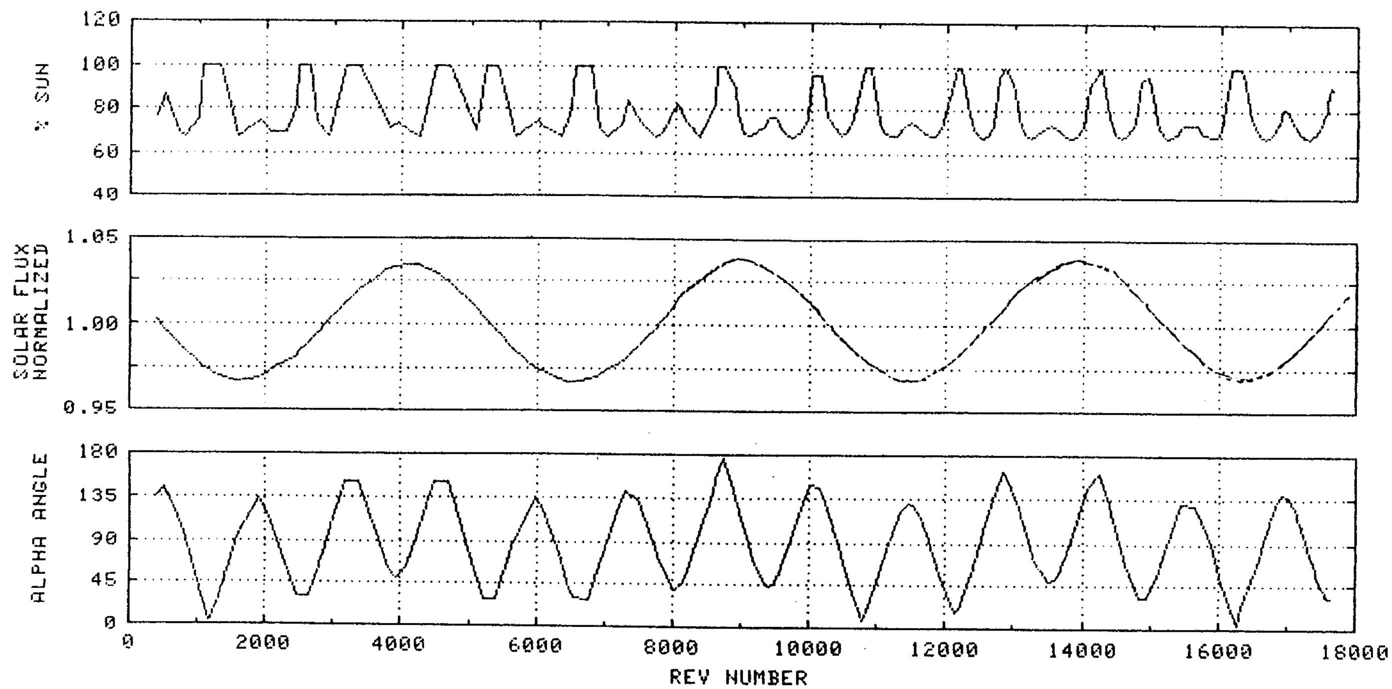

Figure 5. Spacecraft profile.

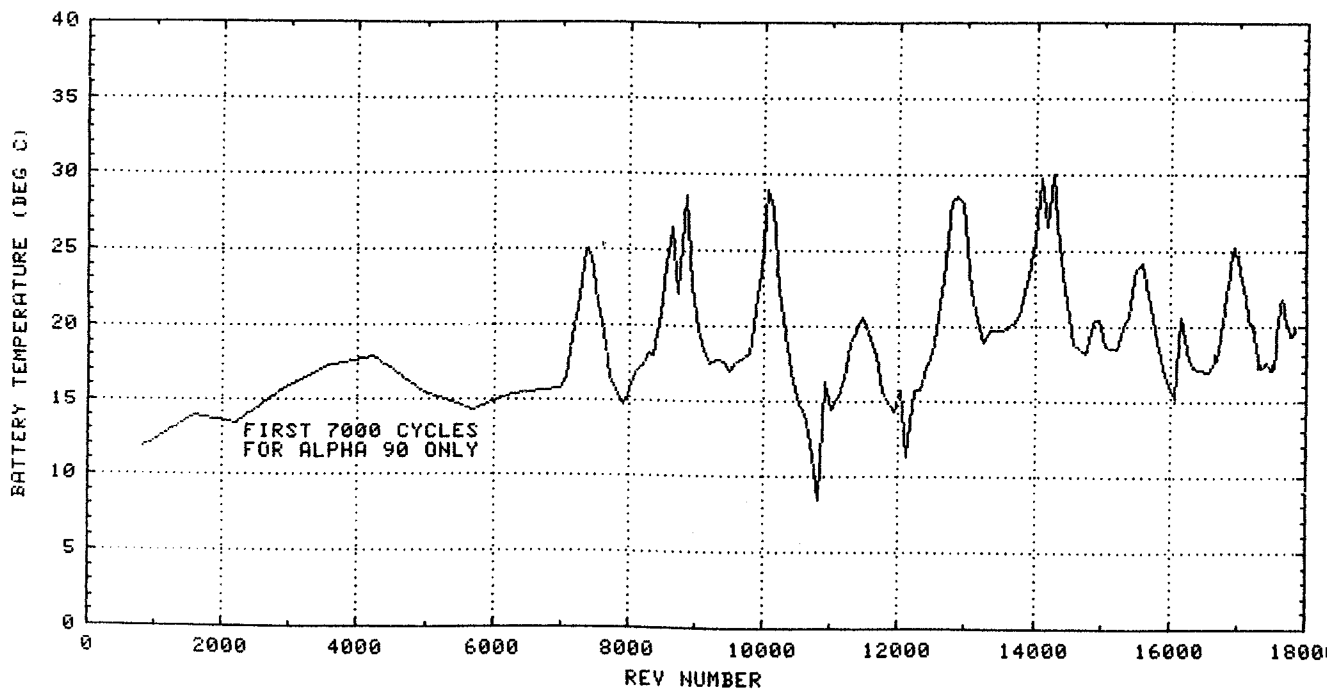

Figure 6. Battery temperature profile.

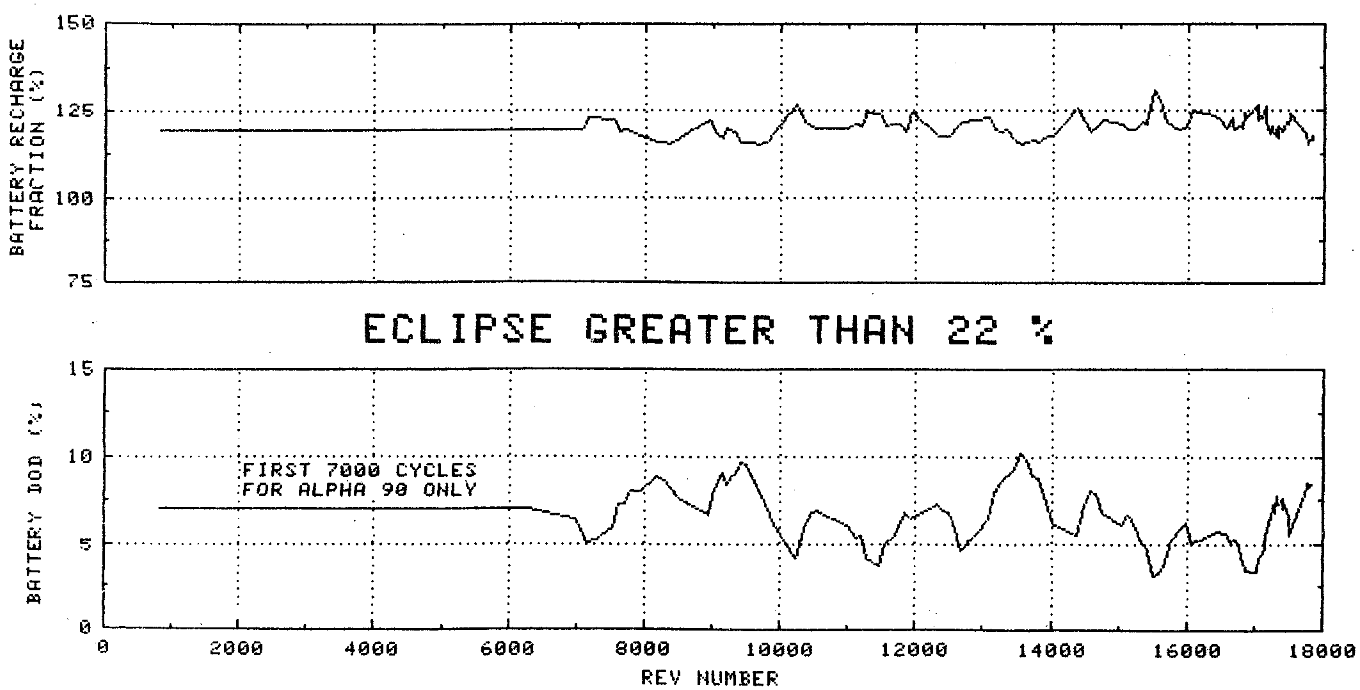

Figure 7. Daily average recharge fraction and depth-of-discharge.

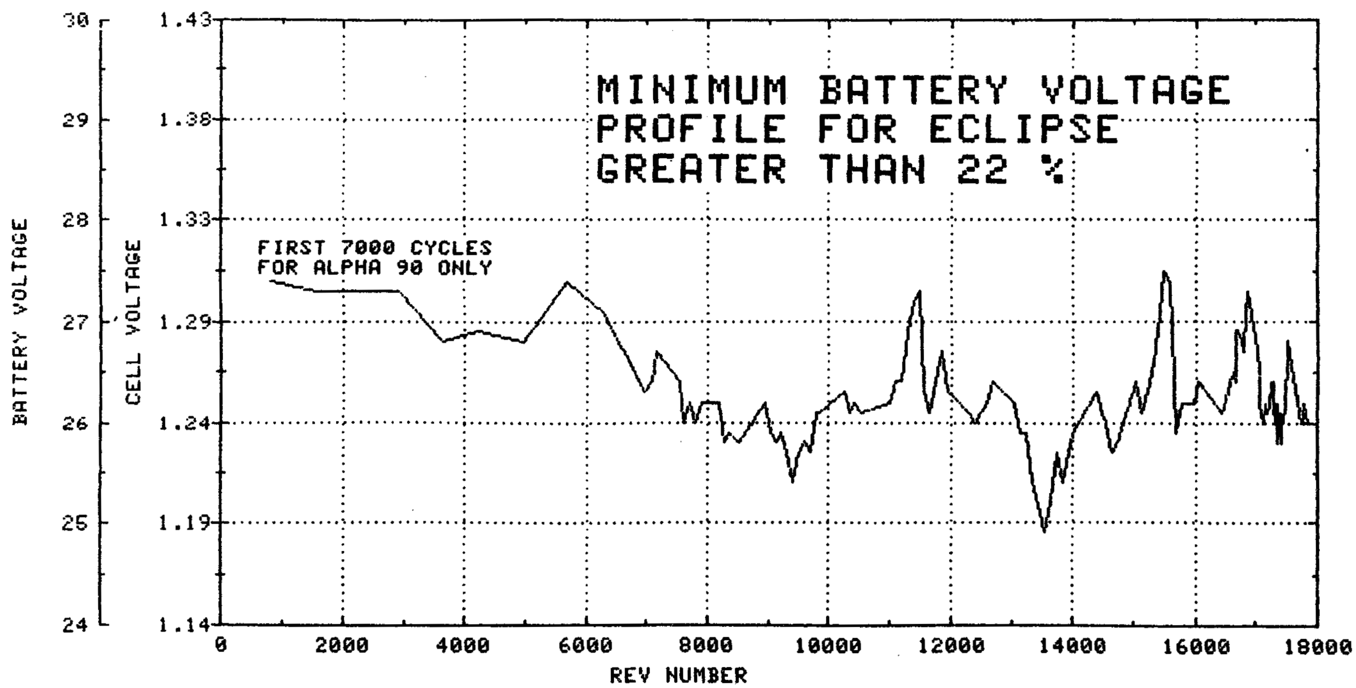

Figure 8. Minimum battery voltage profile.

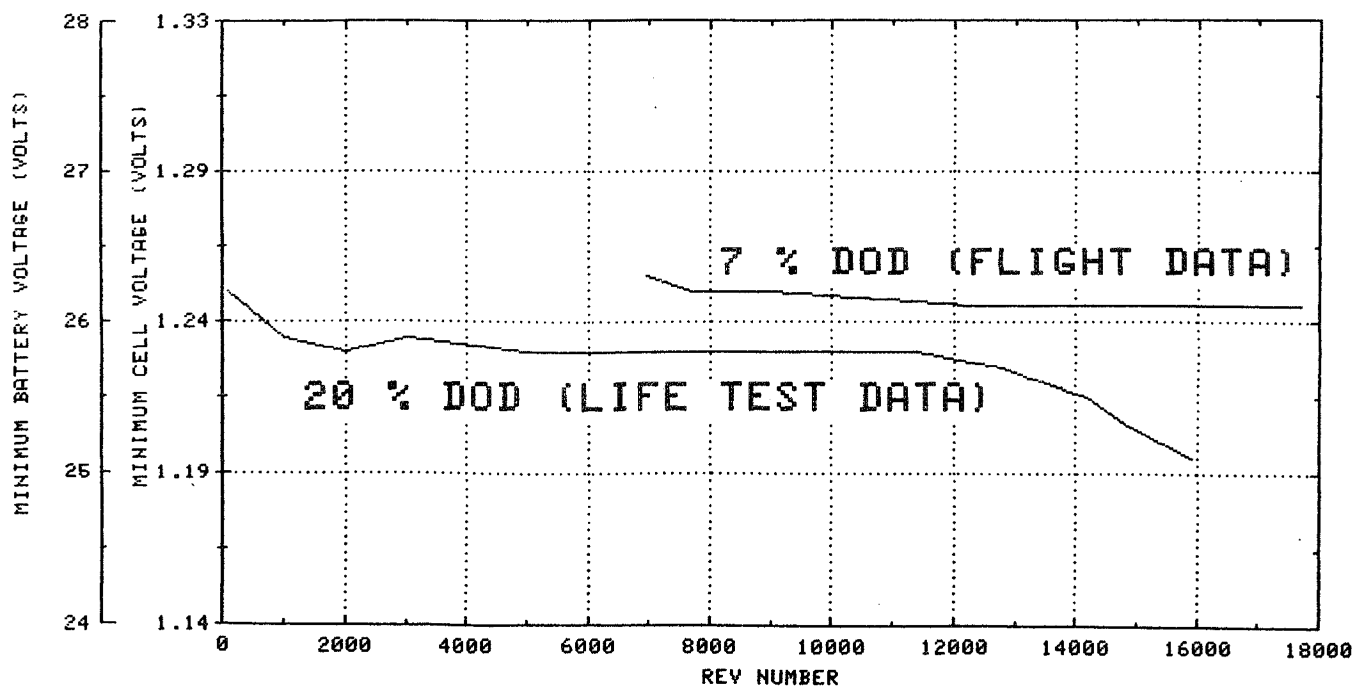

Figure 9. Flight battery versus life test depth-of-discharge comparison.

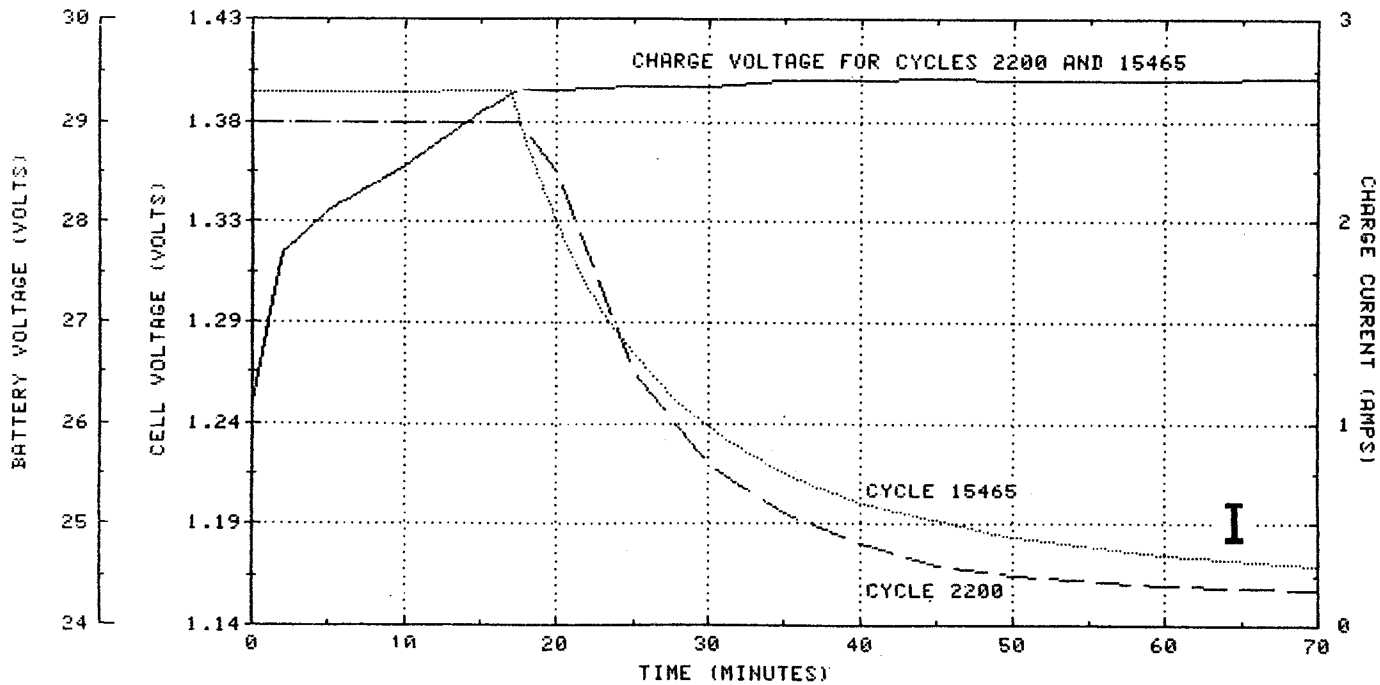

Figure 10. Life cycle test charge curves.

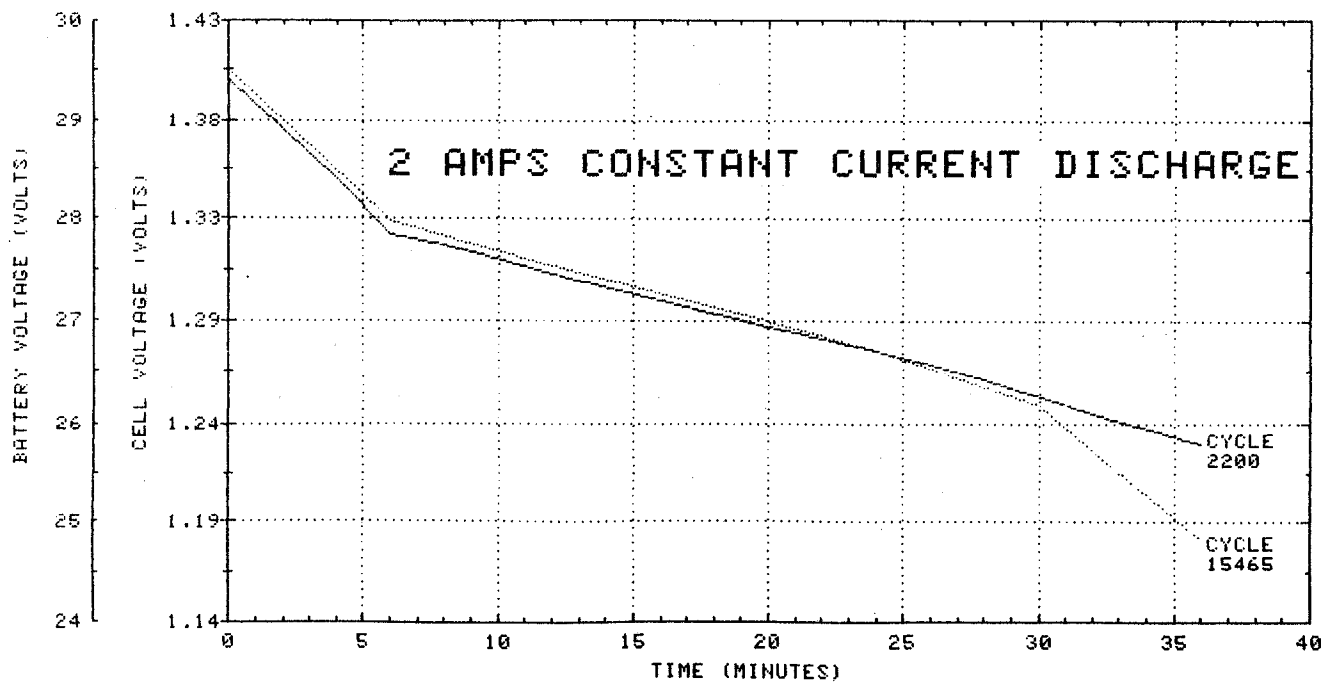

Figure 11. Life cycle test discharge curves.