MCR-86-674

REQUIREMENTS SPECIFICATION

FOR

NICKEL CADMIUM BATTERY EXPERT SYSTEM

NAS8-35922

DEVELOPED FOR

NASA/MARSHALL SPACE FLIGHT CENTER

HUNTSVILLE, ALABAMA

PREPARED BY

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AEROSPACE DIVISION

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## TABLE OF CONTENTS

# GLOSSARY

| | | |
|------|---|------|
| AHI | – | ampere hours in |
| AHO | – | ampere hours out |
| BPRC | – | battery protection and reconditioning circuits |
| CCC | – | charge current controllers |
| DOD | – | depth of discharge |
| EOC | – | end of charge |
| EOD | – | end of discharge |
| EOF | – | end of file |
| EPS | – | electrical power system |
| HST | – | Hubble Space Telescope |
| MMDA | – | Martin Marietta Denver Aerospace |
| MSFC | – | Marshall Space Flight Center |
| NICBES | – | Nickel-Cadmium Battery Expert System |
| SOW | – | Statement of Work |
| SPA | – | solar panel array |

# SECTION 1.   SCOPE

## 1.1   Identification.
This part of the specification establishes the requirements for performance, design, test, and qualification of a computer program identified as NICBES - Nickel Cadmium Battery Expert System. This contract, NAS8-35922, is from Marshall Space Flight Center (MSFC) in Huntsville, Alabama.

## 1.2   Functional Summary.
The specific spacecraft power system configuration selected was the Hubble Space Telescope (HST) Electrical Power System (EPS) Testbed located at MSFC.   A detailed model description of the energy storage components is given in Appendix A.   Power for the HST comes from a system of 13 Solar Panel Arrays (SPAs) linked to 6 Nickel-Cadmium Batteries (discussed in Appendix B) which are connected to 3 Busses.  An expert system, NICBES, will be developed at Martin Marietta Denver Aerospace (MSFC) to recognize a testbed anomaly, identify the malfunctioning component and recommend a course of action.   Besides fault diagnosis, NICBES will be able to evaluate battery status, give advice on battery status and provide decision support for the operator.   Information for the Nickel-Cadmium batteries will be extracted through knowledge engineering utilizing the "Nickel Cadmium Battery experts" at MSFC who are involved with the HST EPS Testbed.   Additional knowledge sources will be elicited from literature searches and personnel at MMDA who have had experience with the operation of these batteries.   Extensive telemetry of the testbed operating conditions will be relayed from a DEC LSI-11 through a RS232 to an IBM-PC AT.   A Data-Handler will be implemented on the IBM-PC AT to monitor the data flow and to summarize and condense the telemetry in a manner determined by the needs of the Expert System.  Its output will be data files for use by the Expert System whose responsibilities are those listed above.   Due to the single tasking constraints of the IBM-PC AT, the two sections of NICBES will be run independently. NICBES will be installed and demonstrated at MSFC upon development completion.  Verification will be done by Software Quality Assurance at MMDA.


# SECTION 2.   APPLICABLE DOCUMENTS
Statement of Work (SOW) - Contract Number NAS8-35922.
                              Modification #4, December 31, 1985.
SAMSO Exhibit 73-3, Standard Engineering Practices for Computer Software
     Design and Development, October 6, 1973.


# SECTION 3.   REQUIREMENTS

## 3.1   COMPUTER PROGRAM DEFINITION.
This section will describe the functional relationship between NICBES and the HST EPS Testbed with which it will be running.

### 3.1.1 SYSTEM CAPACITIES.

Telemetry from the HST battery testbed is sent from a DEC LSI-11 through an RS232 at 9600 baud to an IBM PC-AT every one minute. The Data-Handler will read the input data, 370 ASCII numbers, integer or 5 place floating point, and perform appropriate processing within the one minute time frame. Unless a fault is detected, it will continue this task for 12 complete orbits, 96 minutes per orbit. List formated data files will be prepared for use by the Expert System. The Expert System portion of NICBES reads the data files and operates accordingly to give fault diagnosis, battery status and advise or decision support. The Expert System is an interactive system which runs at the direction of the user with no timing constraints except for fault diagnosis which must be given within 20 minutes of fault detection.

### 3.1.2 INTERFACE REQUIREMENTS.

NICBES can be considered an add-on to the HST EPS Testbed System. In no way will it impact the Testbed operation. NICBES will have two modes of operation. The Data-Handler, to be written in MICRO_SOFT C, will be responsible for reading, processing and writing summarized data output files derived from the HST EPS Testbed telemetry. The Expert System will be programmed in PROLOG and will perform the fault diagnosis along with the battery status, advice and decision support from information in the data files created by the Data-Handler. NICBES is connected to the Testbed by a RS232. The Expert System and the Data-Handler work independently. Print-outs can be obtained from the STAR-SD-15 Printer MSFC has acquired to support the IBM-PC AT.

### 3.1.3 INTERFACE BLOCK DIAGRAM.

The Interface Block Diagram for HST EPS Testbed and NICBES is given in Figure 1.

### 3.1.2.2 DETAILED INTERFACE DEFINITION.

Telemetry is sent from a DEC LSI-11 to an IBM-PC AT where the NICBES package resides. Refer to SECTION 3.5.1 for a detailed description of the telemetry format as well as the format for the data files created by the Data-Handler. An Interrupt Handler will be implemented to receive the incoming telemetry accurately. A computer operator starts and stops the Data-Handler after which the Expert System can be enacted. The Expert System utilizes the output data files from the Data-Handler for its analysis. The Expert System is totally interactive, driven by menus and user input. There is also an STAR-SD-15 Printer attached to the IBM-PC AT so that the user can get a hardcopy of any Expert System screens.

### 3.2 DETAILED FUNCTIONAL REQUIREMENTS.

The following paragraphs will give the detailed functional requirements necessary to develop the computer program NICBES. Since NICBES is composed of two main sections, the functional requirements will be given first for the Data-Handler and then for the Expert System.

2

# NICBES FUNCTIONAL DIAGRAM
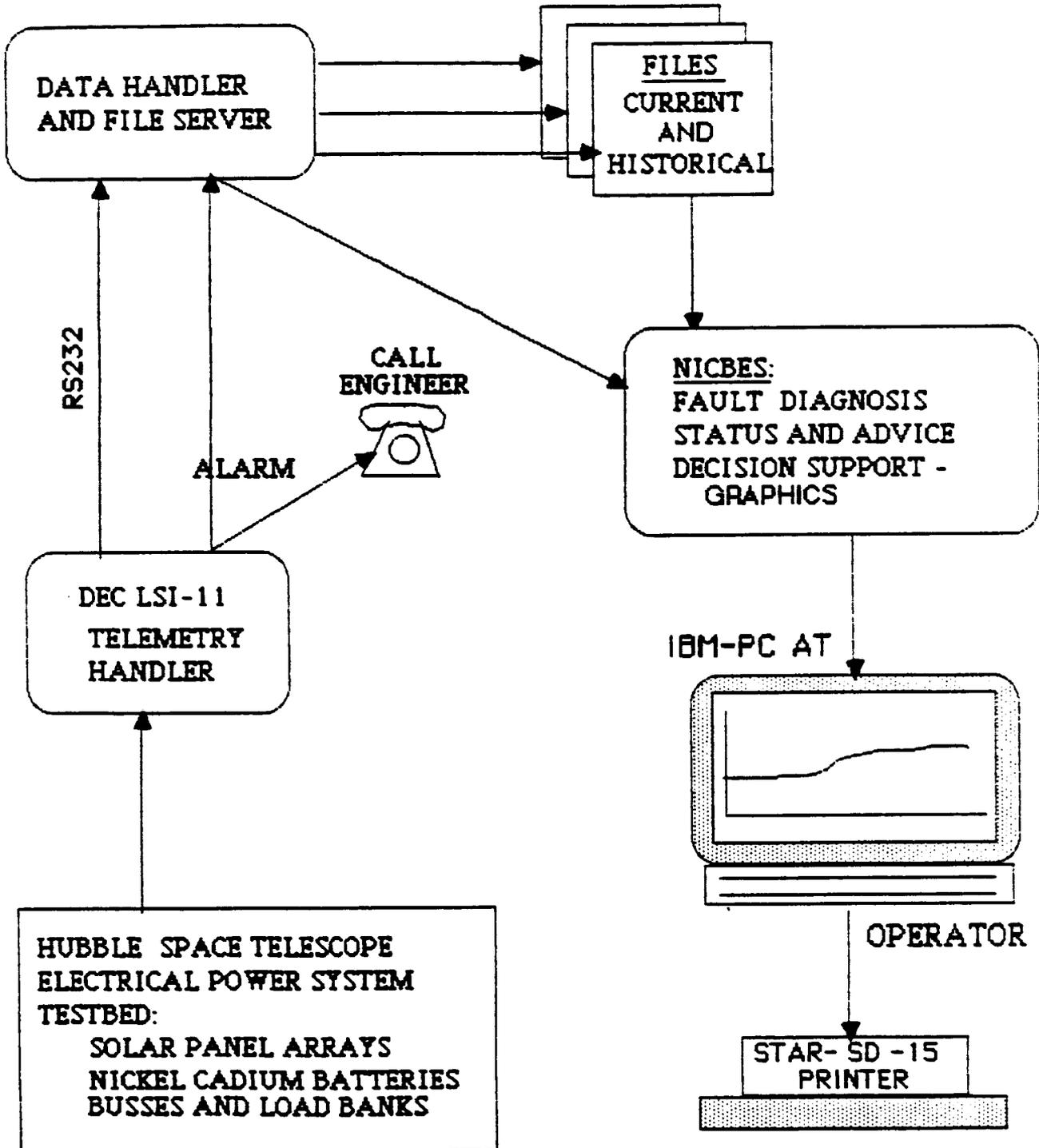


FIGURE 1

### 3.2.1    Function Main.

Main is the driver for the Data-Handler. It calls routines to initialize, read data, process data, write data files and exit. All header information as include file names, define statements, global structures, matrices and arrays will reside in a single include file.

### 3.2.1.1   Inputs.

Once the computer operator has started the Data-Handler and checked to make sure telemetry is coming across the RS232, there are no further actions or inputs required.

### 3.2.1.2   Processing.

Main controls the calling sequence of all routines. It does little processing besides determining the current phase (charge or discharge) and keeping track of the orbits.

### 3.2.1.3   Outputs.

A message will be printed to the screen at the end of each orbit.
Phase and orbit parameters will be passed to other routines.

### 3.2.2 Function Initialization.

Initialization sets up the data catching scheme which takes over the IBM poling techniques and replaces it with an interrupt handler which takes incoming data and puts it in a buffer for program access.

### 3.2.2.1 Inputs.

There are no inputs.

### 3.2.2.2 Processing.

The communication port is set. The globally defined matrices and arrays used for processing are initialized. Telemetry is read until the start of an orbit is reached signaling the true start of the Data-Handler. (An orbit starts at night minute 1 of the discharge phase and ends after the charge phase.)

### 3.2.2.3 Outputs.

A message is printed when the orbit start is found.

### 3.2.3  Function Read Data.

Telemetry comes in from the DEC LSI-11 every one minute. Read data retrieves the telemetry from the interrupt handler buffer -- 370 values, preceded by an 'A' to indicate the beginning of the data.

### 3.2.3.1  Inputs.

The interrupt handler buffer is accessed to read the telemetry input.

### 3.2.3.2  Processing.

The telemetry is read character by character from the interrupt handler buffer into a interim buffer and then put into a globally defined structured array using a 'sscanf' command. Telemetry reading will be synchronized with the character 'A' signalling the start of the data stream. Telemetry is read in groups. First the header information as date, orbit, phase, etc. Then data for each of the six batteries is read. Last is solar panel array (SPA) and bus data. Each line of telemetry has an associated value, new line and carriage return. If an EOF (end__of__file) is encountered while reading telemetry error checking will be activated. No communication will also alert an error checking process. In addition, as telemetry is received, fault checking will be done against ranges specified in Section 3.2.9, unless it is decided that a fault signal will be sent from the DEC LSI-11.

### 3.2.3.3  Outputs.

Telemetry is stored in a globally defined structured array (containing all 370 data points) for the next stage of processing. The structured array will have two columns, one for the last set of telemetry and one for the current set. Error messages for communication problems will be written to the screen.

6

### 3.2.4 Function Process Data.

Telemetry needs to be summarized and condensed. Process data takes data stored in the globally defined structured array, performs mathematical operations and keeps the results in globally defined buffers until it is time to write them to data files. Some stored values are the result of an entire orbit's data while other values are derived and written to output files every minute.

### 3.2.4.1 Inputs.

Telemetry which has been stored in the globally defined structured array will serve as input.

### 3.2.4.2 Processing.

Telemetry is processed by keeping running sums, maximums, minimums and averages. There are three cases for processing: End of Charge (EOC), End of Discharge (EOD) and Every Minute. The processed data will be written to files at the appropriate times. Information needed includes EOD battery voltage, high battery voltage during charge, recharge ratio, EOD cell voltages, cell voltages at high point during charge, average battery temperatures, time on trickle charge, current during reconditioning, cell pressure at one-minute intervals during last charge, cell voltages, AHI and AHO, current from each of the SPAs and the three busses, and orbit number. For most of these parameters, values will be kept for the last 12 orbits, based upon an "expert's opinion" that enough data could be collected for confident decision making. Following is a synopsis of what processing needs to be done for each data file.

Fault file - Contains a fault flag = 1 if there was a fault
                                    = 0 if no fault was detected.

Current file 1 - Contains the current orbit number and
                 a reconditioning flag for each battery
                             = 1 for reconditioning
                             = 0 no reconditioning.

Current file 2 - Contains Phase (charge or discharge)
                          Day_min
                          Current from 13 SPAs (Solar Panel Array)
                          Voltage from 3 Busses
                          Average Temperature per Battery (6)

Current file 3 - Contains Battery Cell Voltages (23 per battery)

Each of the following Data files has 6 rows of data, one for each battery. In many of the Data files there are 12 columns, one for each orbit. They are listed in chronological order.

Data file 1 (6x12) - File contains battery voltage taken at EOD per orbit for last 12 orbits.

Data file 2 (6x12) - File contains the battery voltage at high in-charge for the last 12 orbits. There are 23 cells per battery. (Note 1)

Data file 3 (6x12) - File contains the recharge ratio = AHO/AHI per orbit for 12 orbits. (Note 2)

Data file 4 (6x36) - File contains cell voltages at EOD, with the high value, low value and average of all values, in this order per orbit for the last 12 orbits. So a row contains 12 high values, 12 low values and then 12 average values.

Data file 5 (6x36) - File contains cell voltages at high-charge; high, low and average of all values, in this order, per orbit for last 12 orbits. Each row contains 12 high values, 12 low values and the 12 average values. (Note 1)

Data file 6 (6x23) - File contains 23 cell voltages at EOD for each battery, from the latest orbit.

Data file 7 (6x23) - File contains 23 cell voltages at high-charge for the latest orbit.

Data file 8 (6x48) - File contains the average of the six temperature sensors (degrees C) per battery, at two minute intervals (1min,3min,...95min) over the latest orbit.

Data file 9 (6x12) - File contains the average battery temperatures per orbit for the last 12 orbits. This is the average of the temperature averages in Data file 8.

Data file 10 (6x46) - File contains the 23 cell pressures taken at EOC and then the 23 cell pressures taken at EOD for each battery in the last full orbit.

Data file 11 (6X12) - File contains the time on trickle charge for each battery per orbit for the last 12 orbits. (Note 3)

Data file 12 (6x49) - File contains battery current during reconditioning, at 2-minute intervals, for last reconditioning of each battery. It is recorded every 2 minutes, only when battery reconditioning flag is 1 and only for one orbit. Column 1 contains the orbit number for which reconditioning is occurring. The file contains zeroes until a battery is reconditioned.

Data file 13 - File contains AHO summed over discharge phase per orbit for last 12 orbits. (Note 2)

Note 1--look for highest voltage of any of the 23 cells in a battery. Compare incoming values to it, keeping the highest, until phase changes to 0. This is used in Data files 2, 5 and 7.

Note 2--recharge ratio is AHO/AHI. Keep running sum of AHO when phase is 0, and running sum of AHI when phase is 1, using battery current. Figure recharge ratio at EOC (phase goes to 0). Used in Data files 3 and 13.

Note 3--during charge phase, when battery current drops to a low value, start counting trickle charge time. Keep incrementing this count each minute, until phase goes to 0.

Note 4--An orbit starts with discharge phase (0), night minute = 1. Charge phase (1) follows, counted by day minutes. There are 96 minutes in one orbit. EOC means End of Charge and EOD means End of Discharge.

### 3.2.4.3 Outputs.
Output will be stored in the form of globally defined matrices and arrays to keep track of the required processed data. Most of these buffers record data over a period of twelve orbits. For the more orbits a recycling process is required, i.e., the first column is dropped, the others are moved to the left one column and the latest orbital data values are put in the 12th column. In this manner only the latest 12 orbits are kept.

9

### 3.2.5  Function Write Files.

Processed data is written to files, some every one or two minutes, others at EOC and EOD per orbit. The processed data has been stored in various globally defined matrices and arrays. There are seventeen output files which are written to at designated times.

### 3.2.5.1  Inputs.

Summarized and condensed data stored in matrices and arrays will serve as input.

### 3.2.5.2  Processing.

The processed data buffers will be written to Data files and Current files in list format. The Fault file will be written initially with fault flag = 0. It will be changed only when a fault is detected. The Data files will contain a main list composed of 6 sublists, one for each battery. These sublists contain the required values followed by commas and enclosed in brackets. An identifier is placed at the beginning of each file consisting of the name of the file and an associated number. For example, Data file 1:

```
show(1,[[a1,b1,c1,d1,e1,f1,g1,h1,i1,j1,k1,l1],
        [a2,b2,c2,d2,e2,f2,g2,...............],
        [a3,................................],
        [a4,................................],
        [a5,................................],
        [a6,................................]]]).
```

In this example there are 12 columns, one per orbit. Orbital data is listed in chronological order.

An example of a Current file is given below:
```
curf(2,[Phase,Day_min,[SPA currents],[Bus voltages],[Battery Temps]]).
```

### 3.2.5.3  Outputs.

The following output files are written

At EOC:
    Data file 2
    Data file 3
    Data file 5
    Data file 7
    Data file 8
    Data file 9
    Data file 11
    Data file 12

Every Minute:
    Current file 1
    Current file 2
    Current file 3

At EOC:
    Data file 1
    Data file 4
    Data file 6
    Data file 10
    Data file 13

When a fault is detected:
    Fault file

10

### 3.2.6 · Function Finish.
Finish will serve as the exiting module for the Data-Handler.

### 3.2.6.1 Inputs.
When the Data-Handler has completed its function, the operator inputs a '^C' to halt processing. Exiting can also occur after read errors which the Data-Handler deems very serious or when a fault is detected..

### 3.2.6.2 Processing.
There is no processing done in Finish except to call functions to write final data files.

### 3.2.6.3 Outputs.
A message will be printed to the screen saying that the Data-Handler is exiting.

### 3.2.7  Function Interupt Handler.

The Interupt Handler will take over control of the standard IBM poling techniques to read telemetry bursts coming from the DEC LSI-11 via a RS232. This is required to ensure the validity of the passed data stream.

### 3.2.7.1  Inputs.

Telemetry from the HST EPS Testbed.

### 3.2.7.2  Processing.

The Interupt Handler will pick up each character from the communication network and place it in a circular buffer which can then be accessed by the Data-Handler programs. Write and read pointers will keep track of information position in the buffer. An EOF designates no data.

### 3.2.7.3  Outputs.

Output will be a buffer in which telemetry characters have been stored.

12

### 3.2.8  Function PROLOG initialization.

This program is automatically executed whenever PROLOG is called.  It will be used to load all the PROLOG programs for the Expert System, copy and load all necessary data files, and start up the Expert System.

### 3.2.8.1  Inputs.

No inputs.

### 3.2.8.2  Processing.

Loads PROLOG programs and data files, and then executes the Expert System.

### 3.2.8.3  Outputs.

No outputs.

## 3.2.9   Function Start.

This is the main driver for the Expert System. It is written in Prolog. Start calls all the other Prolog programs and also displays all the menus for the user interface. The Fault Diagnosis routine is called automatically if a fault has been detected. The other routines are called when the user selects them from the menus.

### 3.2.9.1   Inputs.

There are two input files:
Fault file - Contains a fault flag = 1 if there was a fault
                                    = 0 if no fault was detected.

Current file 1 - Contains the current orbit number and a
                 reconditioning flag for each battery
                        = 1 for reconditioning
                        = 0 no reconditioning.
The remaining inputs to this program involve user selections to menus.

### 3.2.9.2   Processing.

Start checks the fault flag and brings up Fault Diagnosis if a fault was detected. It then directs the system flow according to user selection to menus. They pick which section to view from a choice of Graphics, Battery Status and/or Advice.

### 3.2.9.3   Outputs.

There will be four menus written to the screen to enable the user to easily traverse within the Expert System. They are:

    Main Menu - 1.  Graphics - Decision Support
                2.  Battery Status
                3.  Battery Advice.
                4.  Quit

    Battery Selection - select Battery 1 to 6.

    Graphics Menu - choice of 12 plots for each battery,
                    corresponding to Data files 1 to 12.

    Advice Menu - 1.  Recondition the battery?
                  2.  Change the workload?
                  3.  Change the charging scheme?

After a selection is made from the Main Menu, a particular battery is chosen before Graphics, Battery Status or Battery Advice is called. Upon completion, another battery may be chosen for viewing with respect to the Main Menu selection or the user can return to the Main Menu.

14

## 3.2.10  Function Fault Diagnosis.

This module performs Fault Diagnosis which is called if the fault flag = 1. Telemetry from the HST Testbed indicating a serious malfunction will cause an alarm to be sent to the engineer and a shut down of the system. There are five categories that will trigger this action. They are:

1. Power Supplies
   - a. SPA current  < 5 amps during first 5 minutes of charge phase.
   - b. SPA current  >= 8 amps for 1-SPAs (1,3,5,7,9,11).
     - SPA current  >= 16 amps for 2-SPAs (2,4,6,8,10,12,13).
   - c. SPA current  > 5 amps during discharge phase.

2. Batteries
   - a. Cell voltage  <= 0  volts for any cell in any battery.
   - b. Cell voltage  > 1.55 volts for any cell in any battery.

3. Load Banks
   - a. Sum of 3 bus currents  > 99 amps.
   - b. Load  < 5 amps on any single bus during discharge phase.

4. Temperature
   - a. Average of the 6 temperature sensors  > 25 C or  < -10 C.

5. Communication
   - a. Missing 3 consecutive telemetry bursts.

## 3.2.10.1  Inputs.

Two current data files are input:
Current file 2 - Contains Phase (charge or discharge)
                          Day_min
                          Current from 13 SPAs (Solar Panel Array)
                          Voltage from 3 Busses
                          Average Temperature per Battery (6)

Current file 3 - Contains Battery Cell Voltages (23 per battery)

## 3.2.10.4  Processing.

Each of the above five fault conditions is checked individually comparing the current data files against the expected data values as predetermined by MSFC.

## 3.2.10.3  Outputs.

Header is displayed, 'FAULT DIAGNOSIS FOR ORBIT #'. One or more of the above five fault conditions is reported as the source(s) of the fault along with the malfunctioning component and if possible its value. For example:  Hard Short in cell 3 of battery 1, or
           Load on Bus 3 < 5 A, load bank error.

3.2.11 Function Status.
The Status portion of the Expert System checks the selected battery for reconditioning, temperature, workload, charging scheme and divergence.

3.2.11.1 Inputs.
Data files are used as input.

Data file 1 - File contains battery voltage at EOD for last 12 orbits, in chronological order.

Data file 2 - File contains the battery voltage during high in-charge for last 12 orbits.

Data file 3 - File contains the recharge ratio = AHO/AHI per orbit for 12 orbits.

Data file 4 - File contains cell voltages at EOD, with the high value, low value and average of all values, in this order for each of the last 12 orbits

Data file 8 - File contains the averages of the six temperature sensors (degrees C), at two minute intervals over the latest orbit.

Data file 9 - File contains the average battery temperatures over entire orbit for the last 12 orbits.

Data file 13 - File contains AHO summed over discharge phase per orbit, for last 12 orbits.

3.2.11.2 Processing.
First check to see if the selected battery is being reconditioned. If so, stop this process since data will be misleading. Otherwise, four procedures are called to check selected battery performance. Averages (battery data averaged over 12 orbits) are used for the status analysis.

| CONDITION | STATUS |
|---|---|
| Temperature check (Data files 8 and 9) | |
| Temperature average over last orbit < 0 and over last 12 orbits < 0 | => Cold |
| Temperature average over last orbit > 11 and over last 12 orbits > 10 | => Hot or possible overcharging |
| Temperature average over last orbit > 11 and over last 12 orbits < 10 | => Possible overcharging |

16

Workload Check (Data files 1 and 13)
      AHO average over last 12 orbits < 3.                 =>   Underwork
      (3.0 Ampere-hours)

      AHO average over last 12 orbits > 14.                =>   Overwork
      (14.0 Ampere-hours)

Charging Check (Data files 2 and 3)
      Recharge ratio average < 1.02                        =>   Insufficient
      and average high-charge voltage < 32.5V                   Charge

      High-charge voltage > 33.8V                          =>   Possible
                                                                Overcharge

Divergence Check (Data file 4)
      Divergence average > .8V between                     =>   High divergence
      high and low cells

      High cell minus average greater than                 =>   Too many cells to
      (average minus low cells) + 1                             low values


### 3.2.11.3  Outputs.

Header is displayed, 'STATUS FOR BATTERY #, ORBIT #'. Messages are printed to the screen detailing which of the above procedures is being checked and whether the battery seems healthy or whether there is a problem(s). The problem(s) is described giving condition and status of the component plus guidance as to where to get more information in the Advice or Graphics modules.

3.2.12  Function Advice.
The Advice section goes into further detail than the Status section on three subjects: whether a battery needs reconditioning, changes in charging scheme, or changes in its workload.

3.2.12.1  Inputs.
Inputs will be in the form of data files which will have been created by the Data-Handler.  They are:
Data file 1 - File contains battery voltage at EOD for last 12 orbits, in chronological order.

Data file 2 - File contains the battery voltages during high in-charge period for each of the last 12 orbits.

Data file 3 - File contains the recharge ratio = AHO/AHI per orbit for 12 orbits.

Data file 4 - File contains cell voltages at EOD, with the high value, low value and average of all values, in this order for each of the last 12 orbits

Data file 9 - File contains the average battery temperatures over entire orbits for the last 12 orbits.

Data file 10 - File contains the 23 cell pressures taken at EOC and then EOD for each battery in the last full orbit.

Data file 13 - File contains AHO summed over discharge phase, per orbit for last 12 orbits.

3.2.12.2  Processing.
Trend analysis and averaging calculations will be performed for the following parameters, data read from the above data files:

| Reconditioning | Charging Scheme | Workload |
|---|---|---|
| EOD batt voltage | in-charge high voltage | EOD batt voltage |
| in-charge high voltage | recharge ratio | EOD cell diverge |
| recharge ratio | temperature | Avg AHO |
| EOD cell divergence | Avg in-charge cell diverge | |
| in-charge cell divergence | Avg EOD cell pressure | |
| | Avg EOC cell pressure | |

Trends will be expressed as none, slightly_up, up, strongly up, slightly__down, down and strongly down.  Trends will be calculated by using two simple mathematical functions.  They can be expressed as:

$$1. \quad \frac{n-1}{2} \sum_{i=1}^{n} X(i) \qquad\qquad 2. \quad \sum_{i=1}^{n} i * X(i)$$

where i <= 1 to 12 orbits and X(i) are the associated parameters.

18

The difference between the weighting functions is taken and then compared to hand crafted deviation factors to determine the trends. The first function weights all parameter values for a battery equally, while the second function weights the recent parameter values more heavily. For a list of constant values, the two functions are equal.
Divergence is simply computed by taking the differences between corresponding values of two lists as high-voltage cells and low-voltage cells.

For reconditioning, 11 conditions need to be checked for a particular battery:
  1. EOD voltage strongly down, in-charge divergence strongly up => reconditioning advised.
  2. EOD voltage strongly down, in-charge voltage strongly down => recondition soon.
  3. EOD divergence strongly up, in-charge divergence strongly up => strongly rising divergence indicates reconditioning.
  4. Voltage trends strongly down or down, recharge ratio and divergence trends strongly up or up => reconditioning is indicated by all 5 trends.
  5. Recharge ratio strongly up => reconditioning indicated.
  6. In-charge voltage is down or strongly down, in-charge divergence is up or strongly up => reconditioning recommended.
  7. EOD voltage down or strongly down, in-charge divergence up or strongly up => reconditioning indicated.
  8. EOD and in-charge divergence both up => consider reconditioning.
  9. Recharge ratio up => consider reconditioning.
 10. Both EOD and in-charge voltages down => consider reconditioning.
 11. None of the above => no need for reconditioning at present.

To determine if the charging scheme for a battery should be changed, nine conditions are checked:
  1. Temperature strongly up, EOD pressure greater than 120, EOC pressure greater than 140 => overcharging causing high pressure.
  2. In-charge voltage strongly up => check for overcharging.
  3. EOD pressure greater than 110, EOC pressure greater than 135 => charge rate may be too high.
  4. EOD voltage strongly down, in-charge voltage strongly down => undercharging may be seriously affecting capacity.
  5. EOD voltage down, in-charge voltage down => undercharging.
  6. EOD voltage strongly down or down, in-charge voltage strongly down or down => undercharging may be causing loss of voltage.
  7. EOD voltage down, in-charge divergence greater than .8 => undercharging may be causing loss of voltage.
  8. EOD voltage strongly down, in-charge divergence greater than .8 => undercharging may be causing serious loss of voltage.
  9. None of the above => no need to change charging scheme.

19

Six conditions are checked to advise as to battery workload change:
1. EOD voltage down, EOD divergence down, AHO average less than 25 => loads probably too light.
2. EOD voltage strongly down, EOD divergence strongly down, AHO average less than 5 => losing capacity due to memory effect, try heavier load.
3. AHO average greater than 14 => possibly destructive overwork.
4. AHO average greater than 9 => heavy workload.
5. EOD voltage down or stongly down, EOD divergence down or strongly down, AHO average above 6 => losing capacity, consider reconditioning.
6. None of the above => no need to change workload.

### 3.2.12.3 Outputs.
A header is displayed, 'ADVICE FOR BATTERY #, ORBIT #'. Messages are printed to the screen detailing which of the three choices is being examined and what the trends are for a particular battery. Given the condition, corrective action is recommended as reconditioning the battery, changing the workload or changing the charging scheme along with an explanation. Support of these decisions can be gotten from by viewing the plots detailed in the next section..

20

3.2.13  Function Graphics.
Graphics supply the user with decision support in the form of 12 plots and histograms for a selected battery.

3.2.13.1  Inputs.
Graphics uses Data file(i) (i = 1 to 12) as inputs. Other input comes from user menu selections which determine which of the 12 graphs to plot and for which battery.

3.2.13.2  Processing.
The appropriate data file is read to get the data for the selected battery.  Graphics primitives are used draw color plots of the data. Titles, vertical and horizontal captions are printed along with battery number and current orbit.  The lists of data are then plotted, point by point.

3.2.13.3  Outputs.
Output consists of 12 plots for any battery (1-6) corresponding to the 12 Data files.

   1.  Battery Voltage at EOD for last 12 orbits
   2.  Battery Voltage at high in-charge for last 12 orbits
   3.  Recharge ratio for last 12 orbits
   4.  Cell Voltages at EOD; high, low, average for last 12 orbits
   5.  Cell Voltages at high in-charge; high, low, avg, last 12 orbits
   6.  Cell Voltages at EOD for latest orbit
   7.  Cell Voltages at high in-charge for latest orbit
   8.  Average Battery Temperature for latest orbit, each 2 min
   9.  Average Battery Temperature for last 12 orbits
  10.  Cell Pressures at EOC and EOD for latest orbit
  11.  Time on Trickle Charge for last 12 orbits
  12.  Battery Current during reconditioning, 1 orbit, each 2 min

The user will be able to get a hardcopy of the plot as displayed on the screen.

21

### 3.3  Special Requirements.

The following paragraphs will give a description of the special requirements which will affect the design of NICBES.

### 3.3.1  Programming Method(s).

Structured Programming methods will be applied to the 'C' routines in the Data-Handler.  The Expert System routines will be written in Prolog which is a logic programming language.  Although the Expert System can not follow structured programming techniques due to its inherent qualities, it will be modular and somewhat procedural.

### 3.3.2  Program Organization.

The Data-Handler and the Expert System will be built as two separate systems whose only dependencies are the data files.

### 3.3.3  Modification Consideration.

There will be no allowable modifications during operation of the Data-Handler.  The Expert System will allow adjusting of the deviation factors and ranges of the plots.  These modifications must be made prior to running the Expert System.

### 3.3.4  Special Features.

Print statements to facilitate the testing of the Data-Handler will be left in the programs, but commented out for actual system execution.

### 3.3.5  Expandability.

Due to the moderate size of NICBES, there is adequate room for expansion.  However true expansion to its function would best be done on a multi-tasking computer.

### 3.3.6  Special Timing.

Since the Data-Handler and the Expert System will be developed and tested independently, there are no special timing requirements.

### 3.4  Human Performance.

The Expert System will be an entirely interactive system whereby the user will make selections from menus to direct the type of information desired.  The menus are described in Section 3.2.8.3.  Responses to menus will usually be item number selection.  Response checking will occur after each user entry.  There are no time or order constraints imposed upon user input.  Displays will remain on the screen until the user opts to continue.

## 3.5 Data Base Requirements.

NICBES is a data driven model. In the following paragraphs exact data base requirements will be listed.

### 3.5.1 Sources and Types of Input.

Input to the Data-Handler is in the form of telemetry bursts, each containing 370 values - one per line, routed from the DEC LSI-11 to the IBM-PC AT every one minute. Following is the format:

Start of Telemetry Burst
    A

Header Information (Integer)
    year
    day of year - 198X
    hour - 0 to 24
    minute - 0 to 60
    second - 0 to 60
    orbit - Positive Integer
    phase - 0 for discharge, 1 for charge
    day minute (minute in charge) - 0 to 70
    night minute (minute in discharge) - 0 to 37

Battery Information (for each of 6 batteries)
    battery number            Integer  1 - 6
    cell voltage              23 Reals  -2 to +2 volts
    cell pressure             23 Integers  0 to 150 psi
    battery voltage           Real  0 to 40 volts
    battery current           Real  -30 to +25 amps
                                    negative for discharge phase
                                    positive for charge phase
    bprc current              Real  0 to 5 amps
    temperature sensors       6 Reals  -15 to 30 (degrees C)
    battery reconditioning    Integer  0 for no, 1 for yes

Miscellaneous Information
    Solar Array current       13 Reals  0 to 20 amps
    Bus Voltage               3 Reals  0 to 40 volts
    Bus current               3 Reals  0 to 90 amps

Reals are five place floating point numbers.

Inputs to the Expert System are the data file outputs of the Data-Handler, see Section 3.24 for a complete description. All other inputs to the Expert System are user selections to menus.

23

### 3.5.2 Destination and Types of Outputs.
Output from the Data-Handler is in the form of data files which will be used as input to the Expert System. All the battery data files and their format are listed under section 3.2.4.2.
Output from the Expert System is in the form of reports, explanations, analysis and graphs. No data files are created.

### 3.5.3 Internal Tables and Parameters.
Global structures and parameters for the Data-Handler will be set-up in an include file. All parameters in the Expert System will be passed to functions as needed, i.e., no global parameters.

### 3.6 Adaptation Requirements.
NICBES will be written specifically for analysis in support of the Hubble Space Telescope Testbed. Adaptations to other EPSs will require seperate efforts, although the concepts may remain the same.

### 3.7 Government-Furnished Property List.
No Government property will be used in the development of NICBES. However the following hardware and software are required at Marshall Space Flight Center for NICBES installation and demonstration:

| Hardware | Software |
|---|---|
| DEC LSI-11 | MICROSOFT C |
| IBM-PC AT | ARITY PROLOG Version 4.1 |
| STAR-SD-15 Printer | |
| RS232 | |

## SECTION 4. QUALITY ASSURANCE PROVISIONS

### 4.1 Introduction and Definitions.
In order to assure functionality and accuracy of NICBES several types of testing will be conducted. All testing will be conducted during development at MMDA. The final system installation and demonstration will be performed at MSFC at the time of delivery.

### 4.2 Testing Structure.
The test program will be structured into the following four levels of testing.

24

### 4.2.1 Module/Unit Testing.

Module/Unit tests are the first informal tests which will be conducted by the programmer prior to establishment of the test baseline. Module/unit testing will demonstrate the accuracy of the operations indicated in the functional requirements, Section 3.2. Each module/unit will be tested using nominal, extreme and erroneous input values and will be tested for error detection and proper error recovery including appropriate error messages. Each decision option will be exercised to execute subordinate units performing input or output functions.

### 4.2.2 Subsystem Integration Testing.

Subsystem integration tests are the final informal tests conducted by the programmer prior to establishment of the test baseline. Subsystem integration testing will demonstrate the accurate implementaion of interfaces between module/units. As each module/unit is integrated into the subsystem, the interface will be tested using nominal, extreme and erroneous input values and will be tested for error detection and proper error recovery including appropriate error messages.
There are only two subsystems for NICBES, the Data-Handler and the Expert System Interface.

### 4.2.3 System Integration Testing.

System integration tests are the formal tests conducted by the programmer after establishment of the formal baseline. System integration testing will demonstrate the accurate implementation of interfaces between subsystems. As each subsystem is integrated into the system the interface will be tested for error detection and proper error recovery including appropriate error messages. The system size/memory requirements and execution time will be measured and evaluated. An integrated system test will be conducted to verify required performance.
For the NICBES system integration test the Data-Handler will be evaluated with telemetry obtained from MSFC HST EPS Testbed over modems. This data will then be used to simulate the data communication network at MSFC by linking two IBM-PCs via a RS232 and transferring data at one minute intervals. The data files generated by the Data-Handler will then be used to evaluate the Expert System.

### 4.2.4 System Demonstration.

A demonstration based on the integrated system test will be conducted at Marshall Space Flight Center upon delivery and installation of the software.

## 4.3  Testing Techniques.
Testing will incorporate two fundamental methodologies.

### 4.3.1  Structure-Based Path Testing.
Path testing will be employed for module/unit level testing.  The objective of path testing is to exercise enough differnet paths through the logic structure of a module/unit to demonstrate the accuracy of the processing performed on the data.  A path equates to an executable instruction sequence that starts at a module/unit's entrance and ends at its exit and may consist of one or more of the operations identified in the functional requirements, Section 3.2.  Enough paths are required to ensure that every instruction in the module/unit has been exercised at least once and every decision has been executed in each posssible direction at least once.

### 4.3.2  Top-Down Integration.
Top-down integration will be employed for both subsystem integration and system integration levels of testing.  The objective of top-down integration is to build a string of modules from the executive or control module.  Modules will be added to the string in increments to allow testing of individual interfaces.  Modules not yet integrated are simulated by stub routines as integration progresses by adding individual modules and testing each interface.

## 4.4  Test Documentation.
Test documentation will be written in the Test Plan, Test Procedures and Test Report.

### 4.4.1  Documentation of Test Plan.
Test implementation information will be stated in the test plan and will specify the following:
1. Facility resources and location.
2. Schedule.
3. Manning requirements.
4. Preparation of input data.
5. Software configuration.
6. Organization of test operations.
6. Output analysis techniques.

### 4.4.2  Documentation of Test Procedures.
A Test Procedures document will be written to accompany the Test Plan.  It will reflect the following:
1. Program initialization instructions.
2. Operater interfaces.
3. Input Data;
4. Required operator responses.
5. Test event sequence.
6. Information recording requirements.
7. Program termination/restart instructions.

## 4.4.3 Documentation of Test Reports.

A Test Reports document will be written to accompany the Test Plan and Procedures. This document will relect the following information:
1.  Actual test results.
2.  Criteria successfully met.
3.  Deviations from expected results.
4.  Reasons for deviations.
5.  Recommendations.

## 4.5 Verification Cross-Reference Matrix.

| Function | Test Requirement |
|---|---|
| 3.2.1 Function Main | Appropriate subroutines called |
| 3.2.2 Function Initialization | Communication ports operate |
| | Data reading starts at beginning of of orbit |
| 3.2.3 Function Read Data | Telemetry read and put in structured array |
| 3.2.4 Function Process Data | Telemetry processed and put in correct matrix or array |
| 3.2.5 Function Write Data | Processed data written to files at appropriate times and in correct format |
| 3.2.6 Function Finish | Data-Handler is exited |
| 3.2.7 Function Interupt Handler | Telemetry is read from the DEC LSI-11 via RS232 and put in accessable buffer |
| 3.2.8 Function PROLOG Initialization | Programs loaded and Expert System started |
| 3.2.9 Function Start | Menus appear in proper order and appropriate modules are called |
| 3.2.10 Function Fault Diagnosis | If fault flag, diagnosis anomaly correctly |
| 3.2.11 Function Status | Battery temperature, workload, charging, divergence and reconditioning checked accurately |
| 3.2.12 Function Advice | Advice for battery reconditioning, charging and workload from trend analysis matches expert opinion |
| 3.2.13 Function Graphics | All 12 plots are accurately drawn on the screen |

27

## SECTION 5.  PREPARATION FOR DELIVERY

Delivery will include the entire NICBES software package recorded on diskettes plus all deliverable written documents.  After coordinating with C&DM, the above media will be hand carried to MSFC in Huntsville, Alabama at the time of NICBES installation and demonstration.

APPENDIX A

HUBBLE SPACE TELESCOPE BATTERY TESTBED

NASA and MSFC are involved in the development of autonomous systems for spacecraft. The electrical power system has been identified in several studies and by the Advanced Technology Advisory Committee as a leading candidate for implementing advanced automation approaches such as knowledge-based and expert systems. The HST EPS Testbed provides an opportunity to take a significant step toward autonomous operation of an EPS for spacecraft.

Power for the HST comes from a system of 20 SPAs and 6 23-cell nickel-cadmium batteries. The HST EPS is simulated by and EPS Testbed at MSFC. Each battery has two power supplies associated with it, divided into 1-SPA and 2-SPA. A seventh 2-SPA brings power directly into the bus distribution system. These 13 power supplies simulate the 20 SPAs. Figure 2 is a schematic diagram for the testbed.

The testbed at MSFC was built to simulate the HST EPS as closely as practical. There are 6 charge current controllers (CCC) that control the operation of various relays that disconnect (when a temperature-dependent voltage level is reached) and connect SPAs to the batteries. Each CCC controls 3 SPAs; a K2 relay controls one SPA and a K1 relay controls two SPAs. Thus only tow power supplies are needed per battery. The 13th power supply simulates the two SPAs that are connected directly to the diode bus.

The batteries are diode isolated from each other. Each two batteries are connected to three diode busses. The diode busses then feed three independently controllable load banks. As on the flight HST, each battery can be switched to a reconditioning load and its associated SPAs can be switched to one of the other two diode busses.

The batteries are mounted three each on two aluminum plates in a single temperature chamber. Each plate has a heater element that can control the battery temperature up to 10 degrees Celsius above the chamber ambient temperature.

Also incorporated in the testbed is a microprocessor controller that was built and programmed at MSFC. This control computer (CC) controls the temperature of the batteries; it controls the load banks in either a constant current or constant power mode; it can maintain a tape charge on the batteries; it controls the over-voltage diode trip point; and it senses CCC relay operation and controls the 13 power supplies in much the same fashion as the HST DF224 flight computer controls the SPA trim relays for a step to trickle charge.

A1

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NOTES:

1. K2X, K1X CONTROLLED BY CCC (SEE SEPERATE SCHEMATIC)
2. EACH PS INDIVIDUALLY CONTROLLED (ON/OFF) BY CC (CON
3. EACH LOAD BANK PROGRAMMED BY CC
4. K5X, K6X SET AND RESET BY FRONT PANEL CKT (SEE SEP
   THESE RELAYS OPEN IF DDAS FAILS, CC FAILS, +15 FAIL
   OR CHAMBER FAILS HOT (SEE TIME-OUT CKT SCHEMATIC).
5. K7X CONTROLLED BY CC VIA OPTO 22
6. S = SHUNT

FIGURE 2

This testbed development work was performed by several people at MSFC. John R. Bush was responsible for the HST breadboard and controller. John A.Pajak was responsible for the data system and the associated maze of wiring. Rober E. Kapustka was responsible for the battery protection and recontioning ciruits (bprc). John R. Lanier is the team leader of EPS Systems Team which has responsibility for this testbed.

## APPENDIX B

## NICKEL-CADMIUM BATTERIES

Nickel-Cadmium batteries are appropriate energy storage media for a wide range of applications. They exhibit a combination of high capacity, long life and low maintenance requirements. There is, however, much that is unkown about the behavior of these batteries, both in terms of design and manufacture, and operating characteristics. Even persons who have been working with these batteries for over 15 years, say that there is no such thing as a battery expert.

General statements can be made about Nickel-Cadmium batteries. The most important factors affecting their performance, ignoring design and manufacture, include ambient temperature, depth of discharge, and charging scheme. It has been observed tat occasional changes in such operating parameters can be of marked benefit in the life cycle of the cell.

As the batteries go through a great number of charge - discharge cycles, aging takes place, due largely to electrolyte migration, separator deterioration, hydrogen generation because of overcharging, and memory effect. This last condition is a result of utilization of only a small part of the battery's capacity over a number of charge - discharge cycles, causing a change in the crystalline structure of the metals on the plates. Reconditioning is done by draining a battery completely, and holding it at a low potential for a period of time, then recharging the battery. This rebuilds a finer crystalline structure and restores much of the battery's capacity. Reconditioning is a strain on the battery and should not be undertaken lightly, but is a valuable tool in enhancing battery capacity. Eventually, deterioration of the battery goes too far, and reconditioning can no longer restore usefulness.

During the draining procedure of recondition, a weak cell can undergo reversal, causing permanent damage. The BPRC prevents this occurrence. BPRCs protect each cell of the batteries.

During battery operation, cell voltages tend to diverge, migrating into groups of strong cells and weak cells. As cells get weaker, they do no carry their share of the load, which must be taken up by the stronger cells. Need for reconditioning is indicated by a high divergence, a low EOD voltage and particularly by both conditions together. A low EOC voltage, particularly if accompanied by a low recharge ratio (ampere hours in divided by ampere hours out), usually indicates that the battery is being insufficiently charged.

If a Nickel-Cadmium battery is overcharged, hydrogen gas is generated causing a sharp increase in cell pressure. Since the hydrogen is not recombined, it is possible that a cell may rupture. Another problem due to overcharging is heat production, causing an increase in intake of current, causing more heat production, and leading to thermal runaway and battery self-destruction. Care must be taken so that overcharging does no occur, usually by shutting off power when a certain cell voltage is reached. After main charge is shut off, the battery remains on trickle charge for the rest of the charging cycle, a non-destructive "topping off" of the charge.

Decision to recondition, change charging scheme or adjust workload are presently made by rule of thumb and intuition gained from years of experience. Battery management remains a difficult subject.