# An environmental aircraft battery (EAB)

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## Abstract

The Battery Branch of the U.S. Air Force Research Laboratory began the development of an environmental aircraft battery (EAB) to replace existing nickel/cadmium (Ni–Cd) and sealed lead-/acid (SLA) batteries to minimize or eliminate use of environmentally hazardous battery materials by the USAF. A three-phase development contract was awarded in 1996 to replace the cadmium in Ni–Cd batteries with a metal hydride (MH) anode. Designs, materials, space battery technology, and results on commercial and government battery programmes were evaluated in the Phase I, Feasibility Analysis. Bipolar and prismatic designs were selected for Phase II development. Materials and cell test data are presented. © 1999 Elsevier Science S.A. All rights reserved.

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## 1. Introduction

The U.S. Air Force (USAF) uses vented Ni–Cd (VNC) batteries in fighter, cargo and bomber aircraft for main and emergency power due to their ruggedness, high capacity and ability to meet military operational conditions and because no other technology was available until the early 1990s. These vented batteries required flight-line battery shops for maintenance and repair, with a large expenditure of manpower and resources roughly estimated at US$50 million per year [1]. Several factors that make this unacceptable for current Air Force requirements are:

(a) the reduction of the military industrial base (IB);
(b) increased environmental impact awareness; and
(c) the need to use commercial off-the-shelf (COTS) components and technology.

During the last decade, public concerns about the environment increased and resulted in goals to eliminate ozone-depleting substances and toxic and hazardous materials from manufacturing and commercial use throughout the United States. Cadmium and lead were two of the materials included on the EPA list of 17 chemicals to be eliminated from use in the USA.

Naturally, military operations which used many of these materials and substances came under public criticism, prompting a change in Air Force and DOD policy [2].

Responding to environmental pressure, numerous commercial companies developed alternative technologies and products to substitute for Ni–Cd batteries. This resulted in the metal hydride (MH) and lithium-ion batteries that are used in many portable applications today. However, military weapon systems require more stringent capabilities than small portable commercial batteries, hence, emphasis shifted to sealed, reduced maintenance, batteries with longer life. This resulted in development of the ultra low maintenance Ni–Cd (ULMNC), the sealed Ni–Cd (SNC) and the sealed lead-/acid (SLA) batteries, which, along with the VNC, are in use today. However, the ULNC, SNC and SLA batteries reduced but did not eliminate lead and cadmium usage in Air Force battery systems. This prompted the Battery Branch of the Air Force Research Laboratory to propose development of an environmental aircraft battery (EAB) replacement for the existing environmentally hazardous aircraft batteries in the current inventory in 1994 as a response to the SAF/AQ Policy Memorandum [2].

Following an initial technology candidate evaluation, a development concept and programme was proposed and funded in 1996 to replace the cadmium in VNC, ULMNC and SNC with a MH anode. The proposed EAB would also eliminate use of SLA batteries in the operational Air Force and convert all aircraft systems to a maintenance-free battery (MFB) concept using a common battery technology. The MH anode was selected since a MH battery is almost a form fit and function ($F^3$) replacement for a Ni–Cd battery in many applications. Using the MH tech-

nology in the EAB would minimize charger modifications and also the implementation costs to convert the existing 6412 USAF aircraft [3].

## 2. The EAB development programme

In the planning phase for the development programme, AFRL/PRPB incorporated the requirements for a planned upgrade to the F-16 Pre-Block 40 aircraft to convert it to a sealed MFB and the energy storage requirements proposed for the More Electric Aircraft (MEA) programme. The final programme objective is to develop a sealed, maintenance-free, 24–25 V, EAB prototype that meets the following requirements:

(a) Demonstrates an environmentally safe alternative $F^3$ battery for the F-16 Pre-Block 40 main aircraft battery in accordance with the existing performance specification; and

(b) Has an energy density goal of 75 W h kg$^{-1}$ for the MEA generation II programme.

The target EAB performance parameters are listed in Table 1. The programme was broken into three phases to accommodate fund availability. These are:

Phase 1: Feasibility Analysis;
Phase II: Cell and Battery Development; and
Phase III: Prototype Battery Production.
The schedule is shown in Fig. 1.

### 2.1. Phase 1: feasibility analysis

#### 2.1.1. Task 1: battery concept development

Discussions were held with all commercial and military suppliers with experience on MH batteries using AB$_5$-type

Table 1
The EAB performance parameters

| Parameter | Target value |
|---|---|
| Nominal voltage (V) | 28 |
| Capacity (A h) | 50 |
| End of life capacity (A h) | 18 (maintained at 14.5) |
| Current (A) | 48 (maximum) |
| Operating temperature range (°C) | −40 to +71 |
| Watt hours (W h) | 1325 |
| Specific energy density (W h kg$^{-1}$) | 75.0 |
| Volumetric energy density (W h dm$^{-3}$) | 177 |
| Total battery weight (kg [lb]) | 18.18 [40.0] |
| Mean time between failures (MTBF) | > 6000 h |
| Maintenance interval | Maintenance-free for 3 years |
| Self discharge ( < 25% over 7 days) | All operating temperatures |

hydrides to validate the conclusions from the commercial technology analysis [4] and to obtain their development insights on the concept of a MH aircraft battery. All suppliers indicated that substitution of the cadmium electrode with a MH electrode was viable and should produce an acceptable EAB at a competitive price. All of them indicated that work would be required to optimize both the nickel and MH electrodes and possibly the electrolyte to obtain equivalent performance to the existing Ni–Cd aircraft battery in a smaller volume. Each supplier was asked to evaluate which developments were needed and to present a concept for the battery design. This resulted in three prismatic and one bipolar design. All designs used a MH anode and either a nickel or silver cathode. Electrolyte optimization studies considered different concentrations of
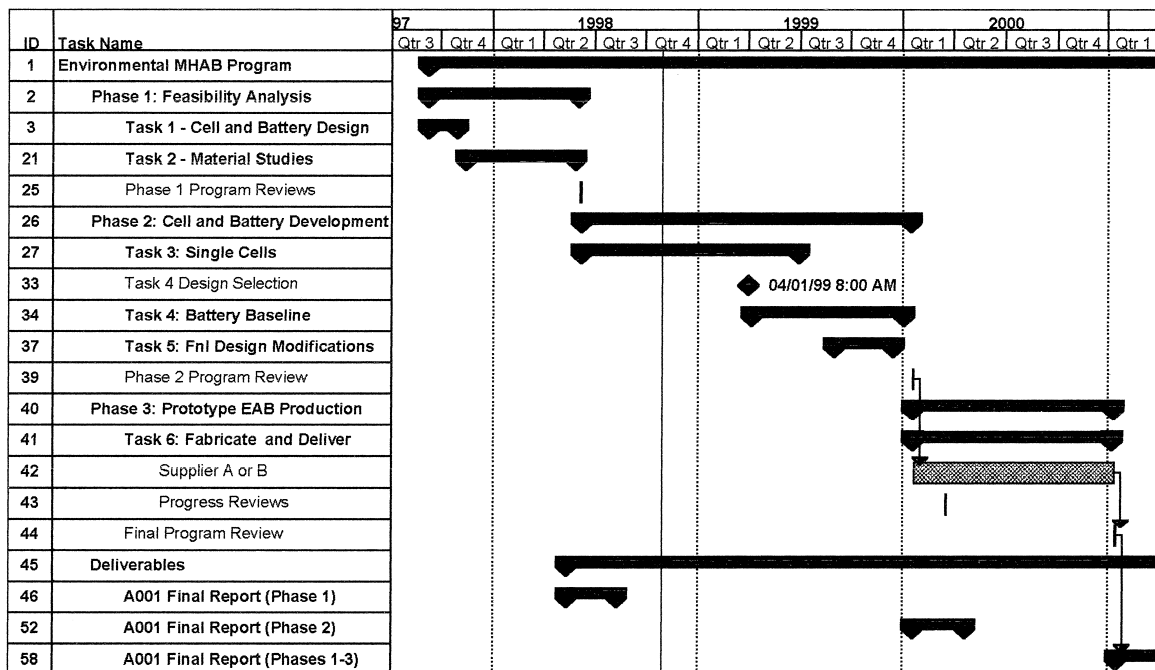


Fig. 1. Overall EAB development programme schedule.

Table 2
Supplier A: Materials evaluation group matrix

| Group | Cathodes | | | | | | Separators | | | Anodes | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | C1 | C2 | C3 | C4 | C5 | C6 | S1 | S2 | S3 | A1 | A2 | A3 | A4 | A5 | A6 |
| G1 | X | | | | | | X | | | X | | | | | |
| G2 | | X | | | | | X | | | X | | | | | |
| G3 | | | X | | | | X | | | X | | | | | |
| G4 | | | | X | | | X | | | X | | | | | |
| G5 | | | | | X | | X | | | X | | | | | |
| G6 | | | | | | X | X | | | X | | | | | |
| G7 | X | | | | | | | X | | X | | | | | |
| G8 | X | | | | | | | | X | X | | | | | |
| G9 | X | | | | | | X | | | | X | | | | |
| G10 | X | | | | | | X | | | | | X | | | |
| G11 | X | | | | | | X | | | | | | X | | |
| G12 | X | | | | | | X | | | | | | | X | |
| G13 | X | | | | | | X | | | | | | | | X |

potassium, lithium and/or sodium hydroxide and mixed combinations of the three. Several different separator materials also required evaluation including non-woven polypropylene, micro-porous polypropylene and grafted felts. One prismatic and one bipolar design were selected for materials evaluation studies with specific formulations for the electrodes, electrolytes and separators based on materials evaluation test data prior to initiation of single cell tests. In these preliminary studies, determinations were made of initial capacity, self-discharge, discharge at various rates and temperatures and supplier-defined accelerated aging. It is important in the interpretation of the results that one considers several factors.

(a) Initial capacity measurements tell you how large and how heavy your cells will have to be to meet the performance objectives of the battery. Therefore, high capacity is desired in order to use the smallest and lightest cells possible.

(b) Rate of self-discharge is critical in that you may have a really high-capacity cell but if you lose a large amount of its capacity due to a minimal change in temperature, then the battery will not be useful over a large temperature range.

(c) The discharge capacity should be as stable as possible, both over the temperature and required range of discharge currents and also throughout the useful cycle life of the battery.

### 2.1.2. Task 2: materials evaluation

Two suppliers were selected to conduct materials evaluations that would verify predicted performance and to select specific formulations for electrodes, electrolytes and separators for subsequent single cell tests. Initially, 11 nickel cathodes, five separators, 12 MH anodes and several electrolyte formulations were proposed for evaluation. Suppliers opted to conduct tests using different methodologies. One used a standard anode, cathode or electrolyte,

while only one of the other two constituents was varied at a time. The other supplier selected a likely formulation for the entire cell based on a matrix of components to be tested and then varied one or more ingredients in the cell formulation in a prescribed manner to minimize test time and samples. Both suppliers evaluated the following.

(a) Discharge capacity over the temperature range at the $C/n$ rate, where $n$ varied from 1 to 4.

(b) Life cycle performance at a selected temperature to a supplier-defined failure point.

(c) Charge retention, starting with fully charged cells at a specified temperature, storage at the test temperatures for selected intervals, and then discharges to determine remaining capacity.

*Supplier A* developed a test programme with 13 design groups and evaluated each against the above criteria. Within each design group, cathodes were designated as C1 to C6, separators as S1 to S3 and anodes as A1 to A6. The group formulations are shown in Table 2. The results for the three tests are presented in Table 3 along with an overall rank for each group. The rank order was based on equal weight for each criterion or a weight of three for discharge capacity, two for cycle tests and one for charge retention.

From analysis of the data in Table 3, it is apparent that the top four candidate design groups remain the same but the order is slightly different depending on how you weight the data. For purposes of this study, the actual values obtained are not critical since the materials evaluation is directed at identifying likely configurations for subsequent Task 3 single cell tests. However, using both weighting criteria, group G12 is the top candidate for evaluation, but groups G4, G10, and G13 are also definite candidates. Analysis of the makeup of the four groups indicates cathodes C1 and C4, separator S1, and anodes A1, A3, A5 and A6 gave the best results.

Table 3
Supplier A: Materials evaluation results and group rankings

| Discharge capacity | | | Cycle life | Charge retention | | Overall group rank | |
|---|---|---|---|---|---|---|---|
| C | C/2 | C/4 | Cycles | 7 days | 14 days | Equal weight | 3–2–1 weight |
| G13 | G13 | G13 | G7 | G5 | G5 | G12 | G12 |
| G9 | G9 | G9 | G12 | G12 | G12 | G4 | G13 |
| G12 | G12 | G12 | G10 | G4 | G4 | G13 | G4 |
| G10 | G10 | G10 | G4 | G1 | G1 | G10 | G10 |
| G4 | G4 | G11 | G2 | G2 | G2 | G2 | G7 |
| G5 | G11 | G7 | G3 | G8 | G8 | G5 | G9 |
| G3 | G2 | G2 | G13 | G13 | G13 | G7 | G2 |
| G2 | G7 | G4 | G1 | G3 | G3 | G1 | G5 |
| G7 | G5 | G5 | G8 | G6 | G6 | G3 | G3 |
| G11 | G6 | G3 | G5 | G10 | G10 | G9 | G1 |
| G6 | G3 | G6 | G9 | G9 | G9 | G8 | G11 |
| G1 | G1 | G8 | G6 | G7 | G7 | G6 | G8 |
| G8 | G8 | G1 | G11 | G11 | G11 | G11 | G6 |

Table 4
Supplier B: Preliminary ranking of positive electrode materials

| Initial capacity (RT) | | Self-discharge (7 days) | | | Initial discharge capacity ($-10°$ to $40°C$) | | | Aging cycles | Overall |
|---|---|---|---|---|---|---|---|---|---|
| C/3 | 1.5C | 23°C | 40°C | 60°C | C/3 | C | 1.5C[a] | 0–600 | |
| P5/P2/P1 | P1/P2/P5 | All | P1 | P3 | P5 | P4/P5 | All | P4/P2/P1 | P1/P2 |
| | | | P3/P2/P4 | P1 | P1/P2/P3/P4 | | | | |
| | | | | P4 | | P3/P2 | | P5/P3 | P4/P5 |
| P3/P4 | P3/P4 | | P5 | P2 | | P1 | | | |
| | | | | P5 | | | | | P3 |

[a] 23°C only.

Additional materials test in combination, as well as some additional anode and cathode materials not available until late in the programme, are under evaluation in Task 3. Selected components from the four candidate groups and the best two group combinations from the additional materials tests are under evaluation in Task 3, single-cell tests.

*Supplier B's* approach used its own standard test configurations to perform preliminary studies of five positive and five negative electrodes, four separators and six electrolytes both to screen the candidates and suggest new ones for test in the definition experiments. Determinations were made of initial capacity, self-discharge, discharge at various rates and temperatures and supplier-defined accelerated aging. It is important in the interpretation of the results that one considers the three test parameters mentioned earlier. The results of the preliminary studies are presented in Tables 4–6.

*2.1.2.1. Positive electrode results.* Results from the analysis of the initial capacity data showed no observable correlation with the ingredients in the electrodes. A high-conductivity network percentage decreased self-discharge. However, the reverse correlation holds when considering the initial discharge performances. Initial discharge performance also appears to correlate with low zinc content. Low cobalt, high zinc and a high amount of the conductivity network improved accelerated aging performance. Overall ranking of the five electrodes indicates a high zinc content and a high percentage of the conductivity network improves performance. This overall evaluation is consistent with the results for the individual areas, with the exception of the correlation for initial discharge performance.

*2.1.2.2. Negative electrode results.* From an analysis of the alloy content of the five samples and their overall performance, as given in Table 6, several correlations appear likely. The initial and discharge performance after 300 cycles, over the temperature and current ranges tested, declines with decreasing nickel and increasing cobalt content of the alloy. In other analyses of the data, overlays of the measured capacity plots during the initial and 300 cycle discharge performance measurements reflect increased capability at lower temperatures for each of the alloys at the C/3 and C rates with the following exceptions:

(a) N3 was unchanged at the C/3 rate and showed about 15% decrease in capacity at the C rate below $-10°C$. It was the only alloy with appreciable capability at $-40°C$ at the C/3 rate;
(b) N2 showed no change in the C rate capacity over the entire temperature range; and
(c) None of the five samples had any appreciable C rate capacity at $-30°C$.

At the 2C rate, N3 was the only negative that had any significant initial capacity at $-20°C$. However, after 300 cycles, the capacity of N3 at $-20°C$ decreased by 50%

Table 5
Supplier B: Preliminary ranking of negative electrode materials

| Initial capacity (RT) | | Initial discharge performance ($-40°C$ to $+23°C$) | | | 300 Cycle discharge performance ($-40°C$ to $+23°C$) | | | Overall |
|---|---|---|---|---|---|---|---|---|
| C/3 | 2C | C/3 | C | 2C[a] | C/3 | C | 2C[a] | |
| All | N2/N5 | N3 | N2/N3 | N3 | N2/N3 | N5/N2 | N2 | N2/N3 |
| | | N2 | | N2 | | | N3 | |
| | N1/N3/N4 | | | | N5/N1 | N3 | | N5 |
| | | N5 | | | | N1 | N1/N5/N4 | |
| | | N1/N4 | N5/N1/N4 | N5/N1/N4 | N4 | N4 | | N1/N4 |

[a] 20°C only.

Table 6
Supplier B: Preliminary ranking of separator materials

| Initial capacity (RT) | | Self discharge (7 days) | | | Initial discharge performance (−10° to +40°C) | | | Aging cycles 0–300 | Overall |
|---|---|---|---|---|---|---|---|---|---|
| C/3 | 2C | 23°C | 40°C | 60°C | C/3 | C | 2C[a] | | |
| All | S2/S3 | S3 | S3 | S3 | S2 | S2/S3/S4 | S2/S3 | S2/S4 | S3 |
| | S1/S4 | S4/S1/S2 | S4 | S4 | S3/S4 | | S1/S4 | S1 | S4/S2 |
| | | | S1/S2 | S1/S2 | S1 | S1 | | S3 | S1 |

[a] 20°C only.

whereas the capacity of N2 increased by an order of magnitude and equalled the initial results with N3 at the same temperature.

These data suggest that the viable negative electrode candidates for use in an aircraft battery are either N2 or N3. The other materials would require the use of heater blankets to maintain internal battery temperature above 0°C, whereas N2 and N3 may be able to provide the desired performance down to −20°C without the use of a heater blanket in the battery. Note there was no attempt to pre-treat the materials, which could significantly influence performance and are being evaluated in Task 3.

*2.1.2.3. Separator results.* One of the stated goals of the separator study was to evaluate different materials to try and reduce self-discharge. Accordingly, the self-discharge test results were weighted double to the other three factors in the overall evaluation. Another factor was the ability of the separator material to absorb nitrogen from the positive electrode. Based on the measured nitrogen trapping capacity of each of the separator materials and nitrogen content of the positive electrode, the ratio of trapping capacity to nitrogen content vs. the self-discharge data at the three temperatures showed a very positive but nonlinear correla-

tion. The higher the ratio, the lower the self-discharge. Therefore, for an aircraft battery with a low self-discharge requirement, the best nitrogen-trapping separator and lowest nitrogen-content positive electrode should be combined.

*2.1.2.4. Electrolyte results.* Initial capacity variations between the six electrolytes showed no significant trends at either the C/3 or 2C discharge rates, with only 4 and 2% variation in the observed capacities at the two temperatures, respectively. Similarly, when discharge performance was measured at the C rate at 23° and −20°C, the variations were only 3 and 4%, respectively. Subsequent resistivity measurements, which extended to −36°C, began to show some slight separation. At −36°C, the measured resistivity for the six electrolytes ranged from 23 to 31 $\Omega$ cm, with E6 giving the highest and E4 the lowest reading. No further electrolyte studies are planned, but the resistivity data suggest that E4 may provide improved performance at temperatures lower than −20°C.

*2.1.2.5. Definition tests.* Based on these preliminary studies, the definition test matrix in Table 7 was developed. It included variations in the positive and negative electrode

Table 7
Supplier B: Definition test matrix

| Positive electrode | | | | | Separator | | Negative electrodes | | | | | | | | Electrolytes |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| P3 | P5 | P5I | P6 | P5A | S1 | S3 | N1 | N3A | N5A | N1A | N6 | N61 | N62 | N63 | E1 |
| | X | | | | | X | | | | | X | | | | X |
| | | X | | | | X | | | | | X | | | | X |
| | | | X | | | X | | | | | X | | | | X |
| | | | | X | | X | | | | | X | | | | X |
| X | | | | | X | | X | | | | | | | | X |
| X | | | | | X | | | X | | | | | | | X |
| X | | | | | X | | | | X | | | | | | X |
| X | | | | | X | | | | | X | | | | | X |
| X | | | | | X | | | | | | X | | | | X |
| X | | | | | X | | | | | | | X | | | X |
| X | | | | | X | | | | | | | | X | | X |
| X | | | | | X | | | | | | | | | X | X |

I—improved material manufacturing process.
A—post-manufacturing material activation process.

Table 8
Supplier B: Positive electrode definition test results

| Initial capacity (RT) | | Discharge performance (RT) | | | | Self-discharge | | Overall |
|---|---|---|---|---|---|---|---|---|
| C/3 | 1/5C | C/3 | C | 1.5C | Range | 40°C | 60°C | |
| P5I | P5I | All | P5I | P5A/P5I | P5A | P6 | P6 | P5I |
| P5A/P5 | P5A | | P5A/P5 | | P5I/P6 | P5I/P5A | | P5A |
| | P5 | | | P5/P6 | | | P5I/P5A | P6 |
| P6 | P6 | | P6 | | P5 | P5 | P5 | P5 |

formation processes and activation treatment of the negative electrodes. These experiments are to identify the most efficient combinations for low- and high-temperature operation and over the discharge current range required for the F-16 application.

*2.1.2.6. Positive electrode definition tests.* The objectives of this series of tests were to optimize efficiency and to minimize the self-discharge loss of the positive plates. The results of these experiments are shown in Table 8. From these data, the improved process used to manufacture P5 and the subsequent activation process both improved the initial capacity measurements and discharge performance, whereas the increased zinc and cobalt content of P6 did not. However, the decreased nitrogen content of P6 markedly reduced the self-discharge rate, but whether the increased zinc and cobalt content contributed was not determined.

The initial capacity test results were inconclusive at room temperature (RT) with negative electrode materials N1, N3A, N5A, N1A and N6 giving the same results at the C/3 and 2C rates.

Negative electrode definition tests. The threefold purpose of this series of tests was to:

(a) Pick the most efficient electrode with the highest capacity;
(b) Determine if an activation treatment could improve low temperature performance; and

(c) Determine the long-term effect of the excess of negative capacity on performance.

The negative capacity excess tests were conducted with three thicknesses of the N6 electrode called N61 to N63, respectively. Six hundred aging cycles were completed at RT. At 250 cycles, measurable differences were within experimental error. At 600 cycles, N61 had lost approximately 9% of the original capacity, N62 approximately 11% and N63 approximately 15%. After 600 cycles, capacity tests were conducted at $-30$°C, $-20$°C and at RT. At $-20$°C, capacity was only 10, 8 and 6%, respectively, of the RT capacity after 600 cycles. This precipitous falloff in capacity between $-20$° and $-30$°C means that none of the negative capacity excess ratios had a marked influence on cyclic performance. However, it also means that the amount of negative material is influential in obtaining equivalent performances. The corresponding changes in material costs and electrode weight and thickness optimize the overall volumetric and gravimetric energy density of the battery. This is highly desirable from a manufacturing and marketing standpoint.

## 2.2. Phase II: cell and battery development

### 2.2.1. Task 3: single cell tests

In order to compare test data for the bipolar and prismatic designs for the EAB, a common set of tests was defined as a baseline for the each of the suppliers. The ultimate purpose of these common baseline tests is to allow a final design for the EAB to be selected for Task 4, Battery Baseline and Task 5, Final Design Modifications

Table 9
Supplier A: Additional materials test matrix

| Group | Cathodes | | | Separator | Anodes | | | | Electrolytes | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | C1 | C8 | C9 | S1 | A5 | A6 | A7 | A8 | E$_c$ | E1 | E2 | E3 |
| G12$_c$ | X | | | X | X | | | | X | | | |
| G121 | X | | | X | X | | | | | X | | |
| G122 | X | | | X | X | | | | | | X | |
| G123 | X | | | X | X | | | | | | | X |
| G13$_c$ | X | | | X | | X | | | X | | | |
| G14 | | X | | X | X | | | | X | | | |
| G15 | X | | | X | | | X | | X | | | |
| G16 | X | | | X | | | | X | X | | | |
| G17 | | | X | X | X | | | | X | | | |

E$_c$, G12$_c$ or G13$_c$ —control electrolyte concentration or group; same as used in Task 2.

Table 10
Supplier A: Task 3. Single cell test matrix

| Group | Cathodes | | | | Separators | | Anodes | |
|---|---|---|---|---|---|---|---|---|
| | C1 | C2 | C3 | C4 | S1 | S2 | A3 | A5 |
| G12 | X | | | | X | | | X |
| G18 (G12 with S2) | X | | | | | X | | X |
| G19 (G4 with C5) | | | | X | X | | | X |
| G20 (G3 with C5) | | | X | | X | | | X |
| G21 (G2 with C5) | | X | | | X | | X | |
| G_ | to be determined—see Table 9 | | | | | | | |
| G_ | to be determined—see Table 9 | | | | | | | |

Table 11
Supplier B: Final positive and negative test configurations

| Positive | P5 | P5I | P6 | P5A | P5 | | |
|---|---|---|---|---|---|---|---|
| Electrolyte | E1 | | | | | | |
| Separator | S3 | | | | | | |
| Negative | N6 | | | | N1 | N1I | N6A |

Table 12
Supplier B: Single cell (SC) test configurations

| Component | SC1 | SC2 | SC3 | SC4 |
|---|---|---|---|---|
| Positive | P3 | | P5I | P5A |
| Electrolyte | E1 | | | |
| Separator | S3 | | | |
| Negative | N1 | | N6 | N6M |

M—modified to match alloy content of N1.

which are scheduled for April 1999. The baseline tests are the following.

(a) Charge performance: charge rates are C/2, C and 2C at $-20°$, $0,°$ RT and $+50°$C, with a standard discharge rate of C/2 at RT to a cutoff of 0.9 V per cell.

(b) Discharge performance: discharge rates are C/2, C and 2C at $-40°$, $-30°$, $-20°$, $0°$, RT, $+50°$ and $+70°$C with a standard charge rate of C/2 at RT. Tests at $-40°$ and $+70°$C are to be run only if the test configuration passes the $-30°$ and $+50°$C conditions, respectively.

(c) life cycle tests: these are based on the profile presented by Lockheed Martin for the F-16 aircraft [5] and are modified to suit single cells instead of batteries.

(d) Charge retention: identical to Task 2 conditions, but only the 7-day test is required at $-10°$, $0°$, RT and $+50°$C.

*2.2.1.1. Supplier A.* From the results of Task 2, two separate but parallel activities are underway. These are additional material tests and single cell tests as shown in Tables 9 and 10, respectively. The additional material tests include electrolyte variation and the results will be used to select two additional groups to be added to the single cell tests by December 1998.

*2.2.1.2. Supplier B.* Final positive and negative electrode tests are underway for later single-cell test experiments and to validate a supplier activation process for the negative electrode. The results of these tests will be included in the final design if Supplier B is selected for Task 4. The configurations under test are shown in Table 11. Supplier B had also defined a set of single cell configurations that contained five positive and four negative configurations,

but unfortunately, one of the positive materials was dropped due to a problem with the source of supply. Electrode fabrication was completed and cell manufacturing was underway in November 1998. The single cell test configurations are shown in Table 12.

## 3. Summary

The results of the Phase I concept design and materials evaluation tasks are complete and indicate that either a prismatic or bipolar design will meet the performance requirements for the F-16 aircraft EAB replacement. However, completion of the additional materials and single cell tests and data analysis are required before a final battery design is chosen. Final material selection tests look promising for both designs and single cell tests are underway. A final design decision is scheduled for April 1999.

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