NASA AEROSPACE FLIGHT BATTERY SYSTEMS PROGRAM

NASA AEROSPACE FLIGHT BATTERY SYSTEMS PROGRAM UPDATE

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1996 NASA AEROSPACE BATTERY WORKSHOP
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BACKGROUND

NASA AEROSPACE FLIGHT BATTERY SYSTEMS PROGRAM - INITIATED IN 1985 TO ADDRESS CONCERNS WITH AEROSPACE BATTERIES

INITIAL CONCERNS - QUALITY, RELIABILITY - PROVIDE BRIDGE BETWEEN DEVELOPMENT AND FLIGHT USE

PROGRAM EVOLVED TO PROVIDE SUPPORT TO NASA ENTERPRISES IDENTIFIED IN RECENT REORGANIZATION

PROGRAM PLAN REVISED TO REFLECT AGENCY’S STRATEGIC PLAN AND SUPPORT FOR NASA ENTERPRISES

The NASA Aerospace Flight Battery Systems Program represents a unified NASA wide effort with the overall objective of providing NASA with the policy and posture which will increase the safety, performance, and reliability of space power systems. The program was initiated in 1985 to address problems experienced with aerospace batteries.

Since the initiation of the program the agency has undergone a reorganization. A strategic plan has been developed to guide the agency over the next 25 years. In the past year, the NASA Aerospace Flight Battery Systems Program has been realigned to be consistent with the NASA strategic plan. The major objectives of the program have been revised to directly support the enterprises that have been identified in the new strategic plan.
### BATTERY PROGRAM SUPPORT OF NASA ENTERPRISES

<table>
<thead>
<tr>
<th>PRIMARY CUSTOMERS</th>
<th>GOALS</th>
<th>RELEVANCE OF BATTERY PROGRAM</th>
</tr>
</thead>
<tbody>
<tr>
<td>Policy Makers</td>
<td>Demonstrate new instruments, technologies and procedures - small smart spacecraft and instruments</td>
<td>Evolve new battery technologies that enable MTPE missions</td>
</tr>
<tr>
<td>Science and Education Communities</td>
<td>Evolve EOS science and technology and demonstrate new instruments, technologies, and procedures</td>
<td>Demonstrate battery technologies and advancements</td>
</tr>
<tr>
<td>Aero Industry</td>
<td>Provide advanced technologies for unpiloted airborne Earth/space observing platforms</td>
<td>Evolve and demonstrate battery technologies to support unpiloted platforms</td>
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<tr>
<td>US Govt Agencies</td>
<td>Provide advanced technologies for unpiloted airborne Earth/space observing platforms</td>
<td>Evolve and demonstrate battery technologies to support unpiloted platforms</td>
</tr>
<tr>
<td>Science and Education Communities</td>
<td>Achieve routine space travel</td>
<td>Evolve and validate lightweight battery technologies with improved life &amp; performance,</td>
</tr>
<tr>
<td>Commercial Sectors</td>
<td>Provide safe, reliable, low-cost transportation</td>
<td>Lower cost batteries</td>
</tr>
<tr>
<td>Space Science Communities</td>
<td>Lower cost missions</td>
<td>Lower cost batteries</td>
</tr>
<tr>
<td>Technology Innovators</td>
<td>Robotic missions</td>
<td>Lightweight, low volume batteries</td>
</tr>
<tr>
<td></td>
<td>Develop demonstrate and infuse new technology to enable and enhance all missions</td>
<td>New technologies to enable missions</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Cooperative government development, technology transfer to industry</td>
</tr>
</tbody>
</table>

NASA has been reorganized into four major enterprise areas: Mission to Planet Earth, Aeronautics, Human Exploration and Development of Space, and Space Science. Customers and goals have been identified for each enterprise. The chart above also relates the Battery Program to the work in each of the Enterprises. Batteries are critical to the path defined for each of the NASA enterprises.
PROGRAM OBJECTIVES

DEVELOP, MAINTAIN AND PROVIDE TOOLS FOR THE VALIDATION AND ASSESSMENT OF AEROSPACE BATTERY TECHNOLOGIES

ACCELERATE THE READINESS OF TECHNOLOGY ADVANCES AND PROVIDE INFUSION PATHS FOR EMERGING TECHNOLOGIES

PROVIDE NASA PROJECTS WITH THE REQUIRED DATABASE AND VALIDATION GUIDELINES FOR TECHNOLOGY SELECTION OF HARDWARE AND PROCESSES RELATING TO AEROSPACE BATTERIES

DISSEMINATE VALIDATION AND ASSESSMENT TOOLS, QUALITY ASSURANCE, RELIABILITY, AND AVAILABILITY INFORMATION TO THE NASA AND AEROSPACE BATTERY COMMUNITIES

ENSURE THAT SAFE, RELIABLE BATTERIES ARE AVAILABLE FOR NASA's FUTURE MISSIONS

The objectives of the NASA Aerospace Flight Battery Systems Program are listed above.
The approach to achieving the program objectives involves:

1) maintaining current battery technology;
2) increasing the fundamental understanding of primary and secondary cells;
3) establishing specifications and design and operational guidelines for primary and secondary cells and batteries;
4) providing for improved process control;
5) opening and maintaining communication lines within NASA and the aerospace community.
The majority of the NASA centers are involved in the execution of specific tasks within the program. The Lewis Research Center Program Manager has full responsibility for technical management, cost and scheduling of the program. The NASA Lewis Research Center Program Manager also provides continuing coordination with all the NASA centers, Jet Propulsion Laboratory (JPL), NASA Headquarters and the NASA Aerospace Flight Battery Systems Steering Committee.

The NASA Aerospace Flight Battery Systems Steering Committee provides advice on battery issues. The Committee is chaired by the Battery Program manager, membership is comprised of one representative from each of the NASA centers, the Aerospace Corporation, the Air Force, the Navy and the CIA.
This program is designed to enhance the safety, reliability, and performance of NASA's aerospace primary and secondary batteries as well as battery power systems. The NASA Aerospace Flight Battery Systems Program is organized under four major task areas: Program Management, Battery Systems Technology, Secondary Battery Technology, and Primary Battery Technology. The program is sponsored by the Office of the Chief Engineer, Code AE and the NASA Lewis Research Center (LeRC), as the lead center, has the overall responsibility for management of the program. Dr. Patricia O'Donnell of the Lewis Research Center is the program manager.
OBJECTIVES:

TO IMPROVE RELIABILITY OF ENERGY STORAGE SPACE POWER SYSTEM DESIGN, INTEGRATION, AND CHECKOUT

ADDRESS SYSTEMS ASPECTS - INTEGRATION OF CELLS INTO BATTERIES AND BATTERIES INTO POWER SYSTEMS

TASKS:

NASA BATTERY HANDBOOKS
BATTERY DATA BASE
NASA BATTERY WORKSHOP
RUSSIAN BATTERY TECHNOLOGY ASSESSMENT
JOINT EFFORTS WITH THE AIR FORCE

The Battery Systems Technology Task addresses the overall systems aspects associated with the integration of cells into batteries and batteries into power systems. The objective is to improve the reliability of energy storage, space power system design, integration, and checkout.

Sub-tasks under the Battery Systems Technology Task are listed above.
OBJECTIVE: DEFINE GOOD CONSISTENT PRACTICES FOR THE DESIGN, INTEGRATION AND CHECKOUT, AND TESTING OF PRIMARY AND SECONDARY BATTERY SYSTEMS. PROVIDE GUIDELINES AND REQUIREMENTS TO ENSURE MISSION SUCCESS

NASA HANDBOOK FOR NICKEL-HYDROGEN BATTERIES *

HANDBOOK FOR HANDLING AND STORAGE OF NICKEL-Cadmium BATTERIES *

PRIMARY BATTERY DESIGN AND SAFETY GUIDELINES HANDBOOK *

GUIDELINES DOCUMENT FOR NICKEL-Cadmium CELLS

GUIDELINES DOCUMENT FOR NICKEL-HYDROGEN CELLS

GUIDELINES DOCUMENT FOR SILVER-ZINC CELLS

* COMPLETED - PUBLISHED

A number of handbooks has been published since the program was initiated in 1985. Some of the more recent publications are listed above. Present efforts in this area focus on the development of "Guidelines/Checklist” type documents for nickel-cadmium, nickel-hydrogen and silver-zinc technologies.
The purpose of the guidelines documents is to provide guidance in the areas of overall design considerations, selection of design features /components for specific applications and to provide background for the proper selection of cells for a specific mission.
**BATTERY DATA BASE - LeRC**

**OBJECTIVE:** DEVELOP DATA BASE FOR THE DISSEMINATION OF TECHNICAL NOTES, POLICY DOCUMENTATION AND TEST DATA THROUGHOUT THE AGENCY

DATA BASE IS FUNCTIONAL - OPERATION HAS BEEN DEMONSTRATED

OPERATIONAL CYCLE TEST DATA - POST 1990 DATA FROM CRANE TESTING HAS BEEN ENTERED INTO THE DATA BASE AND IS AVAILABLE ON-LINE

LOCKHEED MARTIN TEST DATA IS BEING INCORPORATED INTO DATA BASE

The Battery Data Base subtask addresses a NASA Battery System Data Base Environment to serve the NASA battery community for the dissemination of technical cell cycle data for the testing at Crane. The majority of the NASA cell test data base resides at the Naval Weapons Support Center, Crane, IN. The Crane data has been organized and structured into a battery test data base. Cycle test data for tests run since 1990 is available on-line.
OBJECTIVE: PROVIDE FORUM FOR OPEN COMMUNICATION OF BATTERY RELATED ACTIVITIES

WORKSHOP ADDRESSES TECHNOLOGY STATUS OF ESTABLISHED AND EMERGING TECHNOLOGIES

SUBJECTS COVERED GENERALLY INCLUDE:

- RESEARCH AND DEVELOPMENT WORK ON STATE-OF-THE-ART AEROSPACE BATTERY TECHNOLOGIES,
- FLIGHT AND GROUND TEST DATA
- ON-ORBIT OPERATION AND PROBLEM RESOLUTION EFFORTS
- FOCUSED TOPIC TO ADDRESS CURRENT ISSUES RELATING TO AEROSPACE BATTERIES

The NASA Battery Workshop comes under the sponsorship of the NASA Aerospace Flight Battery Systems Program. Previously held at NASA Goddard, the Marshall Space Flight Center has hosted yearly Workshops since December 1990. The workshop serves as a forum for open communication of battery related activities between industry and government.
RUSSIAN BATTERY TECHNOLOGY EVALUATION

OBJECTIVE: DEVELOP SEPARATOR SPECIFICATIONS FOR Ag/Zn CELL DESIGNS BASED ON EVALUATION OF RUSSIAN TECHNOLOGY

NAVY PROGRAM WITH NASA INVOLVEMENT

INCORPORATE IMPROVED SEPARATORS IN DOMESTIC CELLS

SEPARATOR ASSESSMENT UNDERWAY
  CYCLE TESTING
  STORAGE TESTING - WET STAND
  DPA

This task was initiated to assess claims of the superiority of Russian Ag-Zn cell technology over domestic silver-zinc technology. In side-by-side tests, Russian cells out-performed cells manufactured in the USA. The tests indicated that the separator may be the component responsible for the improved performance. The present effort is a follow-on to the original evaluation that incorporates candidate separator materials into cells for evaluation. This is a primarily a Navy effort with NASA involvement.
COOPERATIVE EFFORTS WITH THE AIR FORCE

OBJECTIVE: LEVERAGE FUNDS BY COMBINING RESOURCES WITH THE
AIR FORCE FOR THE DEVELOPMENT OF EFFORTS TO
SUPPORT THE VERIFICATION OF SECONDARY
CELLS/BATTERIES FOR AEROSPACE APPLICATIONS.

AREAS OF COMMON INTEREST

COMMON PRESSURE VESSEL (CPV) NICKEL-HYDROGEN BATTERIES
SINGLE PRESSURE VESSEL (SPV) NICKEL-HYDROGEN BATTERIES
INDIVIDUAL PRESSURE VESSEL (IPV) NICKEL HYDROGEN CELLS
SUPER NICKEL-CADMIUM CELLS
DEPENDANT PRESSURE VESSEL (DPV) NICKEL-HYDROGEN BATTERIES

NASA and the Air Force share common interests in aerospace batteries. In order to
leverage efforts in these times of shrinking budgets, a Memorandum of
Understanding between NASA and the Air Force was signed that permits cooperation
in the area of “Joint Spacecraft Battery Verification.” Areas of common interest have
been identified as shown on the chart above.
The joint tasks that have been initiated to date are as follows:

**CPV Evaluation** - The Air Force has 21, 45 Ah, 2-cell CPV’s for technology evaluation that are part of the program. The Air Force and NASA have jointly agreed upon the test conditions for the three packs so that the data will be useful to both agencies.

**Ni-H₂ Storage Test** - NASA is funding the life cycle tests for Ni-H₂ cells that had been stored for five years as part of an Air Force test on the effects of storage on the cycle life of Ni-H₂ cells. The cells are being cycled at the same conditions used for the sister packs that were cycled without storage.

**Super Ni-Cd Storage Test** - The effects of storage on super-Ni-Cd cells has long been a concern. This task evaluates the effects of storage temperature and cell lot on the capacity and cycle life of super Ni-Cd cells.
SECONDARY BATTERY TECHNOLOGY TASK

OBJECTIVES:

IMPROVE PERFORMANCE, QUALITY, SAFETY AND RELIABILITY OF SECONDARY BATTERY SYSTEMS.

MAINTAIN AND IMPROVE ESTABLISHED TECHNOLOGIES AND AID IN DEVELOPMENT OF EMERGING TECHNOLOGIES

TASKS:

NICKEL-CADMIUM BATTERY TECHNOLOGY
NICKEL-HYDROGEN BATTERY TECHNOLOGY
NICKEL-METAL HYDRIDE BATTERY TECHNOLOGY
LITHIUM-ION BATTERY TECHNOLOGY
FLIGHT BATTERY MISSION TESTS
SECONDARY BATTERY TECHNOLOGY SUPPORT

The Secondary Battery Technology Task was established to improve the performance, quality, safety, and reliability of secondary battery systems. This task is presently structured to maintain and improve established technologies such as nickel-cadmium and nickel-hydrogen, and to aid in the development and assimilation of emerging technologies such as lithium ion and nickel-metal hydride.

The Secondary Battery Technology Task areas are listed on the chart above.
OBJECTIVE: PROVIDE INDEPENDENT VERIFICATION OF MANUFACTURING FLIGHT CELLS BY PROCURING AND TESTING REPRESENTATIVE CELLS FROM VARIOUS MANUFACTURERS

FOREIGN CELL EVALUATION - LeRC
SANYO CELLS 25, 35 AH CELLS
SAFT CELLS 21, 50 AH CELLS

ADVANCED Ni-Cd EVALUATION - LeRC, GSFC
SUPER Ni-Cd CELLS 25, 21 AH CELLS
10, 50 AH CELLS
MAGNUM Ni-Cd CELLS 25, 21 AH CELLS

ALTERNATE SOURCE CELL EVALUATION - LeRC
ACME CELLS 12 EA 18 & 55AH CELLS
NYLON & PP SEPARATORS

In order to support flight programs and address NASA's future needs with respect to nickel-cadmium cells, the NASA Aerospace Flight Battery Systems Program has a subtask that involves the evaluation of current technology Ni-Cd cells from the following sources: Hughes, SAFT, Sanyo, and Acme.
NIckel-Cadmium Cell Verification

Verification Test Plan

Repeat portions of manufacturers inspection acceptance tests

Run NASA standard acceptance test procedure for information only

Perform life cycle testing

1 Pack Perform V/T characterization
1 Pack Accelerated GEO
3 Packs LEO regime @ various temperatures

Cells have been procured in groups of 20-25 and being evaluated according to the plan outlined above. The testing involves a repeat of a portion of the manufacturer's acceptance tests to verify performance, running the NASA Standard Acceptance Test procedure, for information only, to establish a common standard data base among the cells from the various manufacturers, and finally, cycle life testing under a variety of conditions.
NICKEL-CADMIUM CELL VERIFICATION

LIFE CYCLE TEST REGIMES FOR Ni-Cd CELL EVALUATION

<table>
<thead>
<tr>
<th>TEST/PACK</th>
<th>DESCRIPTION</th>
<th>DOD (%)</th>
<th>TEMP (°C)</th>
<th>DETAILS OF REGIME</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>V/T CHARACTERIZATION - SHOCK/VIBRATION</td>
<td></td>
<td></td>
<td>V/T CHARACTERIZATION - PROCEDURE</td>
</tr>
<tr>
<td>2</td>
<td>STANDARD STRESS TEST</td>
<td>40</td>
<td>20</td>
<td>CHARGE - 1 HR, 0.8C TO V/T LIMIT, TAPER DISCHARGE - 0.8C FOR 30 MINUTES - TO 40% DOD</td>
</tr>
<tr>
<td>3</td>
<td>HIGH TEMPERATURE STRESS TEST</td>
<td>40</td>
<td>30</td>
<td>CHARGE - 0.8C TO V/T LIMIT, TAPER DISCHARGE - 0.8C FOR 30 MINUTES - TO 40% DOD</td>
</tr>
<tr>
<td>4</td>
<td>LOW TEMPERATURE STRESS TEST</td>
<td>40</td>
<td>0</td>
<td>CHARGE - 0.8C TO V/T LIMIT, TAPER DISCHARGE - 0.8C FOR 30 MINUTES - TO 40% DOD</td>
</tr>
<tr>
<td>5</td>
<td>ACCELERATED GEO</td>
<td>80</td>
<td>10</td>
<td>2 WEEK SUN PERIODS/RECONDITIONING TBD</td>
</tr>
</tbody>
</table>

PLAN REQUIRES MINIMUM OF 25 CELLS - IF ONLY 20 CELLS ARE AVAILABLE - THE SAME PACK WILL BE USED FOR TESTS 1 AND 5.

The chart above summarizes the test conditions for the test packs of nickel-cadmium cells.
## NICKEL- CADMIUM LEO TEST SUMMARY

<table>
<thead>
<tr>
<th>PACK ID</th>
<th>VENDOR</th>
<th>DESCRIPTION</th>
<th>CAP (AH)</th>
<th># OF CELLS</th>
<th>DOD (%)</th>
<th>TEMP (°C)</th>
<th>CYCLES</th>
<th>COMMENTS</th>
</tr>
</thead>
<tbody>
<tr>
<td>6000A</td>
<td>HUGHES</td>
<td>ADVANCED Ni-Cd - Z/PS</td>
<td>20</td>
<td>5</td>
<td>40</td>
<td>20</td>
<td>28723</td>
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<td>ADVANCED Ni-Cd - Z/PS</td>
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<td>5</td>
<td>40</td>
<td>20</td>
<td>28308</td>
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<tr>
<td>6002A</td>
<td>HUGHES</td>
<td>ADVANCED Ni-Cd - PP/PBI</td>
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<td>5</td>
<td>40</td>
<td>20</td>
<td>25358</td>
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<tr>
<td>6003A</td>
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<td>8</td>
<td>40</td>
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<td>6004A</td>
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<td>8</td>
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<td>30</td>
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<td>6005A</td>
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<td>30</td>
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<td>6006A</td>
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<td>SUPER Ni-Cd - Z/PBI + ADD</td>
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<td>8</td>
<td>40</td>
<td>20</td>
<td>21601</td>
<td>Stopped Testing</td>
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<tr>
<td>6024S</td>
<td>SAFT</td>
<td>VOS A</td>
<td>24</td>
<td>5</td>
<td>40</td>
<td>0</td>
<td>39238</td>
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<td>40</td>
<td>20</td>
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<td>6140S</td>
<td>SAFT</td>
<td>VOS B</td>
<td>24</td>
<td>5</td>
<td>40</td>
<td>20</td>
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<td>6601S</td>
<td>SAFT</td>
<td>Ni-Cd</td>
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<td>5</td>
<td>40</td>
<td>0</td>
<td>9611</td>
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<td>6621S</td>
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<td>Ni-Cd</td>
<td>50</td>
<td>5</td>
<td>40</td>
<td>20</td>
<td>10077</td>
<td>Failed at 30, temp reduced to 10</td>
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<td>SAFT</td>
<td>Ni-Cd</td>
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<td>5</td>
<td>40</td>
<td>30</td>
<td>10006</td>
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<tr>
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<td>SANYO</td>
<td>Ni-Cd - advanced cell</td>
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# Nickel-Cadmium LEO Test Summary - Continued

<table>
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<tr>
<th>PACK ID</th>
<th>VENDOR</th>
<th>DESCRIPTION</th>
<th>CAP (AH)</th>
<th># OF CELLS</th>
<th>DOD (%)</th>
<th>TEMP (°C)</th>
<th>CYCLES</th>
<th>COMMENTS</th>
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<tbody>
<tr>
<td>0020E</td>
<td>EP-CS</td>
<td>Magnum Ni-Cd</td>
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<td>Magnum Ni-Cd</td>
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<td>5</td>
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<td>Super Ni-Cd</td>
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<td>Magnum Ni-Cd</td>
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<td>11645</td>
<td></td>
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<td>6506M</td>
<td>EP-CS</td>
<td>Magnum Ni-Cd</td>
<td>50</td>
<td></td>
<td>VAR</td>
<td>0</td>
<td>12126</td>
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</table>
APPLIED NICKEL-CADMIUM TECHNOLOGY - JPL

OBJECTIVE: DEVELOPMENT OF Ni-Cd PERFORMANCE MODEL FOR PREDICTION OF BATTERY PERFORMANCE UNDER SPECIFIED SPACECRAFT OPERATIONAL CONDITIONS

BASED ON FIRST PRINCIPLES

DESKTOP - MACINTOSH VERSION OF MODEL IS UNDERGOING FIELD TESTING

CAPABILITIES SUMARIZED IN J.ELECTROCHEM SOC 143, 803 (1996)

CURRENT PLANS INVOLVE THE FOLLOWING REFINEMENTS
INCLUDE DEGRADATION CAPABILITIES,
BETTER DEFINED CHEMICAL EQUATIONS,
MORE SOPHISTICATED ALGORITHMS
IMPLEMENTATION ON DESKTOP COMPUTERS

The Jet Propulsion Laboratory is responsible for the Applied Nickel-Cadmium Technology subtask. This subtask involves the development of an electrochemical model of the nickel-cadmium system that involves physical, chemical, and electrochemical studies at the component and cell levels. The model will be used to develop an accelerated test which can be used to determine the quality and reliability of flight lot cells without extensive life testing and to predict the performance of a battery from a set of spacecraft operating conditions. The model is scheduled for completion this fiscal year.
The major goal of the Nickel-Hydrogen Technology subtask is to evaluate design features for incorporation into nickel-hydrogen cells for NASA missions. The Lewis Research Center has responsibility for the Nickel-Hydrogen Technology subtask. Currently, the effects of the NASA advanced design features and the effects of 26% vs 31% KOH, cell design variations including stacking arrangements and impregnation processes are being evaluated in flight cells being tested at Crane.
There are many design variations for nickel-hydrogen cells. The systematic testing being performed in this task is intended to differentiate between the design features and components. Cells from various manufacturers with varied design features are being tested. The status of the current tests on cells is summarized above.
The life cycle testing at Lockheed-Martin in Denver is the longest running nickel-hydrogen test program. NASA began supporting this program in 1992. In return for this support, all of the information relating these cells has been made available to NASA. This includes the pack histories, cell design information, DPA results and all cycle test data. The cycle test data is being incorporated into the NASA data base at Crane.
The chart above lists the design features for the cells in the Lockheed-Martin program. Ongoing tests are highlighted.
The chart above summarizes the status of the ongoing tests in the Lockheed-Martin program. Ongoing tests are highlighted.
NICKEL-HYDROGEN BATTERY TECHNOLOGY

CPV BATTERY EVALUATION

OBJECTIVE: EVALUATE POTENTIAL OF EMERGING CPV TECHNOLOGY TO MEET NASA's FUTURE NEEDS. DEVELOP DATA BASE TO INSURE OPTIMUM BATTERY MANAGEMENT AND SUPPORT FOR MISSIONS

EVALUATION OF 2.5" CPV BATTERIES - LeRC
10, 2 CELL, 10AH CPV BATTERIES EAGLE PICHER
LEO LIFE TEST, 40% DOD, 10°C
12,700 CYCLES - ONE CELL REMOVED FOR DPA

CHARACTERIZATION OF 2.5" CPV BATTERIES - JPL
CHARACTERIZATION/MISSION SIMULATION TESTS ON 2.5"CPV TESTS

JOINT TASK WITH AIR FORCE - 3.5" CPV BATTERIES
21, 2-CELL, 45AH CPV BATTERIES - EAGLE PICHER
3 PACKS - 2 LEO 40% DOD -5°C, 10°C, 1 GEO

As NASA missions change to smaller, less expensive satellites with volume and weight concerns, there is a need to incorporate new technologies to meet these needs. CPV batteries are being baselined for a number of NASA missions. This task provides a data base that will aid in insuring optimum battery management for systems using this technology.
As NASA missions change to smaller, less expensive satellites with volume and weight concerns, there is a need to incorporate new technologies to meet these needs. SPV batteries are being considered for future NASA missions. This task provides a data base that will aid in insuring optimum battery management for systems using this technology.
NICKEL-HYDROGEN MODEL - JPL

OBJECTIVE - DEVELOP A COMPUTER MODEL CAPABLE OF PREDICTING ORBITAL PERFORMANCE OF A NICKEL-HYDROGEN BATTERY USING A CELL LEVEL ELECTROCHEMICAL MODEL BASED ON FUNDAMENTAL PHENOMENA

DEVELOPMENT PARALLELS Ni-Cd MODEL

PRELIMINARY VERSION OF THE MODEL THAT OPERATES ON A PC IS AVAILABLE AND UNDER EVALUATION

PLANS INCLUDE
CONTINUED VALIDATION AND CALIBRATION
INCORPORATION OF THERMAL MODEL

JPL is responsible for developing a computer model for nickel-hydrogen batteries that parallels the work done on the nickel-cadmium model.
DEVELOPMENT OF Ni-H$_2$ STRESS TEST - MSFC

OBJECTIVE: DEFINE AND VERIFY A STRESS TEST FOR NICKEL-HYDROGEN, COMPARABLE TO THE 40% DOD, 20°C TEST FOR NICKEL-CADMIUM CELLS

60% DOD, 10°C - PRELIMINARY PROFILE FOR THE STRESS TEST

MATRIX DEVELOPED FOR IDENTIFICATION OF TEST CONDITIONS

<table>
<thead>
<tr>
<th>TEMPERATURE</th>
<th>DEPTH OF DISCHARGE</th>
</tr>
</thead>
<tbody>
<tr>
<td>20°C</td>
<td>35% 50% 65%</td>
</tr>
<tr>
<td>10°C</td>
<td>45% 60% 75%</td>
</tr>
</tbody>
</table>

EAGLE PICHER 48 AH CELLS FOR AXAF
AVERAGE CAPACITY AT 10°C - 63.5 AH AT C/2, WHERE C = 48,

The Marshall Space Flight Center is responsible for the task defining the conditions for a nickel-hydrogen stress test similar to the 40% DOD, 20 °C test currently used for Ni-Cd cells. An analysis of the nickel-hydrogen data base resulted in a preliminary recommendation of 60% DOD, 10°C as the comparable Ni-H$_2$ test conditions. A matrix has been developed to identify the appropriate test conditions. Eagle Picher 48 Ah cells, similar to those ordered for AXAF are being used in this evaluation.
DEVELOPMENT OF Ni-H₂ STRESS TEST - MSFC

STRESS TEST STATUS

EARLY FAILURES

- 65% DOD - 20°C  961-1177 CYCLES
- 75% DOD - 10°C  1085-1188 CYCLES
- 60% DOD - 10°C  2037-2400 CYCLES
- 50% DOD - 20°C  2375-3200 CYCLES

CONTINUING TESTS

- 35% DOD - 20°C
- 45% DOD - 10°C

CAUSE OF FAILURES IS UNDER INVESTIGATION

Testing of the cells per the matrix discussed on the previous chart has begun. To date four of the packs have experienced early failures after less than 3200 cycles. The cause of the failures is under investigation.
NICKEL-METAL HYDRIDE TECHNOLOGY

NICKEL-METAL HYDRIDE TECHNOLOGY EVALUATION

OBJECTIVE EVALUATE POTENTIAL OF Ni-MH TECHNOLOGY TO MEET NASA's FUTURE NEEDS

EVALUATION OF AEROSPACE DESIGN CELLS - LeRC

EAGLE PICHER - 6-10Ah CELLS - 40% DOD, 10°C
3 FAILURES - 10000, 14047, 16129 CYCLES
ONGOING TESTS - 17556 CYCLES

SANYO - 25 - 35Ah CELLS -
CHARACTERIZATION TESTS COMPLETED
TO BE RUN IN Ni-Cd VERIFICATION PROFILE

Nickel-metal hydride batteries have the potential to replace nickel-cadmium and in some cases nickel-hydrogen batteries. This task is evaluating this potential. Aerospace design cells from Eagle Picher are on LEO life test at 40% DOD, 10°C. Aerospace design cells from Sanyo are being evaluated in tests that parallel the nickel-cadmium verification tests previously discussed.
NICKEL-METAL HYDRIDE TECHNOLOGY

CHARACTERIZATION OF CELLS FROM OVONICS - GSFC

6.7 Ah CELLS

CALORIMETRIC ANALYSIS, CAPACITY, CHARGE RETENTION

6 CELLS - ACCELERATED GEO CYCLES - 240 CYCLES

LEO CYCLES - 20°C, 40% DOD - 830 CYCLES TO FAILURE

GSFC is responsible for basic calorimetric measurements on nickel-metal hydride cells. Cells from Ovonic Battery Company are being evaluated in LEO and GEO cycle regimes.
NICKEL-METAL HYDRIDE TECHNOLOGY

NI-MH COMMERCIAL CELL EVALUATION - JSC

EVALUATE Ni-MH POTENTIAL FOR EVA’s, IVA’s FOR SPACE STATION

DETERMINE BEST AVAILABLE COMMERCIAL Ni-MH

EVALUATE CHARGE METHODOLOGY
  BURP CHARGING DEMONSTRATED ADVANTAGES -
  CHARGE EFFICIENCY, MINIMIZE CHARGE DURATION, INCREASED
  CAPACITY & CYCLE LIFE

  900 - 100% DOD CYCLES WITH SANYO 4/3 A CELLS

Ni-MH DEMONSTRATED GOOD ABUSE TOLERANCE

DEVELOP AND CERTIFY Ni-MH BATTERY FOR EMU BACKPACK, ADVANCED
HELMET LIGHTS, CUFT CHECK LIST

JSC is evaluating nickel-metal hydride batteries, chargers and charge methods for
use in IVA’s and EVA’s. Replacement of primary batteries with secondary batteries
for in-cabin applications on the space shuttle and for the space station has the
potential of significant cost savings.
NASA AEROSPACE FLIGHT BATTERY SYSTEMS PROGRAM

LITHIUM -ION BATTERY TECHNOLOGY

OBJECTIVE
EVALUATE POTENTIAL OF Li-ION TECHNOLOGY TO MEET NASA's FUTURE NEEDS. ENABLE TECHNOLOGY DEVELOPMENT FOR AEROSPACE APPLICATIONS

Li-ION TECHNOLOGY ASSESSMENT - JPL

TECHNOLOGY REVIEW - STATUS ASSESSED FOR AEROSPACE APPLICATIONS

EVALUATE COMERCIAL PRODUCTS FROM SONY, SAFT, SANYO, & YARDNEY

DOCUMENTATION OF MANUFACTURING PROCESSES

DEVELOPMENT OF GUIDELINES DOCUMENTS

NASA is evaluating the potential of Lithium Ion technology to meet our future needs. Li-Ion is an enabling technology for many NASA missions. This technology offers the potential for reduced weight and volume.

The preliminary assessment consists of a review of the status of the technology available from the various manufacturers and characterization and life-cycle testing of today's technology.
LITHIUM -ION BATTERY TECHNOLOGY

LITHIUM ION CELL CHARACTERIZATION - GSFC

CHARACTERIZATION, CYCLE TESTING, DPA OF CELLS FROM CURRENT MANUFACTURERS

SAFT - 3.5" CELLS EVALUATED FOR TEMPERATURE EFFECTS ON CAPACITY, VOLTAGE AND SELF DISCHARGE

LI-ION DESIGN DEVELOPMENT - LeRC

IMPROVE ANODE - MODIFY CARBON SUBSTRATES TO FACILITATE Li ION INSERTION AND INCREASE Li CAPACITY
LITHIUM -ION BATTERY TECHNOLOGY

LI-ION COMMERCIALCELL EVALUATION - JSC

INCORPORATION OF NEW TECHNOLOGY BATTERIES INTO GFE EQUIPMENT - LAPTOP COMPUTERS, CAMCORDERS - REQUIRES UNDERSTANDING OF SAFETY ISSUES RELATING TO SPACE USE AND QUALIFICATION OF NEW TECHNOLOGY

OBTAIN COMMERCIAL CELLS - PERFORM EVALUATION CHARACTERIZATION,
CHARGE CONTROL PARAMETERS,
PERFORMANCE
THERMAL CHARACTERIZATION
ABUSE TOLERANCE
FLIGHT BATTERY MISSION TESTS

TOPEX - JPL
MISSION SIMULATION TESTS

MARS GLOBAL SURVEYOR - JPL
20 AH 2-CELL CPV’s
STRESS TEST, MISSION SIMULATION, PERFORMANCE VERIFICATION

CLARK SATELLITE SPV DESIGN EVALUATION - LeRC
15AH, 28 VOLT, FLIGHT SPARE, I&T BATTERIES

BATTERY TEST BED - JPL
MISSION SUPPORT - GRO, UARS, EUVE, TOPEX.
MANAGE DIVERGENT CELLS/BATTERIES - FACILITY SIMULATE MPS POWER SYSTEM

NASA projects are beginning to baseline non-traditional battery systems for future missions. In order to increase the data base on these systems and to provide timely support, these technologies are being investigated as part of the battery program. In many cases these efforts are entered into jointly with the programs or other NASA codes. The test data and experience provide benefits throughout the agency.
SECONDARY BATTERY TECHNOLOGY SUPPORT

DEVELOPMENT OF DPA TEST PROCEDURES - MSFC

OBJECTIVE: DEFINE GENERAL GUIDELINES TO BE FOLLOWED BY
FACILITIES PERFORMING DPA PROCEDURES ON NICKEL-
CADMIUM AND NICKEL-HYDROGEN CELLS

AVAILABLE PROCEDURES HAVE BEEN EVALUATED

DRAFT GUIDELINES DOCUMENTS HAVE BEEN PREPARED

AEROSPACE WILL WRITE MANUAL

The Marshall Space Flight Center has the responsibility for developing and
establishing guidelines for NASA for the performance of destructive physical analyses
for Ni-Cd and Ni-H₂ chemistries. Current DPA procedures used in the industry are
being evaluated in an effort to identify a standard procedure for the agency. Drafts
of the guidelines documents have been prepared.
The Lewis Research Center has produced a manual that recommends standard separator test procedures. The manual defines improved tests that will more closely evaluate separator characteristics as related to the actual cell environment. Publication of a document containing the recommended test procedures is expected before the end of the fiscal year.
PRIMARY BATTERY TECHNOLOGY TASK

OBJECTIVE:

IMPROVE PERFORMANCE, QUALITY, SAFETY AND RELIABILITY OF PRIMARY BATTERY SYSTEMS

TASK

SAFETY CONTROLS FOR LITHIUM CELLS

The objective of the Primary Battery Technology Task is to improve the performance, reliability and safety of primary battery systems. The Johnson Space Center has primary responsibility for work performed in the primary battery area.

The major task in the primary battery technology area is the development of safety controls for primary Li-BCX Cells.
SAFETY CONTROLS FOR LITHIUM CELLS

OBJECTIVE
INCREASE SHORT CIRCUIT HAZARD TOLERANCE BY REDUCING MOLARITY OF ELECTROLYTE AND THUS REDUCE CAPABILITY TO SUSTAIN HIGH SHORT CIRCUIT CURRENT FOR EXTENDED TIME

Li-BCX CELLS FROM WGL - C, D, DD

DETERMINE MINIMUM CONCENTRATION TO MAINTAIN CAPACITY REQUIREMENTS WHILE REDUCING SHORT CIRCUIT CURRENT TO PREVENT VENTING OR RUPTURE

PERFORMANCE, ABUSE, SHELF LIFE DETERMINATIONS AND QUALIFICATION OF CELLS WITH REDUCED ELECTROLYTE LEVELS

LEVELS ESTABLISHED FOR C AND D CELLS, DD EFFORT IS UNDERWAY

Successful implementation of safety controls for Li-BCX cells will result in the elimination of the need to fly the cells with a waiver. The approach used in this task is to reduce the electrolyte concentration to a level that will no longer support a short circuit current and thus prevent cell venting and ruptures.
SUMMARY REMARKS

BATTERY PROGRAM HAS BEEN REALIGNED TO BE CONSISTENT WITH NASA's STRATEGIC PLAN

EMPHASIS HAS SHIFTED FROM RELIABILITY, QUALITY ASSURANCE ROLE TO BROAD SUPPORT FOR NASA ENTERPRISES

BATTERY PROGRAM HAS RESULTED IN INCREASED COMMUNICATION AND COOPERATION AMONG NASA CENTERS AND WITHIN THE AEROSPACE BATTERY COMMUNITY

THE PROGRAM ADDRESSES FLIGHT BATTERY ISSUES RELATING TO NASA's FLIGHT PROGRAMS

The NASA Aerospace Flight Battery Systems Program has been realigned to be consistent with NASA's strategic plan. Emphasis in the program has been shifted to provide broad support for each of the NASA enterprises.

The program has provided for increased communication within the agency and with the battery industry as well. The program addresses flight battery and related flight power system activities which are essential for ensuring safe and reliable performance.