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DEVELOPMENT OF FIRST GENERATION

AEROSPACE NiMH CELLS

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Program Description

- o Gates Energy Products involved in NiMH development since 1987
- o GAB aerospace cell development program begun in 1990 in conjunction with GEP
- o Prismatic cell testing begun in 1991
- o Initial work aimed at demonstrating feasibility and identifying problem areas
- o Recent work focused on improvements to alleviate identified problems

Gates Aerospace Batteries in conjunction with Gates Energy Products has been developing NiMH technology for aerospace use since 1990. GEP undertook the development of NiMH technology for commercial cell applications in 1987. This program focused on wound cell technology for replacement of current NiCd technology.

As an off shoot of this program small wound cells were used to evaluate initial design options for aerospace prismatic cell designs. Early in 1991, the first aerospace prismatic cell designs were built in a 6 Ah cell configuration. These cells were used to initially characterize performance in prismatic configurations and begin early life cycle testing. Soon after the 6 Ah cells were on test several 22 Ah cells were built to test other options. The results of testing of these cells were used to identify potential problem areas for long lived cells and develop solutions to those problems.

Following these two cell builds a set of 7 Ah cells was built to evaluate improvements to the technology. To date results from these tests are very promising. Cycle lives in excess of 2,200 LEO cycles at 50% DoD have been achieved with cells continuing on test.

Results from these cell tests are discussed and data presented to demonstrate feasibility of this technology for aerospace programs.

Table I

NiMH Prismatic Cell Design Summary

Item	6 Ah	22 Ah	7 Ah
Positive Electrodes			
Number	14	15	14
Thickness (mm)	0.71	0.71	0.71
Capacity (Ah) theoretical	7.5	27.6	9.31
Negative Electrodes			
Number	15	16	15
Thickness (mm)	0.32	0.32	0.32
Capacity (Ah)	11.5	42.2	14.4
Separator			
Type	Nylon-2538	Nylon-2538	Nylon-2538 Others
Negative to Positive			
Capacity Ratio (nominal)	1.5	1.5	1.5
Electrolyte			
Type	KOH	KOH	KOH
Concentration (%)	31	31	31
Cell Dimensions (mm)			
Overall Height	69.9	112.5	70.1
Case Height	59.2	101.8	58.8
Width	53.8	75.7	54.2
Depth	20.8	22.6	21.1

Table I summarizes the design parameters for the three types of cells tested to date. The 6 Ah and 22 Ah cell sizes were initial test bed sizes and the 7 Ah size is planned to be used for initial qualification testing. The 6 Ah cells were used to test three configurations of positive electrodes with two separator types. The 22 Ah cells continued these tests in a larger cell configuration to identify any potential problems with scaling up of the cell size.

The initial baseline separator used was nylon 2538 and the electrolyte 31% KOH. Cell dimensions are conventional NiCd cell dimensions although for lower rated cells.

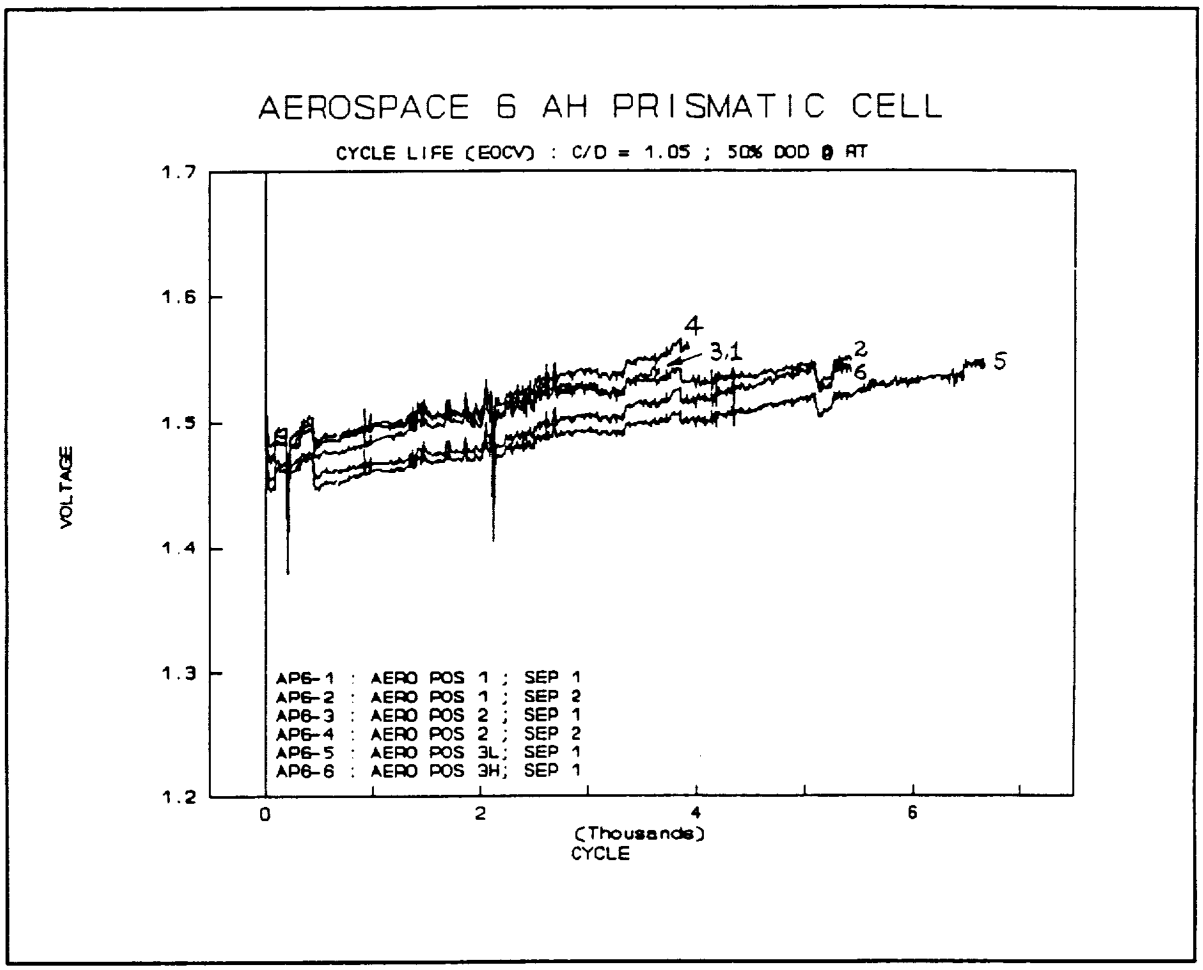

Figure 1 Performance of 6 Ah Cells in Initial Configuration

Cycling of all cells included in this paper was performed in a LEO simulation regime using an integrator controlled cycler. Each cell is monitored using a FLUKE scanning multimeter interfaced to a PC based data collection system. Cell pressures are monitored by direct reading of gauges (Ashcroft A1S1) attached to the cells. Pressure data is manually entered into the correct data file.

This figure illustrates the EOCV performance for the initial build of 6 Ah NiMH prismatic cells. One cell of this group provided greater than 6,000 LEO cycles at 50% DoD. Three primary failure modes were observed in these cells, end of charge pressure increases, shorts, and declining EODV. These cells included three types of positive electrodes with one alloy type and two separators.

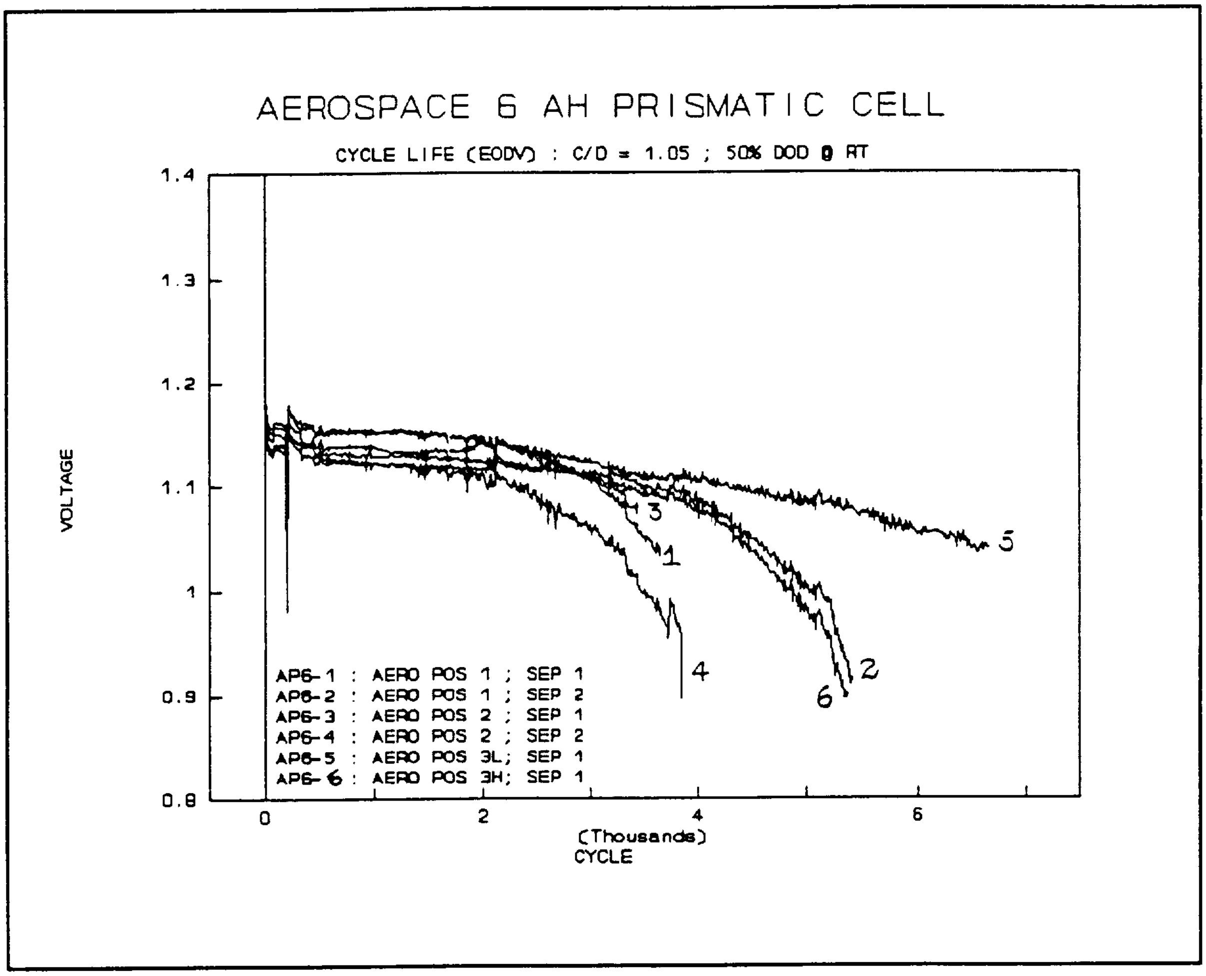

Figure 2 EODV Performance for 6 Ah Cells in Initial Configuration

This figure illustrates the EODV performance trend for the same cells identified in Figure 1. As can be seen from the curves the earliest failures were at about 3500 cycles due to shorts. These shorts were identified to be caused by the substrate in use and this problem has been corrected for future cells. Three cell configurations were terminated due to low EODV and high EOCP and the last cell was terminated due to high EOCP (Figure 3).

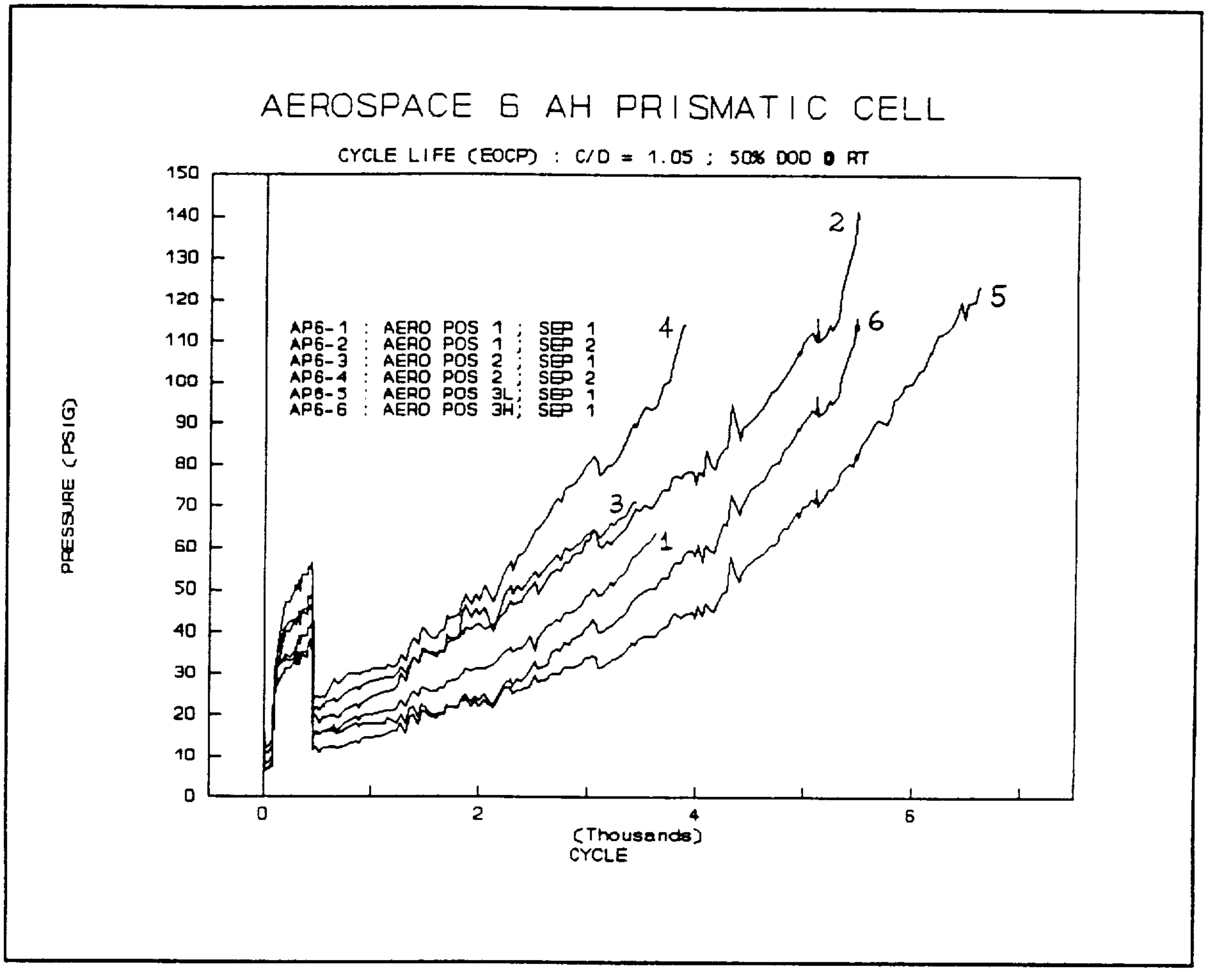

Figure 3 EOCP Performance of 6 Ah Cells in Initial Configuration

This figure shows the increase in EOCP as a function of cycle life for the initial 6 Ah cell configurations. Initially, the recharge ratio was 1.10 and the pressures appeared to rise rapidly early in life. The ratio was reduced to 1.05 at about 500 cycles and the performance improved. However, the cells exhibited a steady increase in pressure with cycling that eventually led to termination of the tests. The increase in pressure has been attributed to a slow degradation of the metal hydride alloy and low negative to positive ratio in the cells. These issues have been addressed in recent cell designs and are reflected in lower EOCP performance with cycle life.

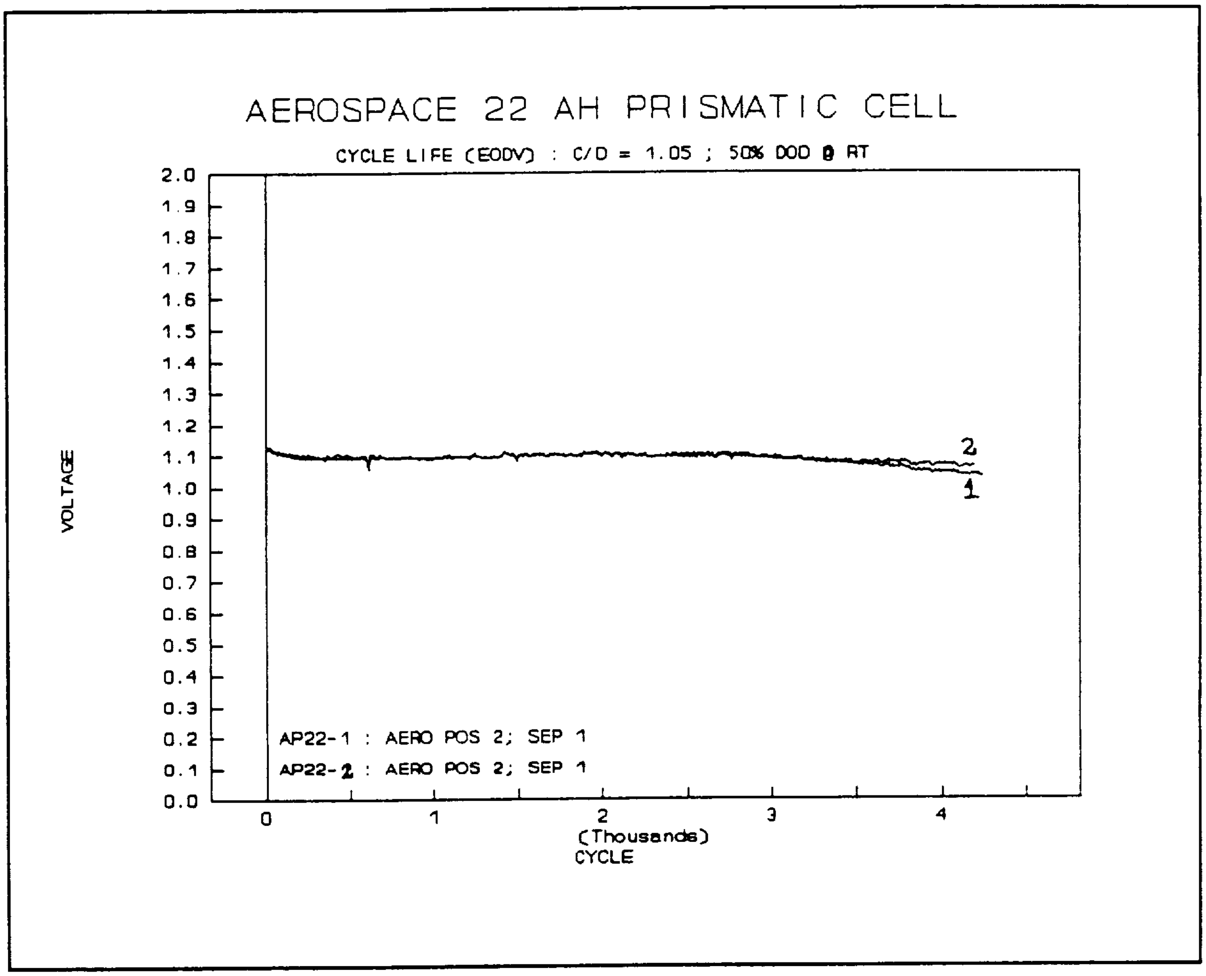

Figure 4 EODV Performance for 22 Ah Cells

The second set of test cells evaluated were 22 Ah cells. These cells were built in 15 Ah equivalent NiCd cases using one type of alloy and one type of positive and separator. This figure illustrates the EODV performance for the cells in 50% DoD LEO cycling. As can be seen from the curves the voltage was stable at about 1.10 V over the cycle life with minor dispersion appearing at about 3600 cycles and continuing until termination of the test.

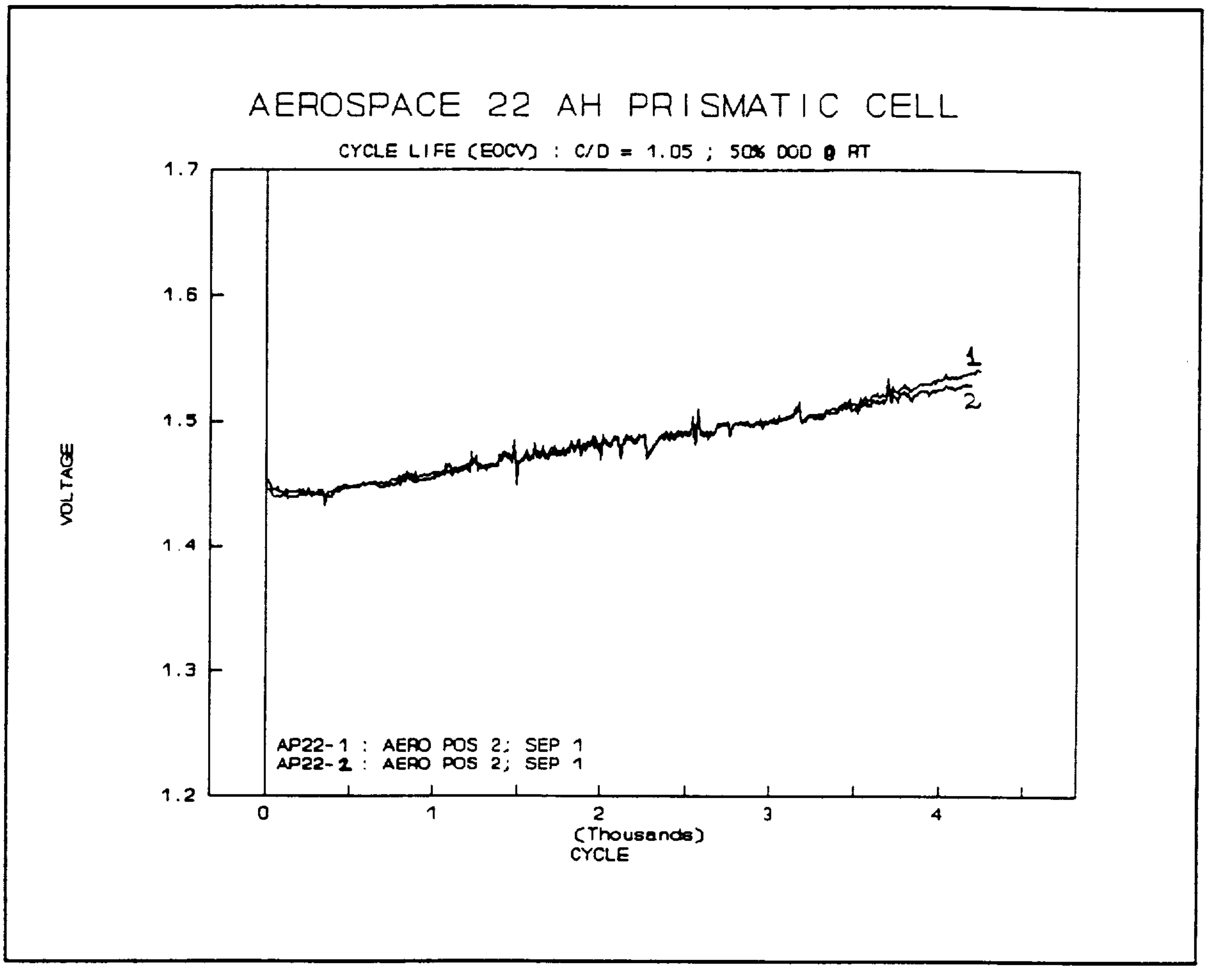

Figure 5 EOCV Performance for 22 Ah Cells

Shown here is the EOCV performance for the 22 Ah cells tested. The data shows an increasing trend over the 4,236 cycles tested. This trend is not desirable for long cycle life. Improvement of the EOCV trend was one of the primary issues addressed in subsequent cell designs that are being tested.

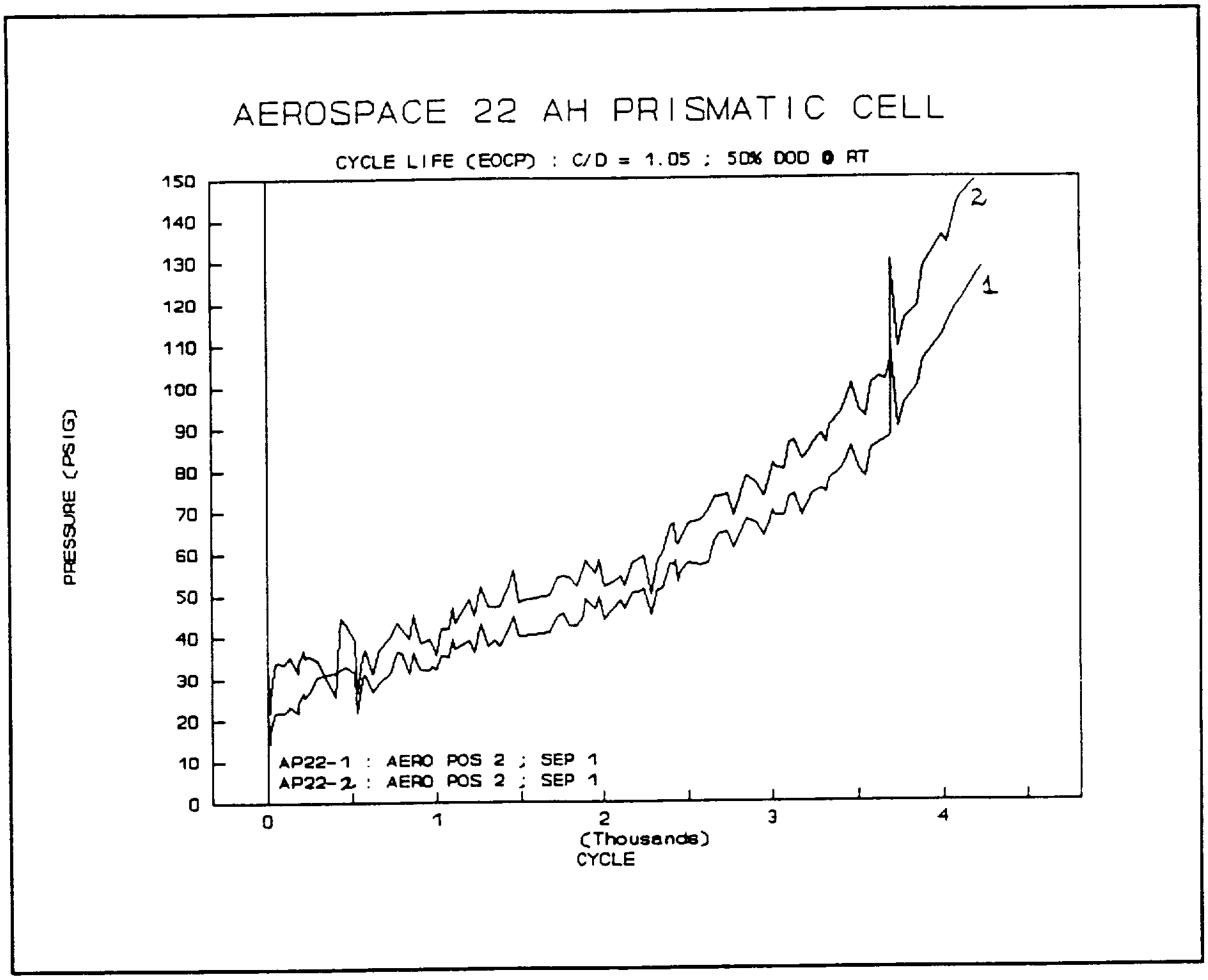

Figure 6 EOCP Performance for 22 Ah Cells

This figure illustrates the EOCP performance for the 22 Ah cells. The trend of increasing EOCP has been the limiting factor in the testing of these cells. Although there have been increases observed in the EOCV the primary reason for termination of the testing of these cells was EOCP. The changes have been attributed to the slow degradation of the alloy being tested combined with a low negative to positive ratio.

Table II

7 Ah NiMH Capacity Performance

Cell Type	Discharge Rate	Mid-Point Voltage	Capacity Ah	Alloy	Sep
AP7-5	C/2	1.201	7.47	MH-2	Sep 1
	C	1.133	6.04		
AP7-6	C/2	1.198	7.33	MH-2	Sep 2
	C	1.131	5.75		
AP7-7	C/2	1.199	7.25	MH-2	Sep 2
	C	1.132	5.62		
AP7-8	C/2	1.209	7.34	MH-2	Sep 3
	C	1.149	6.62		
AP7-9	C/2	1.202	7.31	MH-2	Sep 3
	C	1.135	5.91		

This table illustrates the capacity performance of the 7 Ah cells in initial testing. All tests were performed at room temperature. Mid-point Voltages were similar at both the C/2 and C rate with the best performance seen in the AP7-8 cell configuration.

Capacity delivery was similar also with the best C/2 performance seen in the AP7-5 cell and the best C rate capacity in the AP7-8 cell. All cells tested were from one alloy of the AB_2 type. The AP7-6,7 cells are the same configuration and the AP7-8,9 cells are of the same configuration.

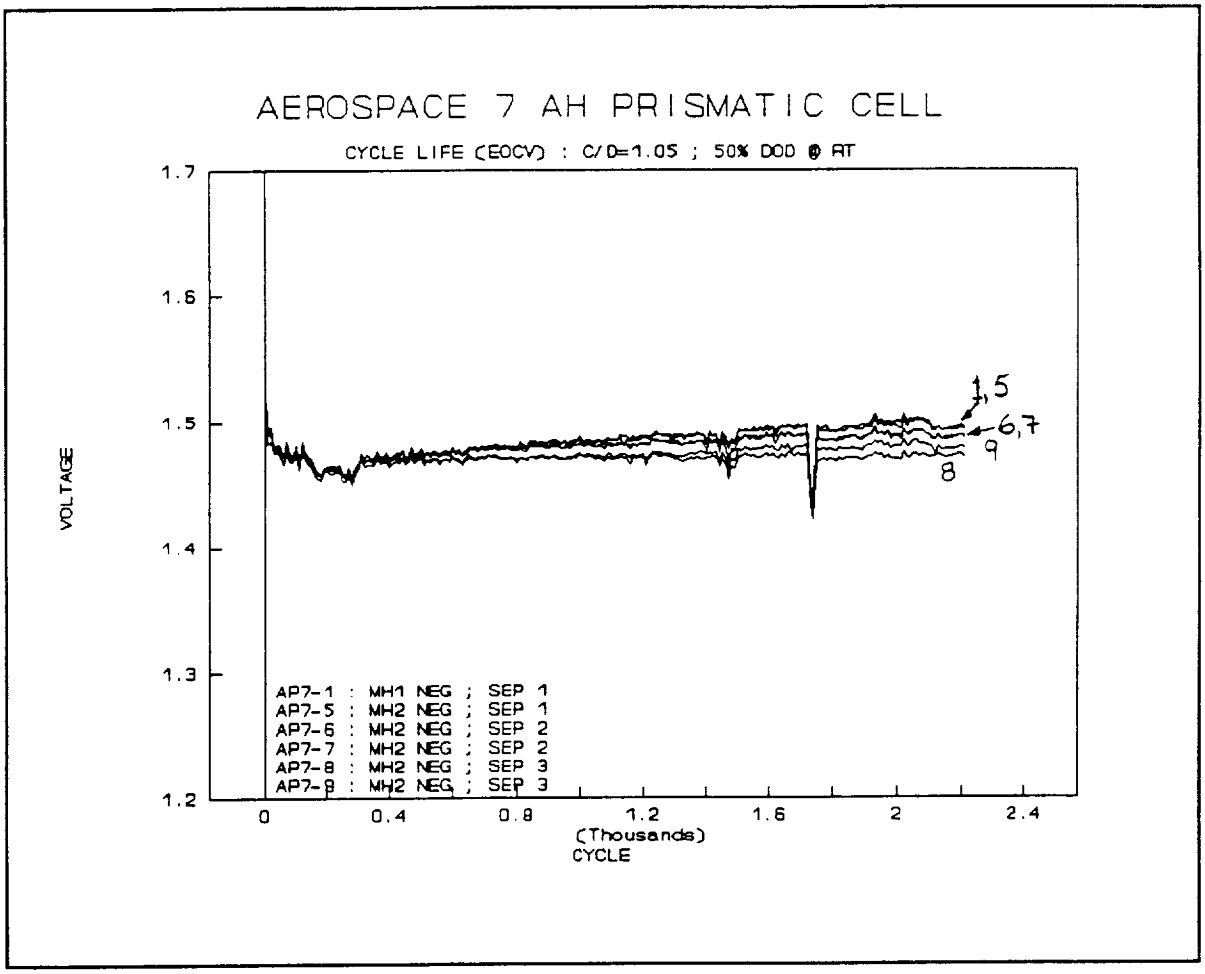

Figure 7 EOCV Performance for 7 Ah Prototype Cells

The 7 Ah cells described in Table II plus one similar cell with alloy type MH-1 were placed in LEO life cycle testing at 50% DoD at room temperature. This figure illustrates the EOCV performance of these cells with cycle life. In general the voltage has been steady with a very slight increase shown for all cells. Within similar cell configurations the EOCV is tracking well except for the AP7-8,9 configurations. These two cells have different electrolyte levels and this is believed to be the cause of the difference. The overall spread across all of the cells is about 0.030 V.

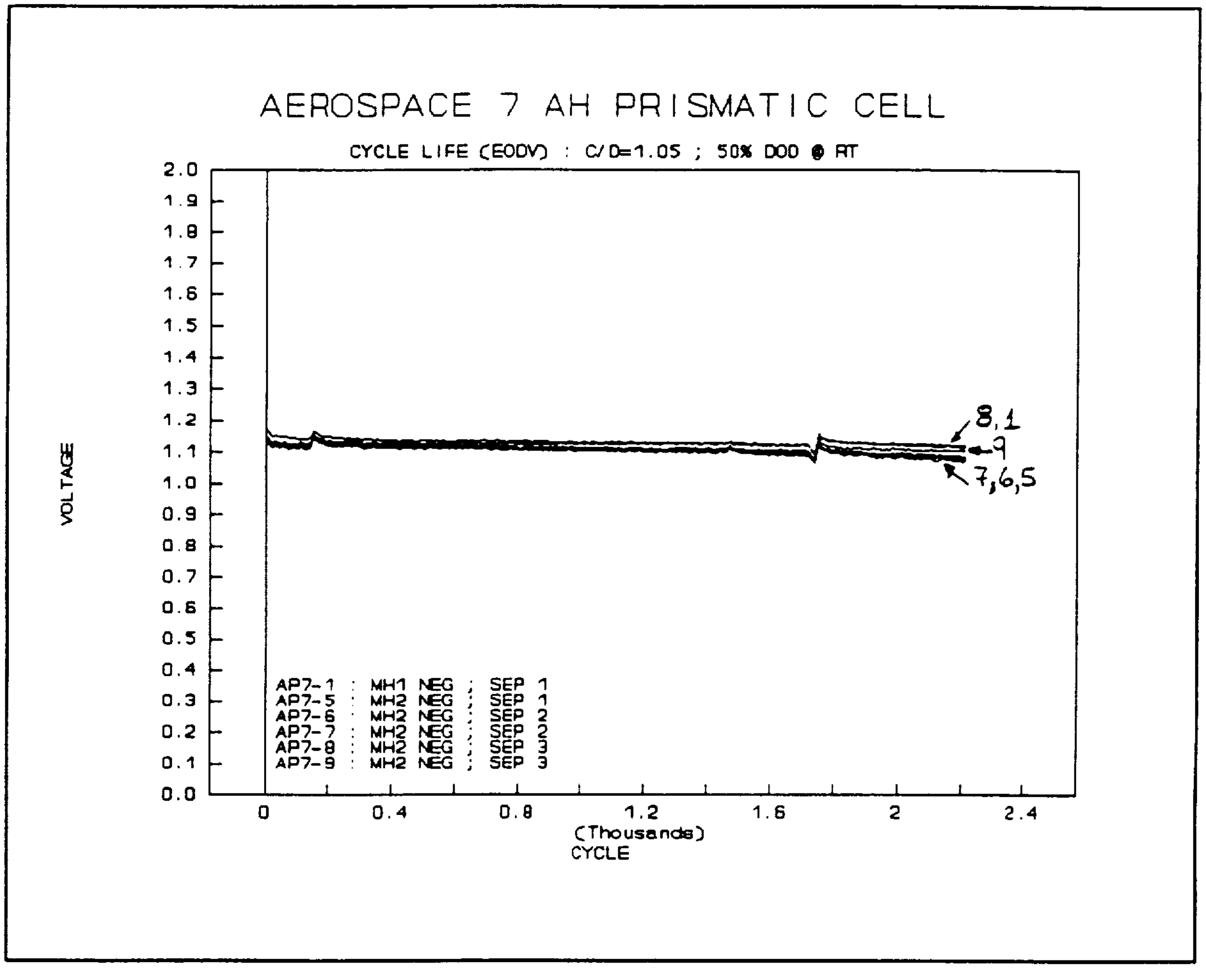

Figure 8 EODV Performance for 7 Ah Prototype Cells

This figure illustrates the EODV performance with cycle life for the 7 Ah cells. The voltage has remained steady over the cycle life to date with only a slight dispersion between cells. The C/D ratio has been maintained at 1.05 during the tests and this has maintained the EODV. The EODV is at 1.06 V for the lowest cell and 1.12 for the highest cell. The performance is similar to that seen in the 6 Ah and 22 Ah cell designs to this point in cycling.

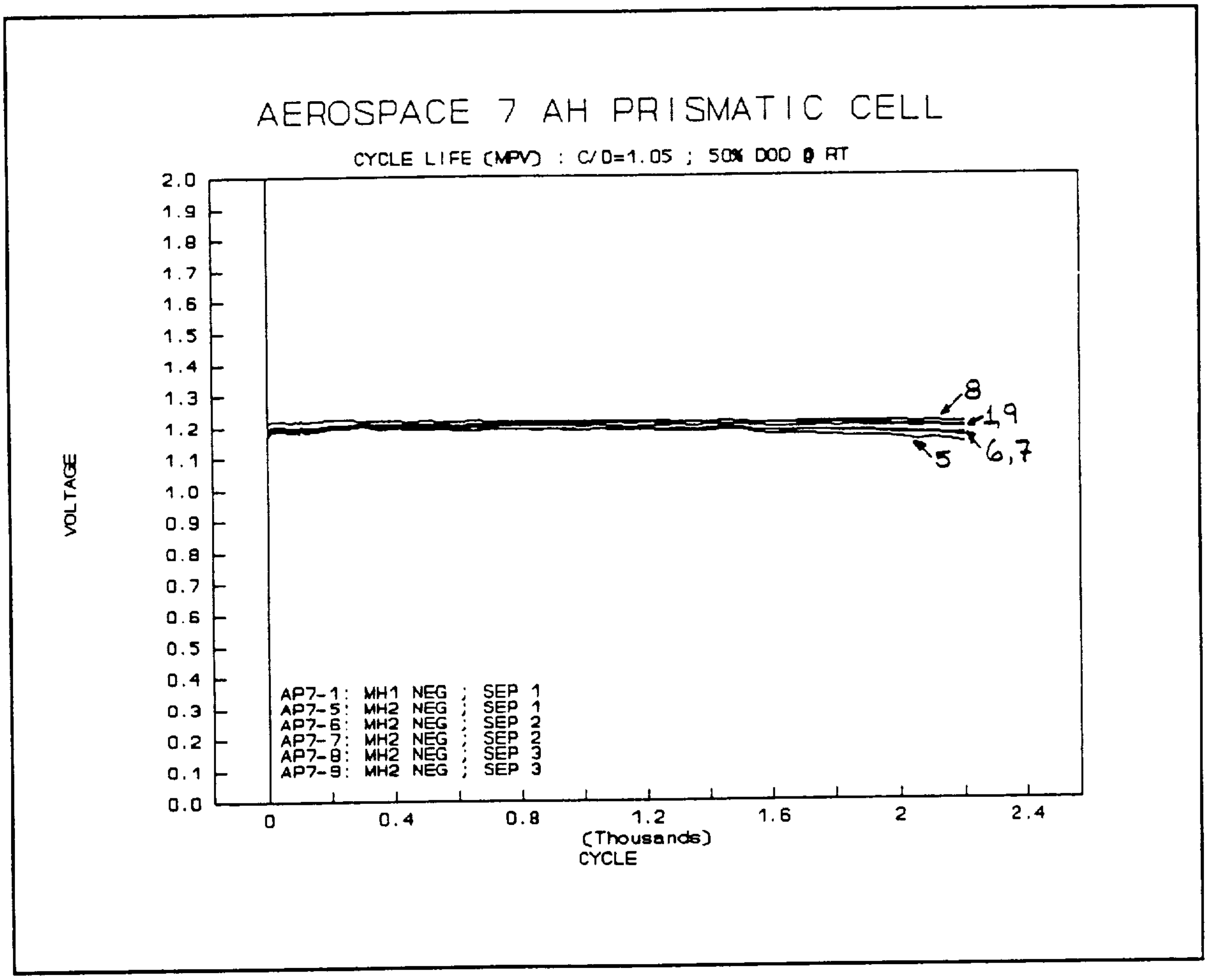

Figure 9   Mid-Point Voltage Performance for 7 Ah Prototype Cells

This figure illustrate the mid-point voltage trend over the cycles completed to date. This voltage is measured at the equivalent of 25% DoD during the discharge. The MPV is currently at 1.14 V for the worst cell and at 1.21 V for the best cell. Within each cell configuration the performance is similar.

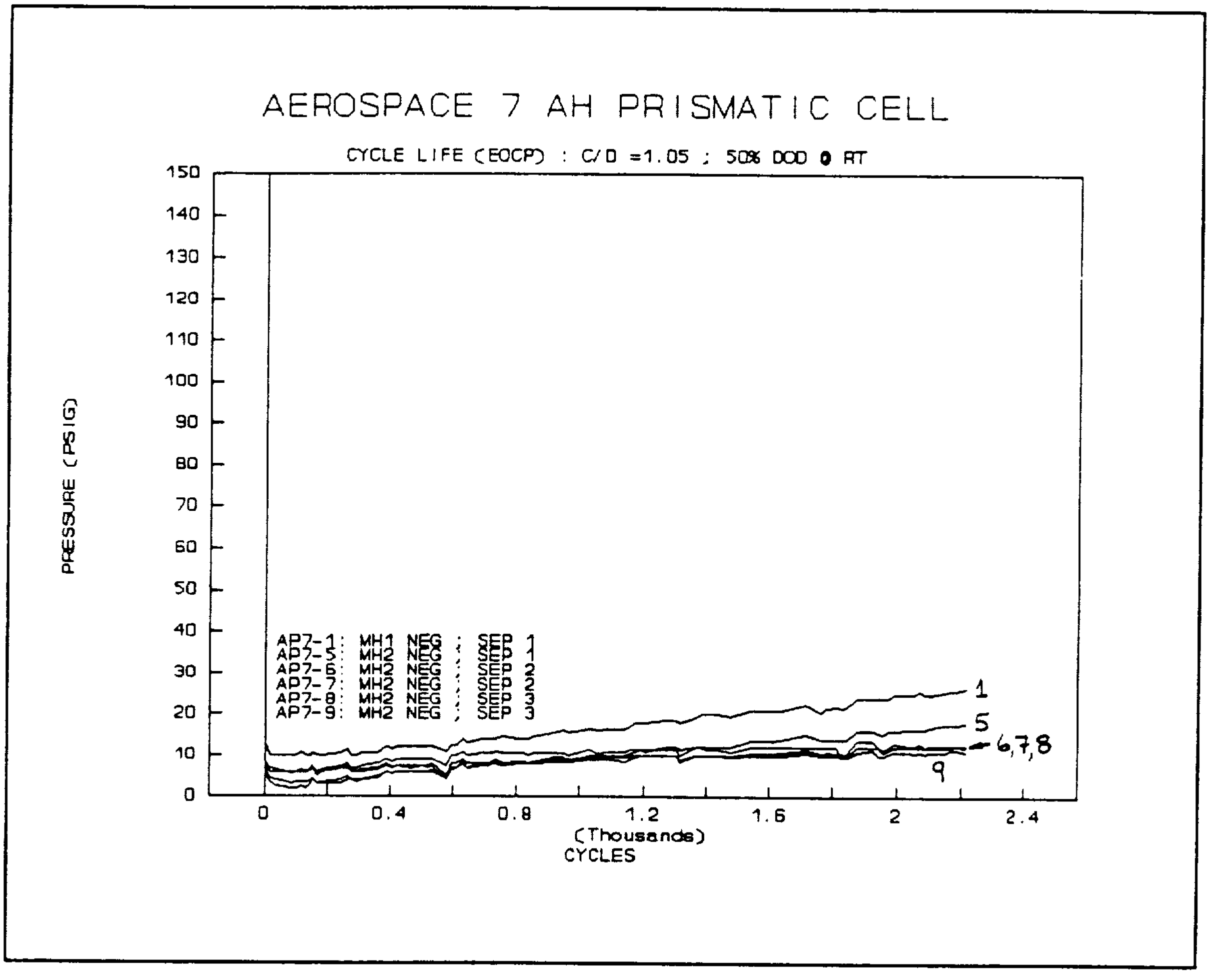

Figure 10 EOCP Performance for 7 Ah Prototype Cells

Increase in pressure with cycle life has been the primary reason for termination of testing on earlier cell configurations. This figure shows the EOCP for all of the 7 Ah cells on test. The data trend shows that the pressure is below 20 psig in all cells except for the one with alloy MH-1. Cells AP7-1 and AP7-5 are showing steady increases with life, however, the four remaining cells are maintaining level performance at less than 10 psig. The 6 Ah and 22 AH cells were showing 20 to 70 psig (Figures 3 and 6), at this point in life. The improvement is very encouraging and is a result of design adjustments made to improve the response over time.

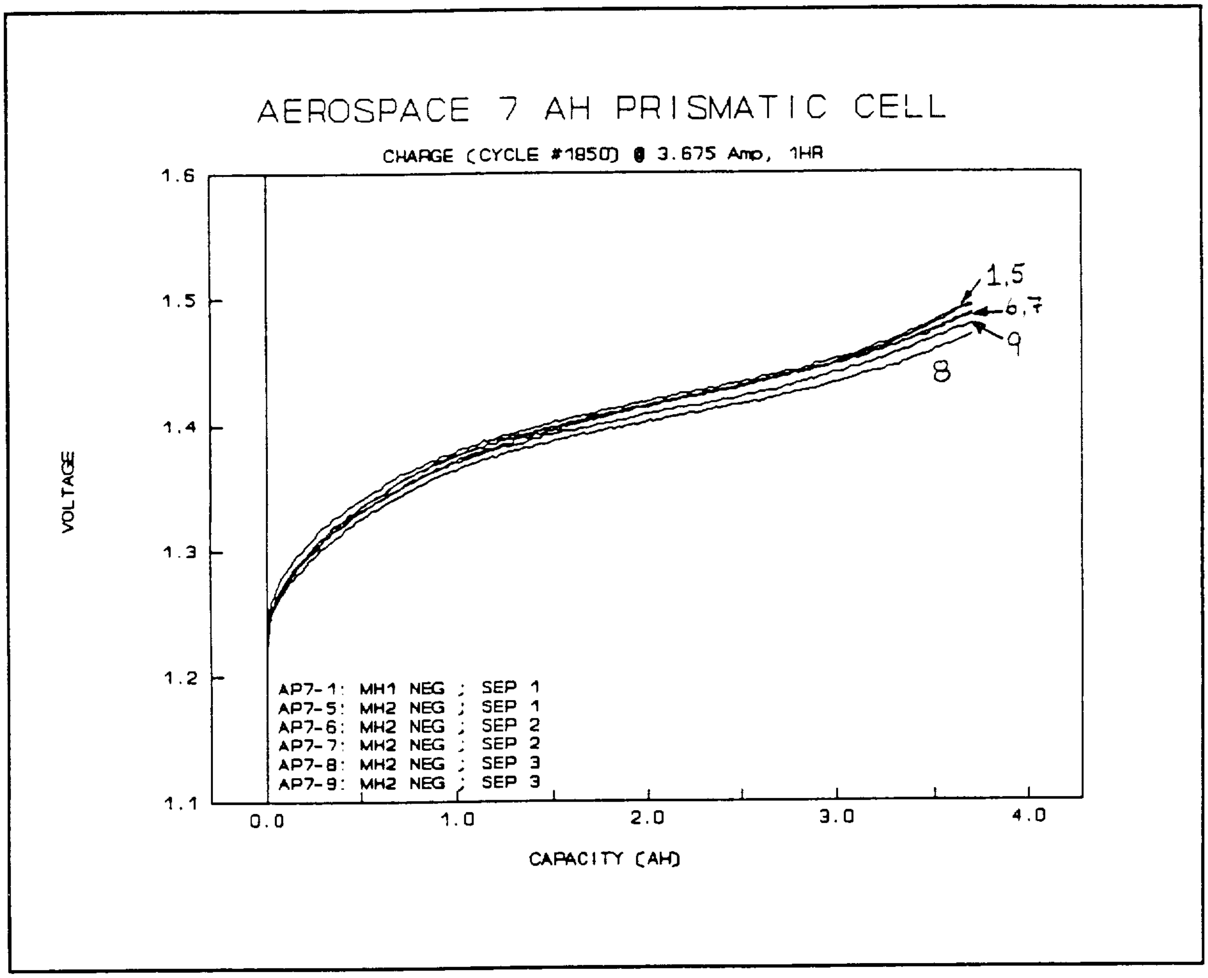

Figure 11 Charge Voltage Profile for 7 Ah Prototype Cells, Cycle 1,850

This figure shows the charge voltage profile for cycle number 1,850. The voltage ranges from 1.47 to 1.49 V at EOC. The curve is relatively smooth and increasing with time and has a slight upturn at the end of charge. This curve is similar to those seen for NiCd cells under similar test conditions and is further evidence of the ability of the NiMH system to replace NiCd cells.

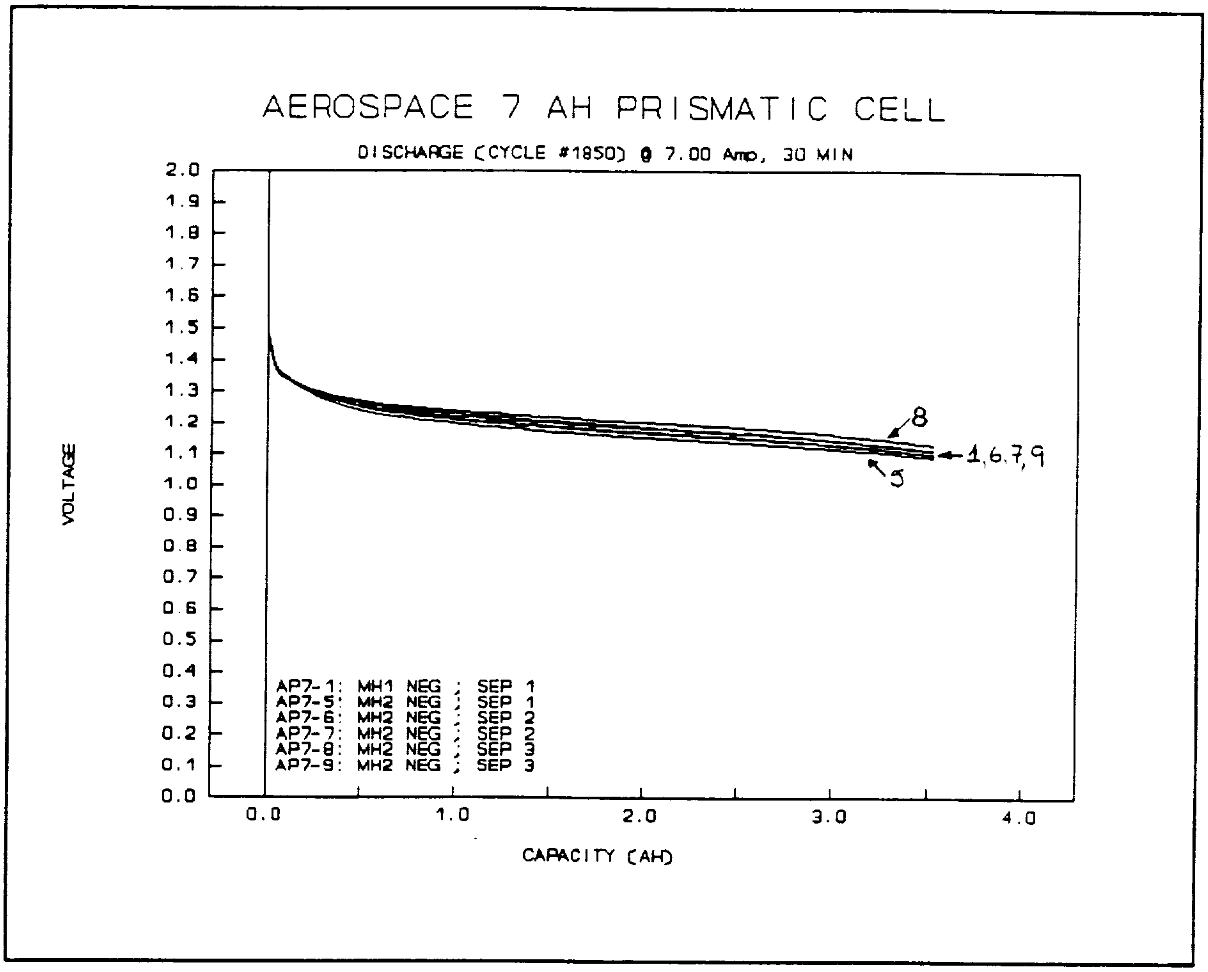

Figure 12 Discharge Voltage Profile for 7 Ah Prototype Cells, Cycle 1,850

This figure shows the corresponding discharge voltage profiles for cycle 1,850 for all cells in test. The curves are relatively flat with mid-point voltages of 1.16 to 1.21 V. The EODV ranges from 1.09 to 1.14 V. The highest discharge voltages are seen with the AP7-8 and AP7-9 cell configurations. Again, this data is very similar to that seen for NiCd cells of similar design.

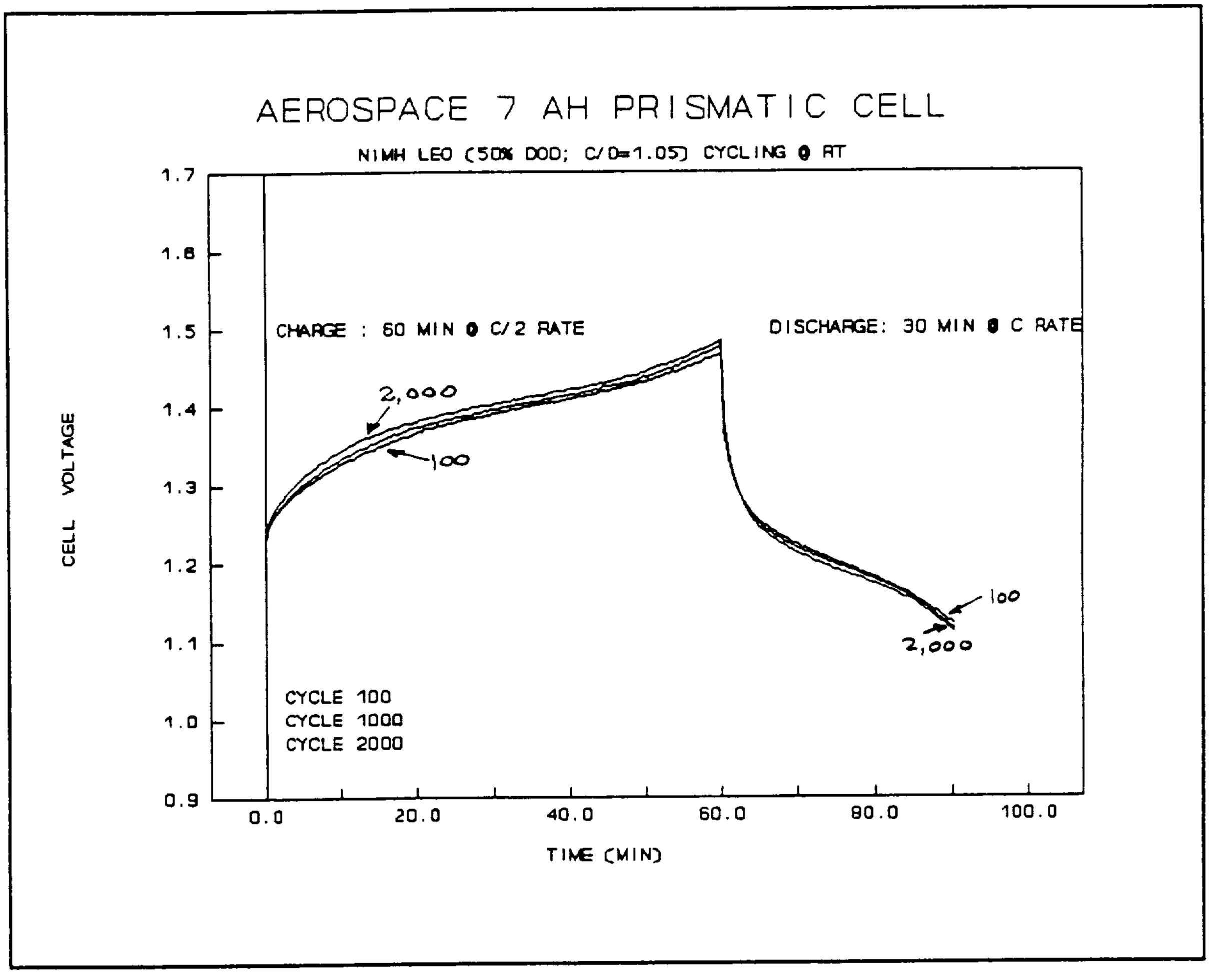

Figure 13 Charge/Discharge Voltage Profile Over Life for 7 Ah Prototype Cells

This figure illustrates the change in voltage profile for one cell during a single cycle at three points in cycle life, 100, 1,000 and 2,000 cycles. These curves are shown to illustrate the stability of the cells during cycle life testing. There is very little change observed relative to the shape of the curve or the voltages obtained. At the 2,000 cycle point there has only been a 0.020 V increase in EOCV and a 0.010 V decrease in EODV.

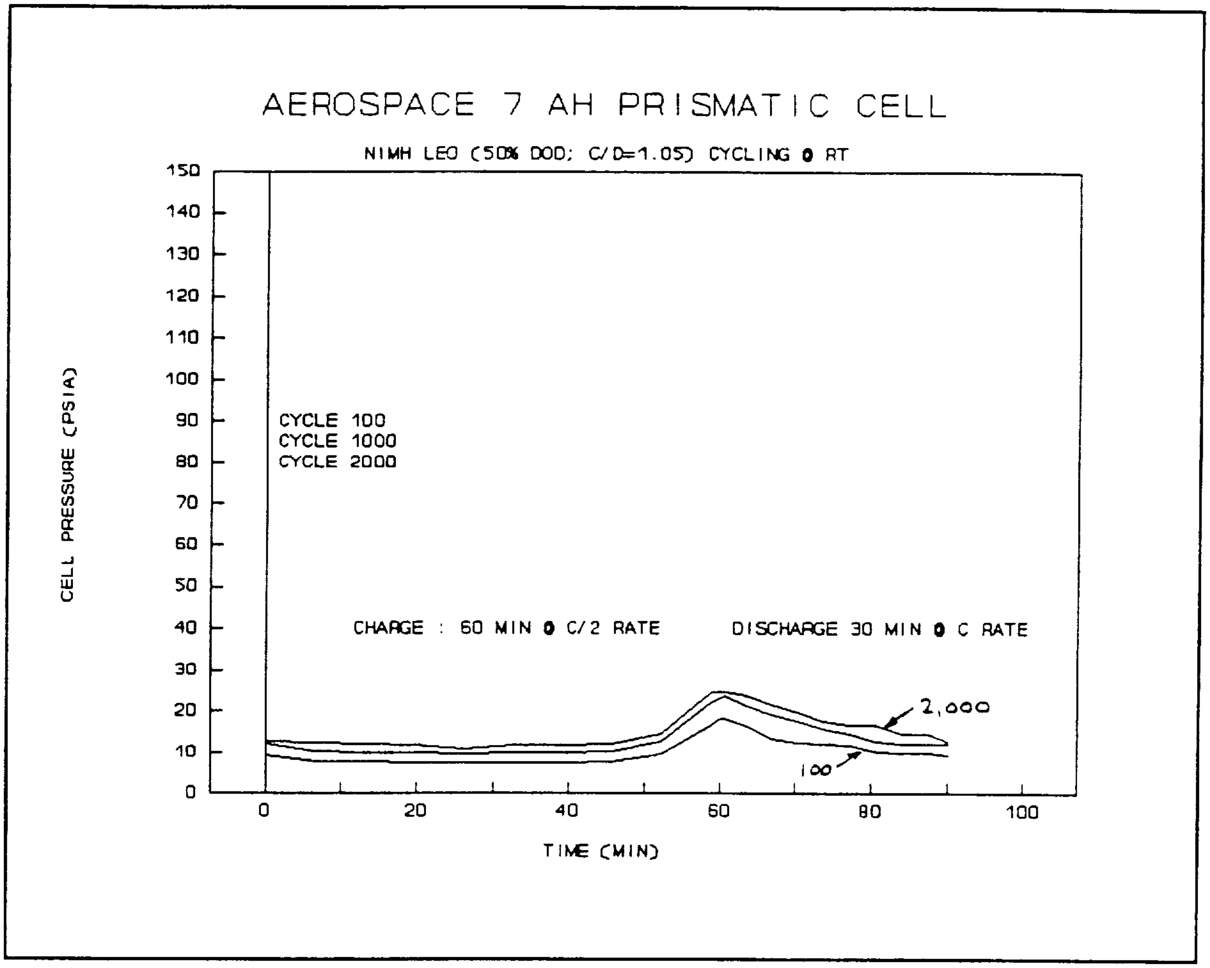

Figure 14 Pressure Response Profiles for 7 Ah Prototype Cells

This figure illustrates the pressure response profiles for one of the 7 Ah cells on test at 100, 1,000 and 2,000 cycles. The overall change in EOCP has been 7 psia over the first 2,000 cycles. As indicated earlier, increasing EOCP has been the primary failure mode observed in previous cell builds. The low pressure results seen here are a significant improvement over the earlier 6 Ah and 22 Ah cell configurations. With pressure performance this low at 2,000 cycles significantly improved cycle life is anticipated.

Summary and Conclusions

- Prototype 7 Ah NiMH cells have demonstrated >2,000 LEO 50% DoD cycles with excellent voltage and pressure performance
- 7 Ah cells size to be used for initial test configuration for qualification testing
- Designs for 24 Ah and 35 Ah cells based on scale up of 7 Ah cells in progress
- Development program continuing with goal of >10,000 LEO 50% DoD cycles by 1995
- NiMH appears to be excellent candidate for use in aerospace cells

Cycle life testing of prototype NiMH cells in 6, 7, and 22 Ah sizes has been discussed. As indicated in the results to date the 6 and 22 Ah cell designs were used as initial test vehicles to identify potential performance issues so that subsequent cell configurations could address those issues. Even though these cells were early designs, cycle lives in excess of 4,000 50% DoD LEO cycles were achieved in both designs. The improvements in design for the 7 Ah cells are reflected in the excellent performance to date.

This 7 Ah cell design will be used to begin initial qualification testing in 1993. In addition, 24 Ah and 35 Ah cell designs are in progress and will also be evaluated in qualification testing. GAB plans to continue this development effort with a goal of achieving >10,000, 50% DoD, LEO cycles in qualification hardware by mid 1995.

Based on the results achieved to date NiMH appears to be a viable alternative to NiCd and NiH_2 cell technology for aerospace applications.

Future Direction

- Continue evaluation of Alloy/Separator/Positive Combinations

  AB_2 and AB_5 Type alloys

  Other non-nylon separator materials

- Expand parametric database using 7 Ah and 24 Ah cells

  Voltage and Capacity performance vs temperature

  Charge retention and overcharge tolerance

- Begin qualification testing on 7 Ah and 24 Ah cells in mid 1993

- Expand available range of NiMH cell designs

Although results of NiMH cell testing to date are promising, qualified designs are still on the horizon. As such GAB intends to continue its development program in order to establish those qualified designs. Future work will be aimed at evaluation of various alloy combinations with different types of separators to optimize the designs.

Testing of current designs will continue in order to establish the database needed for cell qualification. This will include various parametric tests including capacity and voltage performance at various temperatures, self-discharge, and overcharge tolerance. It is GAB's intention to have cells available to begin internal qualification testing in mid-1993.

GAB will also develop an expanded range of NiMH cell designs in 1993.