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**THE DEVELOPMENT OF  
NICKEL-METAL HYDRIDE TECHNOLOGY  
FOR USE IN AEROSPACE APPLICATIONS**

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## BACKGROUND

The nickel metal hydride technology for battery application is relatively immature even though this technology was made widely known by Philips' Scientists as long ago as 1970. In particular Willem's 1984 dissertation in the Philips Journal of Research, Volume 39 Supplement No. 1, summarized for the reader the implications of metal hydrides for battery applications. However, recently, because of the international environmental regulatory pressures being placed on cadmium in the workplace and in disposal practices, battery companies worldwide have initiated extensive development programs to make this technology a viable commercial option. These hydrides do not pose a toxicological threat as does cadmium. In addition, they provide higher energy density and specific energy when compared to the other nickel based battery technologies as will be shown. For these reasons, the nickel metal hydride electrochemistry is being evaluated as the next power source for varied applications such as laptop computers, cellular telephones, electric vehicles and satellites.

The NIMH system uses a positive electrode that is similar to both NiCd and NiH<sub>2</sub> systems. The negative electrode is a metal alloy that absorbs hydrogen generated on charge and desorbs hydrogen during discharge. This leads to a cell that operates at a much lower pressure than a NiH<sub>2</sub> cell, 50 psig versus 950 psig. The technology would be a direct replacement for NiCd technology in most applications, along with a significant improvement in both specific energy and energy density. Since the technology is low pressure and has similar electrical performance to a NiCd

cell, it can be used in prismatic designs that are similar to current aerospace NiCd cell designs. In addition, since the cells would be prismatic in design, the battery design would be very similar to current NiCd battery designs.

GAB's parent company, Gates Energy Products (GEP), has a substantial ongoing effort to develop commercial NiMH wound cell technology. GEP's investigations and development started in mid 1987 in search of the best technology. A license agreement, established with Ovonic Battery Company in October 1990, initiated an intense product development.

GAB has a parallel development effort with GEP to look at aerospace applications for NIMH cells. This effort is focused on life testing of small wound cells of the commercial type to validate design options and development of prismatic design cells for aerospace applications. The manufacturing techniques for NiMH cells will be similar to current NiCd manufacturing techniques; however, some development of technology for flat plate metal hydride electrodes is required.

Although the promise is beckoning, one cannot lose sight of the shortfalls. These must be identified, studied, overcome or circumvented. The list includes end-of-life failure mechanisms; identification of optimum charge rates and charge termination methods; and stability of end-of-charge pressure. This will require intensive dedicated effort in the years ahead.

## DESCRIPTION OF TABLES AND FIGURES

TABLE I: A comparison of nickel metal hydride, nickel cadmium and nickel hydrogen 22AH cell performance attributes.

The data tabulated compares two current well-established Aerospace NiCd & NiH<sub>2</sub> product designs with the prototype 22AH NiMH cells assembled with flight qualified hardware. As can be seen, the specific energy and energy density of the NiMH cell are significantly better than that of the NiCd and NiH<sub>2</sub> cells. The advantage which the NiMH cell exhibits relative to the NiCd cell is derived from the higher energy density of the metal hydride electrode, expressed as AH/in<sup>3</sup>, versus the sintered cadmium electrode. On the other hand, the disadvantage the NiH<sub>2</sub> exhibits relative to the NiMH cell stems primarily

from the pressure vessel weight and volume, which is a particularly large percentage of the total cell weight and volume for capacities less than about 30AH.

TABLE II: A comparison of nickel metal hydride, nickel cadmium and nickel hydrogen 22AH cell dimensions.

TABLE III: A comparison of 6 and 22AH nickel metal hydride cell designs.

It should be noted that for the 6AH cell design nylon separator is employed as the baseline and is therefore listed. However, some of these cells have been assembled with polypropylene separator which is di-

mensionally a direct substitute for the nylon. The significance for examining polypropylene is its stability in the alkaline environment of the cell. This is to be contrasted to the slow degradation experienced by nylon, even though nylon is the primary separator utilized in most qualified Aerospace nickel cadmium cell applications.

**FIGURE 1:** Prototype Aerospace Prismatic 6AH cells on cycle life test.

**FIGURE 2:** Prototype Aerospace Prismatic 6AH cell discharge rate capability.

To examine the dependence of capacity as a function of discharge rate, cells were discharged at either the C/2, C or 3C rate following a C/10 charge. These tests were conducted at room temperature. As can be seen, the dependence on discharge rate over the range tested is minimal.

**FIGURE 3:** Cylindrical cell capacity vs temperature @ C rate.

**FIGURE 4:** Prototype Aerospace Prismatic 6AH cell EOCV and EODV trends as a function of number of 50% DOD LEO cycles.

The data shown illustrates the end-of-charge voltage (EOCV) and end-of-discharge voltage (EODV) trend over the cycle life accumulated to date. The discharge/charge regime is currently set at 3.00AH and 3.15AH, respectively. This equates to a 1.05 recharge ratio. Seventeen cycles are accumulated in a 24 hour period which totals to over 6000 cycles per year. Thusfar, the performance has been stable and appears promising.

**FIGURE 5:** Prototype Aerospace Prismatic 6AH cell charge voltage curve while undergoing 50% DOD LEO cycle: Recharge ratio = 1.05, cycle 1010.

**FIGURE 6:** Prototype Aerospace Prismatic 6AH cell discharge voltage curve while undergoing 50% DOD LEO cycle: Recharge ratio = 1.05, cycle 1010.

**FIGURE 7:** Prototype Aerospace Prismatic 6AH cell pressure curve while undergoing 50% DOD LEO cycle: Recharge ratio = 1.05, cycle 788.

The pressure fluctuates during the course of a given cycle. Hydrogen builds up somewhat and is present during the entire regime. Towards the conclusion of charge, the nickel electrode begins to evolve oxygen resulting in a pressure spike. The oxygen is simultaneously being consumed at the metal hydride electrode where it reacts with hydrogen to form water. At the conclusion of the charge sequence, the oxygen evolution from the nickel electrode ceases and the oxygen in the gas space is removed by its continued reaction at the metal hydride electrode.

**FIGURE 8:** Prototype Aerospace Prismatic 22AH cell EOCV and EODV trends as a function of number of 50% DOD LEO cycles.

The data shown illustrates the end-of-charge voltage (EOCV) and end-of-discharge voltage (EODV) trend over the cycle life accumulated to date. The discharge/charge regime is currently set at 11.0AH and 11.6AH, respectively. This equates to a 1.05 recharge ratio. Seventeen cycles are accumulated in a 24 hour period which totals to over 6000 cycles per year. Thusfar, the performance has been stable and appears promising.

**FIGURE 9:** Prototype Aerospace Prismatic 22AH cell charge voltage curve while undergoing 50% DOD LEO cycle: Recharge ratio = 1.05, cycle 512.

**FIGURE 10:** Prototype Aerospace Prismatic 22AH cell discharge voltage curve while undergoing 50% DOD LEO cycle: Recharge ratio = 1.05, cycle 512.

**FIGURE 11:** Prototype Aerospace Prismatic 22AH cell pressure curve while undergoing 50% DOD LEO cycle: Recharge ratio = 1.05, cycle 401.

**FIGURE 12:** Program conclusions to date.

**Table I**  
**Comparison of Nickel Battery Cell Performance in 22AH Geometries**

| <b>Performance Attribute</b>         | <b>Nickel Cell Electrochemistry</b> |                                    |                         |
|--------------------------------------|-------------------------------------|------------------------------------|-------------------------|
|                                      | <b>NiCd</b><br>(Note 1)             | <b>NiH<sub>2</sub></b><br>(Note 1) | <b>NiMH</b><br>(Note 2) |
| Midpoint Discharge Voltage (v)       | 1.20                                | 1.24                               | 1.24                    |
| Typical Capacity @ C/2 (AH)          | 27                                  | 22                                 | 22                      |
| Charge Retention (% , Note 3)        | 92                                  | 82                                 | 90                      |
| Cell Weight (Kg)                     | 0.80                                | 0.79                               | 0.57                    |
| Specific Energy (WH/Kg)              | 33.0                                | 34.5                               | 47.9                    |
| Energy Density (WH/in <sup>3</sup> ) | 1.67                                | 0.62                               | 2.56                    |

*Note 1: Gates Aerospace Batteries Product*

*Note 2: Actual Prototype Cell Data*

*Note 3: Room Temperature 72 Hour Retention*

**Table II**  
**Comparison of Nickel Cell Dimensions in 22AH Geometries**

| <b>Cell Dimensions</b><br><b>(Inches)</b> | <b>Nickel Cell Electrochemistry</b> |                                    |                         |
|---|-------------------------------------|------------------------------------|-------------------------|
|   | <b>NiCd</b><br>(Note 1)             | <b>NiH<sub>2</sub></b><br>(Note 1) | <b>NiMH</b><br>(Note 2) |
| Overall Height                            | 4.97                                | 8.25                               | 4.43                    |
| Base Height                               | 4.55                                | 5.94                               | 4.01                    |
| Width                                     | 3.66                                | 3.44(Dia)                          | 2.98                    |
| Depth                                     | 0.95                                | N/A                                | 0.89                    |

*Note 1: Gates Aerospace Batteries Product*

*Note 2: Actual Prototype Cell Data*

Table III

NiMH Prismatic Cell Design Summary

Prismatic Cell Design (Note 1)

| <b>Item</b>                         | <b>6AH</b> | <b>22AH</b> |
|-------------------------------------|------------|-------------|
| <b>Positive Electrodes</b>          |            |             |
| Number . . . . .                    | 14         | 15          |
| Thickness (in) . . . . .            | 0.028      | 0.028       |
| Capacity (AH) theoretical . . . . . | 7.5        | 27.6        |
| <b>Negative Electrodes</b>          |            |             |
| Number . . . . .                    | 15         | 16          |
| Thickness (in) . . . . .            | 0.0125     | 0.0125      |
| Capacity (AH) . . . . .             | 11.5       | 42.2        |
| <b>Separator</b> . . . . .          | Nylon-2538 | Nylon-2538  |
| <b>Negative to Positive</b>         |            |             |
| <b>Capacity Ratio</b> . . . . .     | <b>1.5</b> | <b>1.5</b>  |
| <b>Electrolyte</b>                  |            |             |
| Type . . . . .                      | KOH        | KOH         |
| Concentration (%) . . . . .         | 31         | 31          |
| <b>Cell Dimensions (in)</b>         |            |             |
| Overall Height . . . . .            | 2.75       | 4.43        |
| Case Height . . . . .               | 2.33       | 4.01        |
| Width . . . . .                     | 2.12       | 2.98        |
| Depth . . . . .                     | 0.82       | 0.89        |

*Note 1: Capacities are C/2 typicals at room temperature for prototype cells*

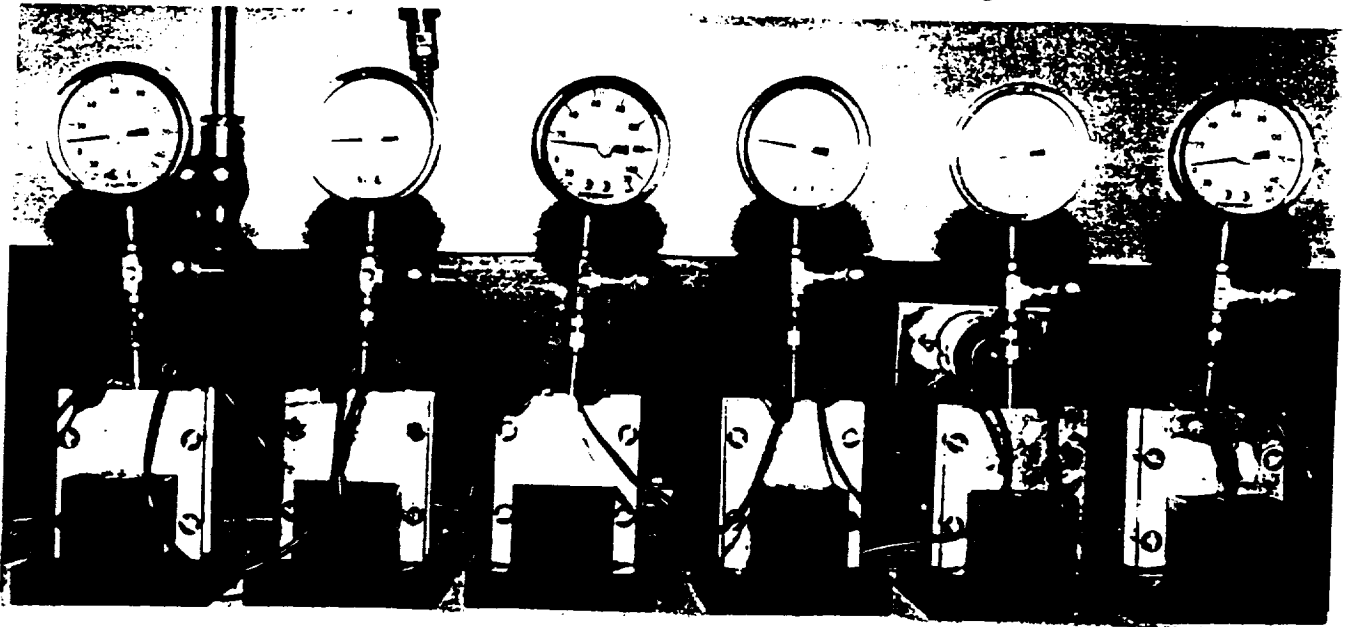


Figure 1 Prototype Aerospace Prismatic 6AH cells on cycle life test

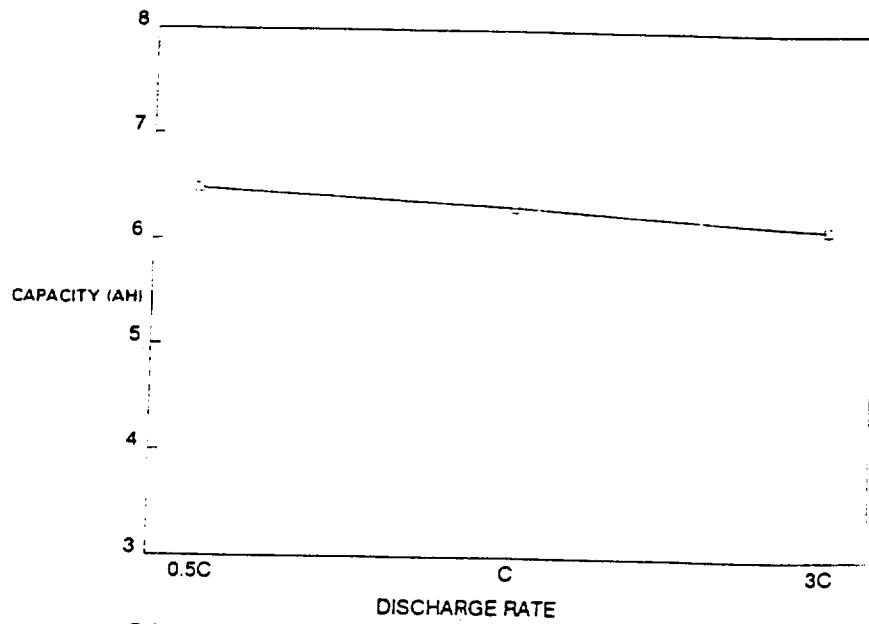


Figure 2 Prototype Aerospace Prismatic 6AH Cell Discharge Rate Capability

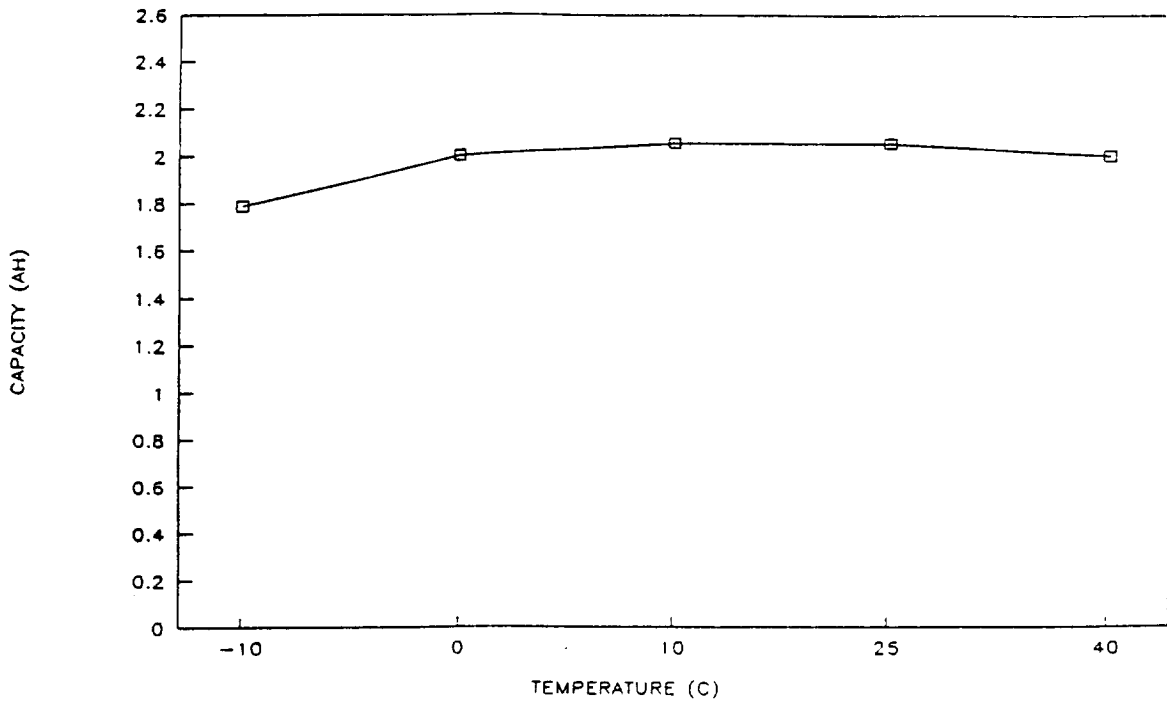


Figure 3 Cylindrical Cell Capacity vs. Temperature @ C Rate

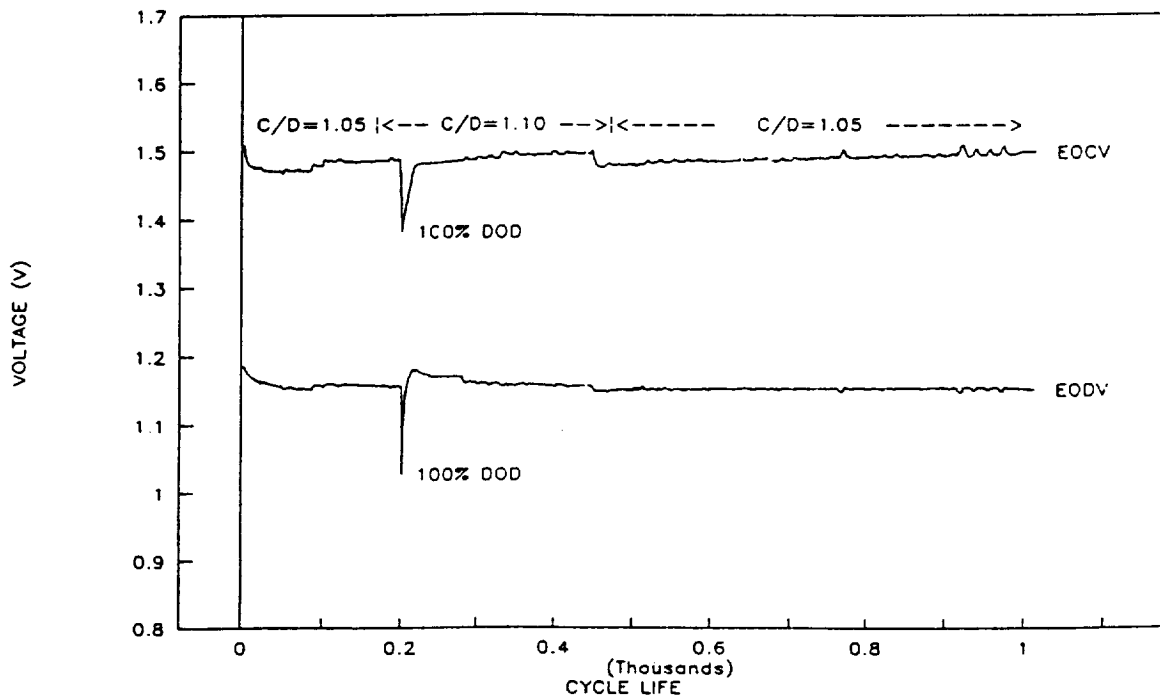
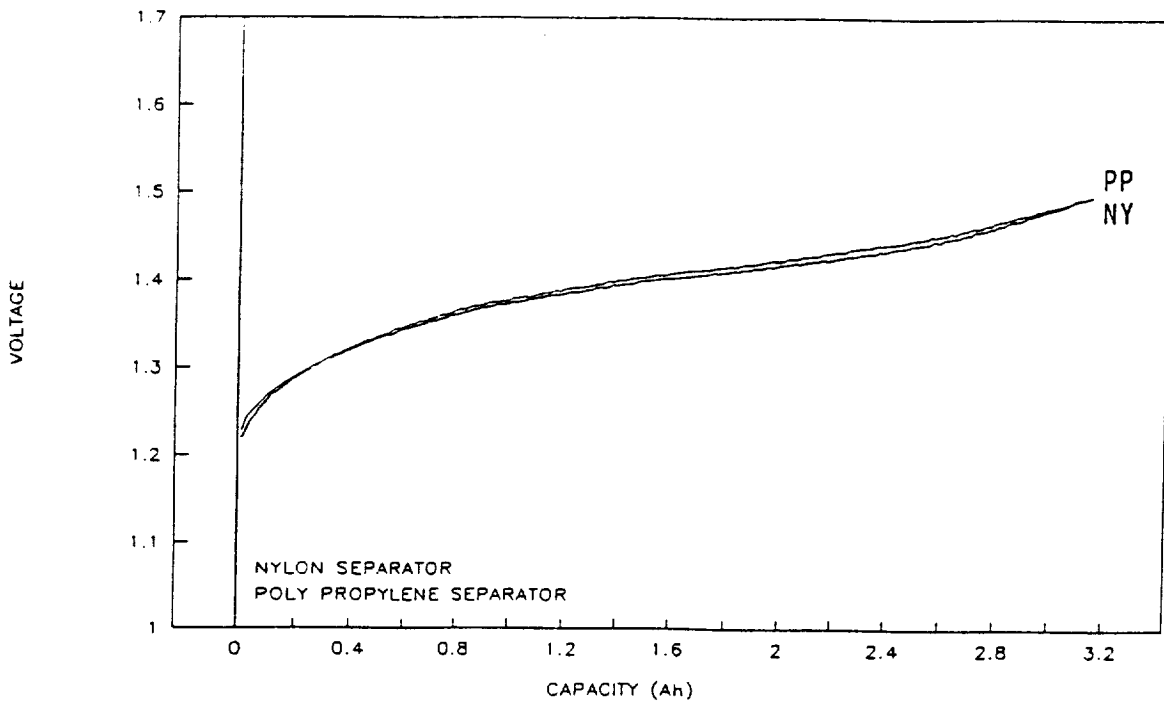
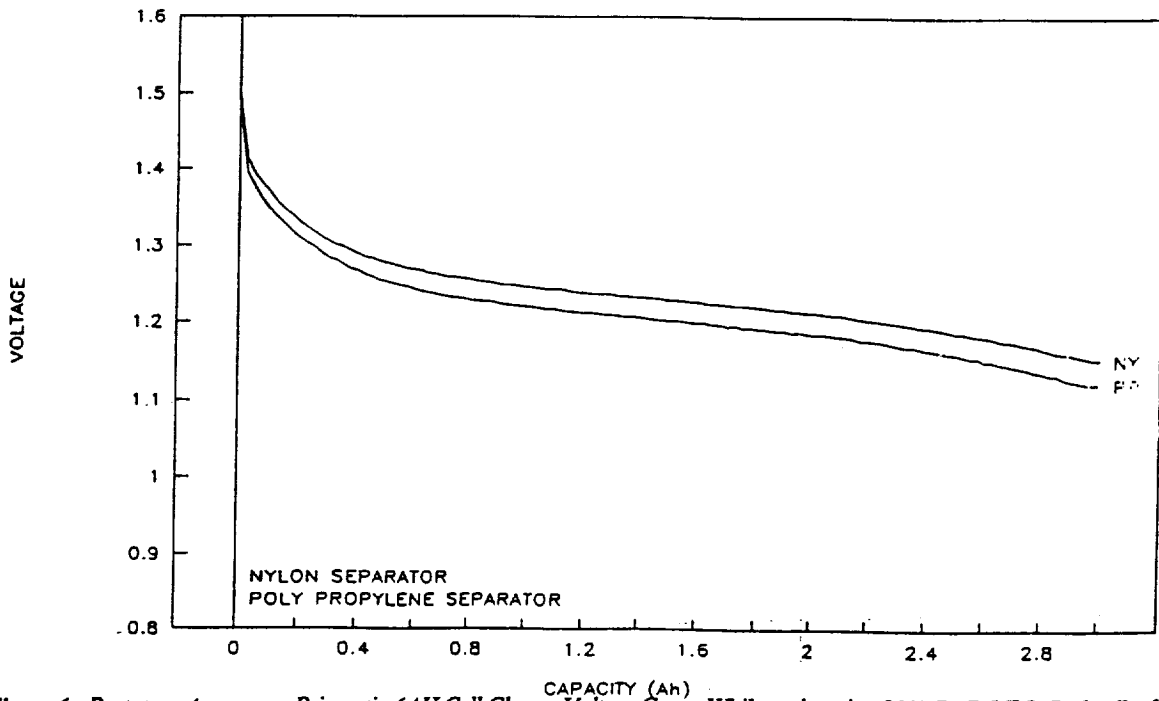


Figure 4 Prototype Aerospace Prismatic 6AH Cell EOCV and EODV Trends as a Function of Number of 50% DoD LEO Cycles

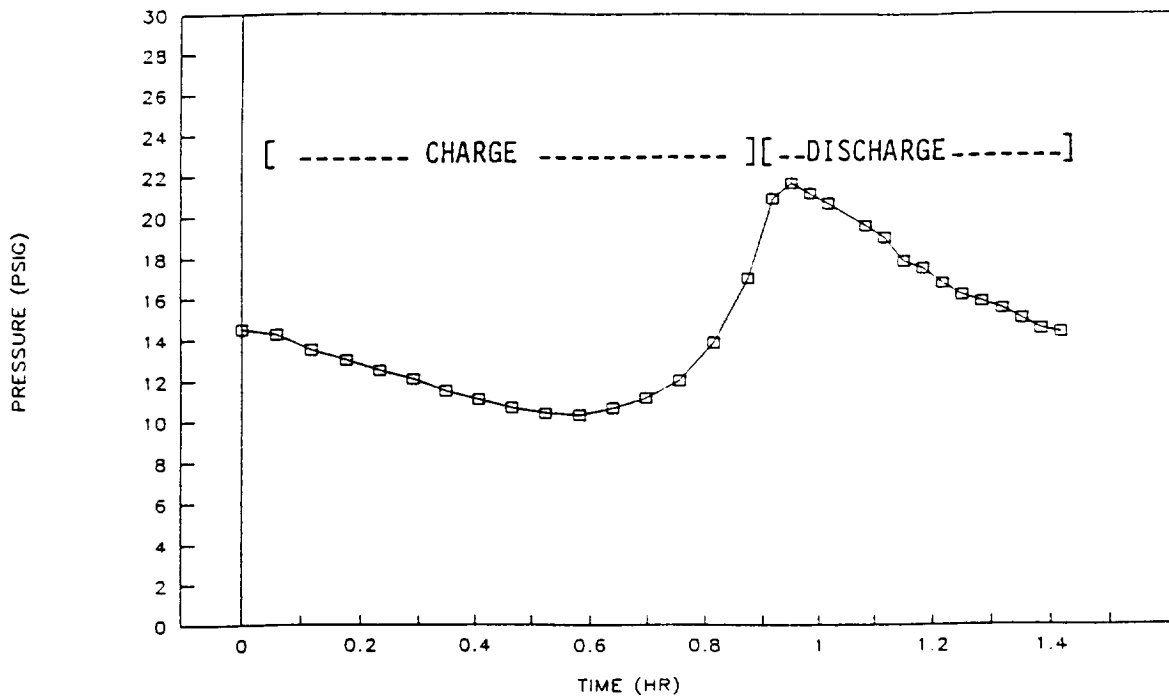


**Figure 5** Prototype Aerospace Prismatic 6AH Cell Charge Voltage Curve While undergoing 50% DoD LEO Cycle: Recharge Ratio = 1.05, Cycle 1010

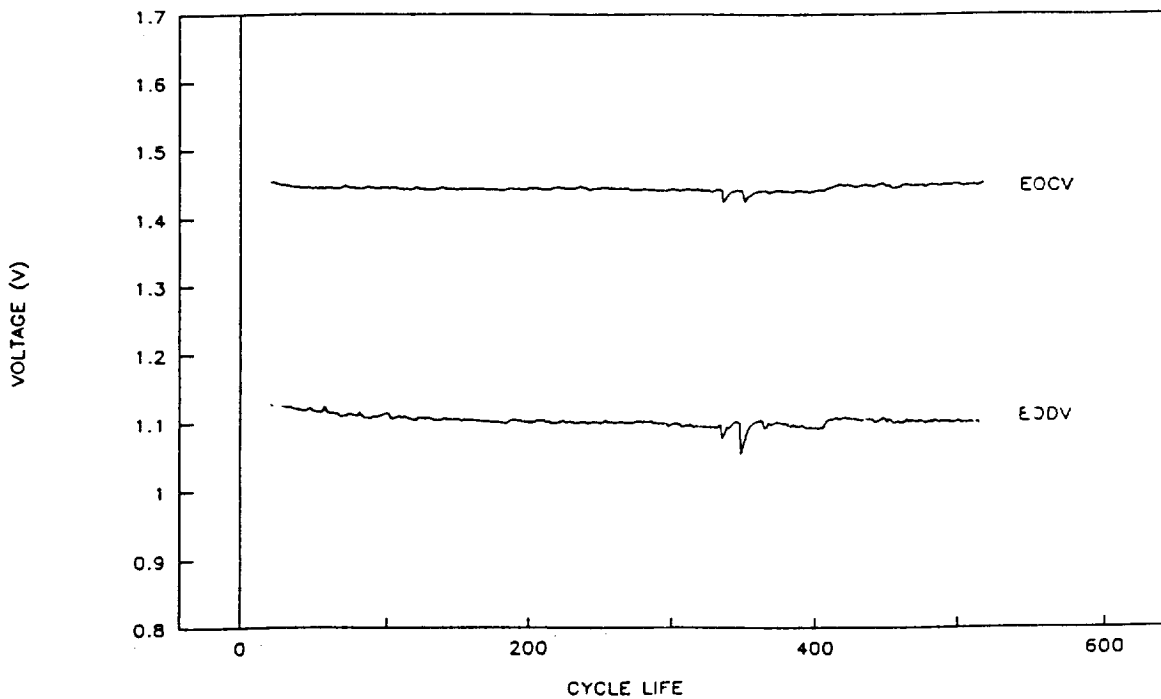


**Figure 6** Prototype Aerospace Prismatic 6AH Cell Charge Voltage Curve While undergoing 50% DoD LEO Cycle: Recharge Ratio = 1.05, Cycle 1010

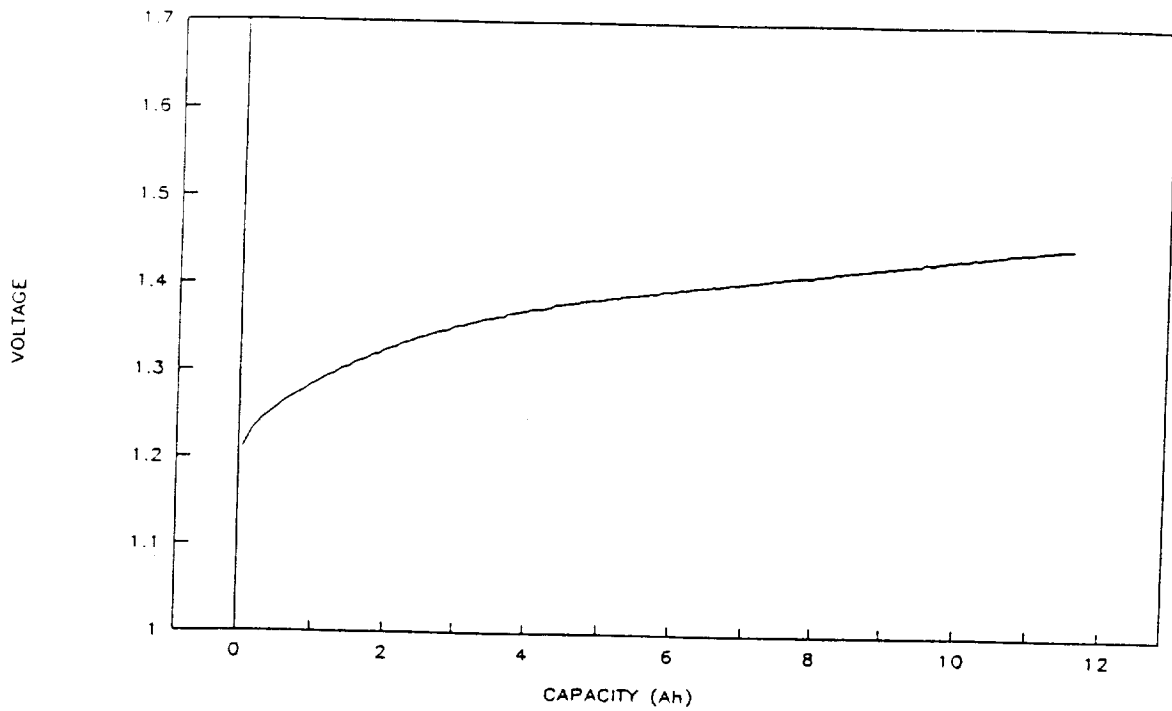




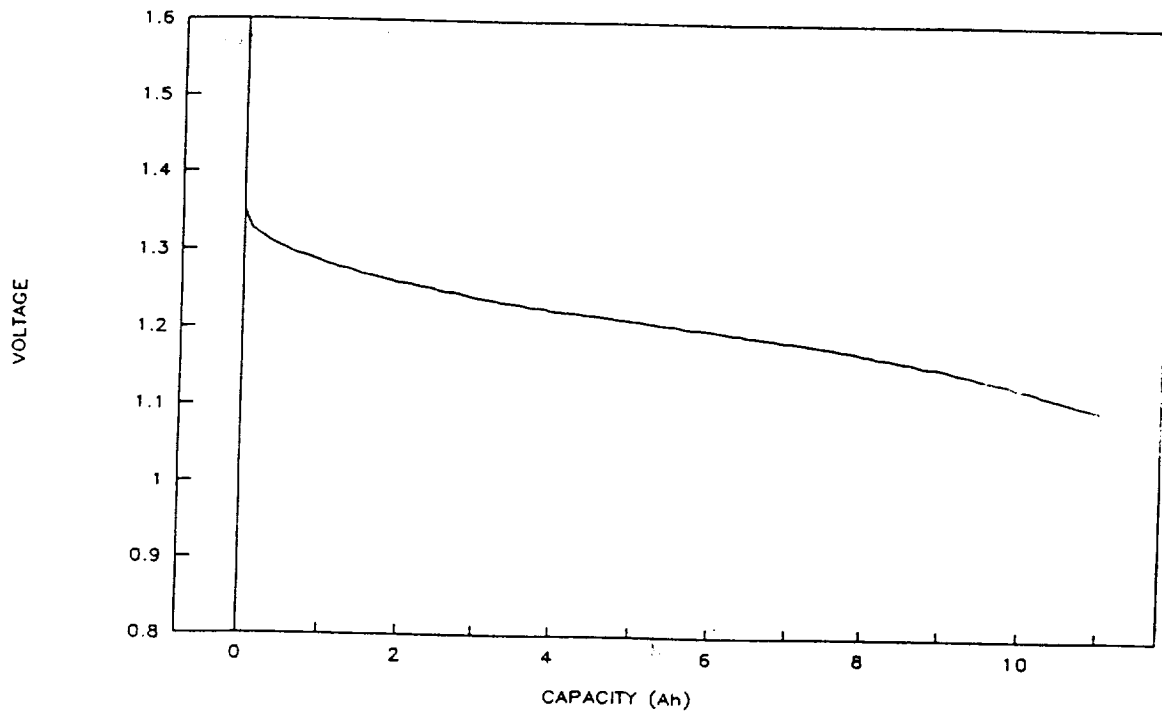
**Figure 7** Prototype Aerospace Prismatic 6AH Cell Pressure Curve While undergoing 50% DoD LEO Cycle: Recharge Ratio = 1.05, Cycle 788



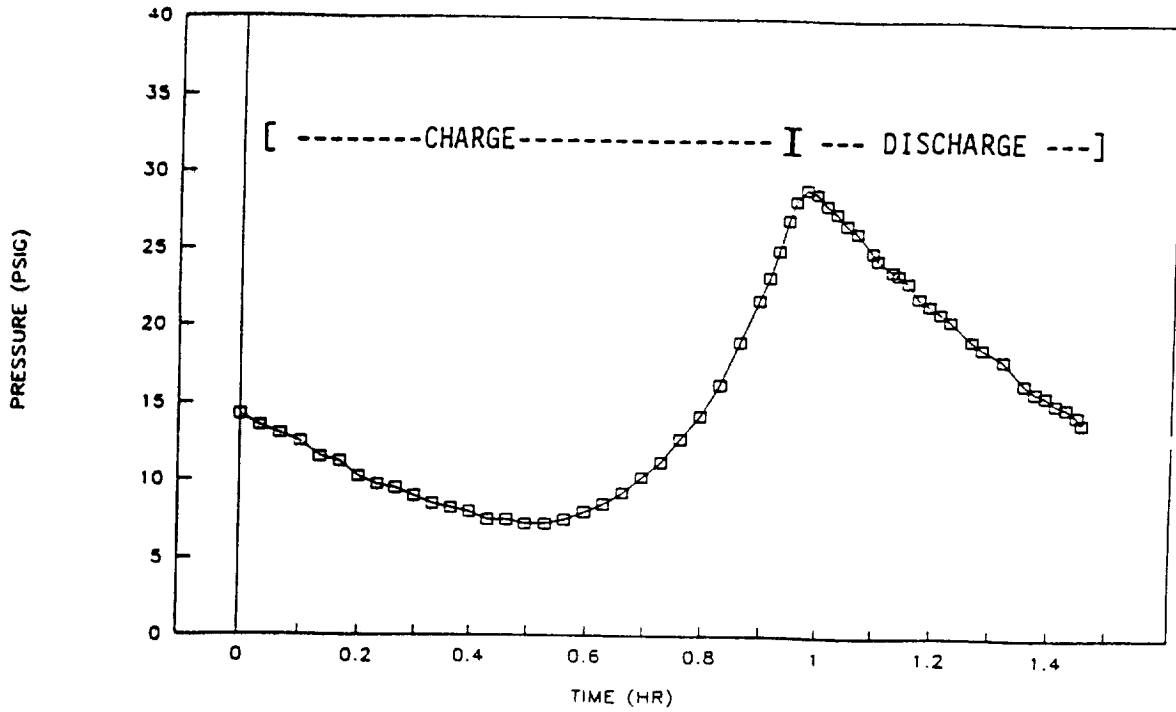
**Figure 8** Prototype Aerospace Prismatic 22AH Cell EOCV and EODV Trends as a Function of Number of 50% DoD LEO Cycles



**Figure 9** Prototype Aerospace Prismatic 22AH Cell Charge Voltage Curve While Undergoing 50 % DoD LEO Cycle: charge Ratio = 1.05, Cycle 512



**Figure 10** Prototype Aerospace Prismatic 22AH Cell Discharge Voltage Curve While Undergoing 50% DoD LEO Cycle: R: charge Ratio = 1.05, Cycle 512



**Figure 11** Prototype Aerospace Prismatic 22AH Cell Pressure Curve While Undergoing 50% DoD LEO Cycle: Recharge Ratio = 1.05, Cycle 401

Figure 12

## Conclusions

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Acceptable Pressures < 50 PSIG

Wide Operating Temperature Range, -10 to + 40 C

Insensitive to High Rate Regime - 3C

Promising Cycle Life - 1000 LEO cycles and counting

Energy Density > NiH<sub>2</sub> and NiCd

Specific Energy > NiCd and NiH<sub>2</sub>