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ADVANCED BATTERY SYSTEM FOR AIRCRAFT

EAGLE PICHER INDUSTRIES, INC.
ELECTRONICS DIVISION
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COLORADO SPRINGS, CO 80911

JUNE 1995

FINAL REPORT FOR 11/01/86-06/01/95

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AEROPROPULSION AND POWER DIRECTORATE
WRIGHT LABORATORY
AIR FORCE MATERIEL COMMAND
WRIGHT PATTERSON AFB OH 45433-7251

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1.0 Introduction

This is the final report on the Advanced Battery System For Aircraft (contract F33615-86-C-2678). This report contains final design and test data on the aircraft battery system and its components developed under this contract by Eagle Picher Industries, Inc. (EPI) (battery development) and ELDEC Corporation (charger/controller development).

Figure 1-1 shows the basic battery system. It contains three elements: Battery, Battery Charger, and Controller. Physically the controller and the charger are housed in one Line Replaceable Unit (LRU). The aircraft interface with the battery system consists of a power interface; three phase input power required is 115Vrms line to neutral at 8A per phase, 400Hz ac bus, and output power is 28Vdc battery bus capable of handling 50A currents. The signal level interface with the aircraft system is in the form of LED drivers for fault and status indication.

2.0 Program Objective

2.1 Discussion

The current state-of-the-art aircraft batteries (vented nickel cadmium and lead acid) are not capable of meeting the desired low maintenance requirements of today's Air Force. Currently used aircraft batteries have a routine maintenance interval period of approximately 90 days, with some cases of high rate type applications needing weekly maintenance cycles.

2.2 Objective

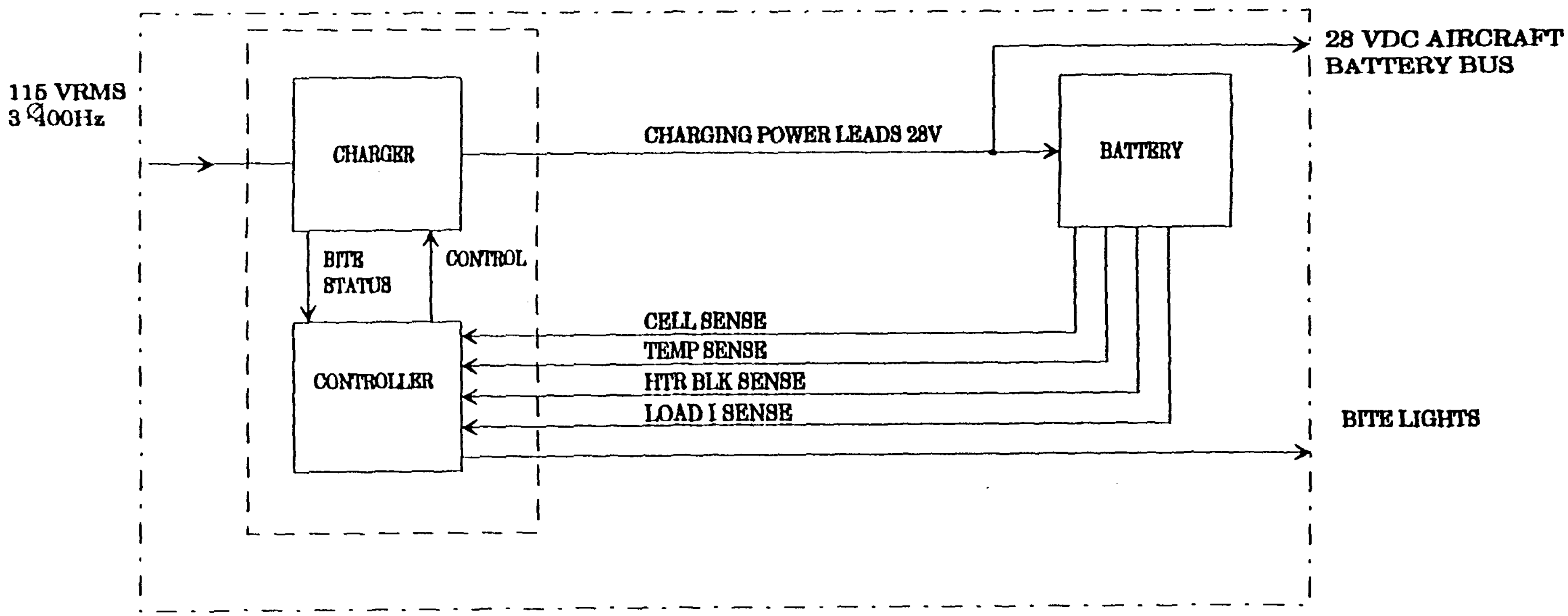
The objective of this effort was "to develop the technology for an advanced aircraft battery system, consisting of a sealed nickel cadmium battery module, a charger module with a microprocessor monitor/self test module that is suitable for use in a broad spectrum of Air Force aircraft applications." This program would address the logistical need to eliminate field maintenance battery shops and flight line maintenance activities necessary for currently used systems. The system was to be designed with the intent of operating for 3 years or 1000 flying hours without maintenance.

2.3 Statement of Work

The objectives for this contract are detailed in the Statement of Work (F33615-86-C-2678), and are summarized below.

1) Meet the program design goal that the battery system must have a three year or 1000 flight hours maintenance free operation.

2) Issue a report on Air Force aircraft battery usage and maintenance requirements. This report was generated and released by EPI reference System Trade-Off Study dated August 15, 1989.



SYSTEM BLOCK DIAGRAM

FIGURE 1-1

JB101.DRW

3) Develop an Advanced Battery System Specification Control Drawing(SCD). ELDEC SCD 4-520 was developed to define the requirements for the hardware to be delivered at the end of the contract.

4) Develop a sealed NiCad battery technology applicable to an aircraft environment for the 0 to 50 Ahr range.

5) Develop a microprocessor controlled charger/controller to provide battery charging and battery system monitoring.

6) During the program, monthly status reports were provided to update the progress of the work.

7) Present a Preliminary Design Review (PDR) and a Critical Design Review (CDR). During the program there were two reviews where government and industry personnel were invited to evaluate the design for the advanced battery system. These were held in Colorado Springs, CO (Battery CDR, Charger/Controller PDR) in Aug 89, and in Bothell, WA (Battery update, Charger/Controller CDR) in Mar 90.

8) The extension to the contract to support flight testing for B-52, E-3, and AC-130 aircraft types will not be covered in detail in this report. A flight test report for each of the aircraft is attached as Appendixes A and B.

3.0 Conclusions and Recommendations

All of the program objectives were met. The deliverable systems are designed to have maintenance free operation for 3 years or 1000 flight hours. The goal of achieving a sealed NiCad battery and a microprocessor controlled charger was also met. Although the contract scheduling required ELDEC and EPI to perform much of battery and charger development in parallel, at program end an integrated and reliable system was delivered.

As with any research or design work, there were trade-offs to be made during the development of the hardware. In the case of the Advanced Battery System a listing of lessons learned or recommendations is presented. These items are suggestions for improvements to the existing design for a potential second phase or follow on contract.

3.1 Battery Recommendations

Overall, the batteries met all requirements of the Program Objectives as set forth by the Statement of Work. Nonetheless, continuous improvements and upgrades to material and processes are being sought to provide a better product.

3.1.1 Separator Material

In batteries bearing Eagle-Picher part nos. 18213 and 18214, polyolefin was used for the separation material. In part nos. 18216 and 18192, polypropylene impregnated with Polybenzimidizole (PBI) was used as separation material. Due to the favorable results from testing 18216 and 18192, Eagle-Picher recommends that polypropylene impregnated with PBI be used as separation material.

3.1.2 Resealable Vent Plug

Original specifications on the Advanced Battery System for Aircraft resealable vent plug were for venting to occur at 90 psi and to reseal at 60 psi. These parameters were found to be inappropriate and the final design was set for venting at 75 psi and reseal at 45 psi.

3.2 Charger/Controller Recommendations

3.2.1 Downloading Data Save RAM

Currently the only way to download the data from the Data Save RAM is to take the system off of the aircraft. Once off the aircraft the data must be downloaded with a special piece of test equipment which will print the data on paper. To improve this process ELDEC proposes that a future charger/controller have a serial interface connector that could be accessed while the unit is on the aircraft. The data could then be downloaded from the charger/controller to a portable computer. This would solve the problem of removing the unit from the aircraft, and would allow for electronic storage of the data.

3.2.2 "Keep-Alive" Battery

The method used to store data and keep track of real time requires a small battery in the charger/controller for memory back-up. From a maintenance standpoint this is a weak link in the design. At the current size of the back-up battery, it would need to be replaced every 3 years to ensure proper operation. For the next generation charger design ELDEC proposes to modify the method of storing data such that the "keep-alive" battery is not required. There are several ways to provide the same function while extending the maintenance life considerably.

3.2.3 Power Draw from the Aircraft Battery

The system Specification Control Drawing (SCD 4-520) calls out a maximum current draw on the aircraft battery of 100mA for the charger. The charger/controller meets this requirement; however, for low amp hour systems this is somewhat excessive. For the next generation charger design ELDEC proposes a design goal of less than 25mA.

3.2.4 Power Stage Design

The power stage design for the charger/controller utilizes a mature technology in both the topology and the power component selection. As such it contributes to the large size of the charger/controller. ELDEC proposes that a follow-on contract require a more progressive design approach for the power stage circuitry. A new approach could utilize state-of-the-art power semiconductors and high frequency design techniques to minimize the size of the power magnetics.

3.2.5 High Density Packaging

The current design of the charger/controller utilizes conventional through-hole plated technology circuit boards and hand wired interconnects. To further reduce the size of the charger/controller, on the next generation design, the use of high density packaging is recommended. This could be either hybrids or Surface Mount Technology for circuit boards, and flex strips for board-to-board interconnects.

3.2.6 Modular Design concepts

The greatest determinant of the size of power conversion equipment is its power level. The charger/controller built for this program is designed to deliver 30V at 50A. This is appropriate for a 40 to 50 Ahr battery; however, for a 10ahr battery it is excessive. ELDEC proposes that the next generation of charger/controller be made from a family of smaller, lower power modules at output levels of perhaps 10, 30 and 50A which could be paralleled to provide higher current applications. Thus, the charger/controller would be truly modular in both the control and power aspects, with software control that could be easily modified for different control schemes or battery types, and plug-in power modules to support different battery sizes.

4.0 Battery Design

4.1 Designs Evaluated

Three different types of batteries were evaluated to find which of the three would be most suitable for this project. They were starved electrolyte, semi-starved electrolyte, and flooded electrolyte/negative limited.

4.2 Design Selected

As the goal of this contract was to produce a battery system that would reduce maintenance and increase life cycle, the starved electrolyte battery design was found through testing to be the most suitable for this project. There were four different batteries used and they are described below:

EPI 18213. A 20 cell nickel cadmium battery with a capacity of 23 ampere hours. This battery uses the EPI-3223 cell, which is manufactured using the dry sinter process. Polyolefin was used for separating material. Cells were activated with 1.30 specific gravity KOH. This design was flight tested on the B-52.

EPI 18214. A 10 cell nickel cadmium battery with a capacity of 55 ampere hours. This battery uses the EPI-3160 cell, which is manufactured using the dry sinter process. Polyolefin was used for separating material. Cells were activated with 1.30 specific gravity KOH. This design was flight tested on the E-3.

EPI 18216. A 20 cell nickel cadmium battery with a capacity of 40 ampere hours. This battery uses the EPI-4240-1 cell, which is manufactured using the dry sinter process. Woven nylon and Celguard was used for separating material. Cells were activated with 1.30 specific gravity KOH. This design was flight tested on the AC-130.

EPI-18192. A 20 cell nickel cadmium battery with a capacity of 24 ampere hours. This battery uses the EPI-2024-1 cell, and is also manufactured using the dry sinter process. Woven nylon and Celguard was used for separating material. Cells were activated with 1.30 specific gravity KOH. This design was also flight tested on the AC-130.

Nylon cell casings were used on all four batteries. The 18216 and 18192 were vented cell batteries. The 18213 and 18214 were fitted with a resealable vent system. The vent system was designed to open when pressure reached 75 psi, and then reseal when the pressure lowered to 45 psi.

5.0 Charger/Controller Design

The charger/controller provides both battery charging and battery system monitoring functions. The basic operation for our 23 Ah battery system is described below.

Battery charging is accomplished by the following method:

Basecharge -	constant current at approximately 2C rate.
Topping Charge -	constant current at approximately C/2 rate.
Float Charge -	constant voltage at 26.5V.

Basecharge and topping charge are terminated when the battery voltage reaches a temperature compensated cut off level.

Monitor functions include the following:

Charger Module -	Overcurrent Overvoltage Undervoltage Input power Input commands
Controller Module -	Microprocessor check Input power Operation date and time "Keep-Alive" battery check
Battery -	Battery temperature Cell overvoltage Cell undervoltage Battery heater blanket Battery load currents

5.1 Electrical Design

The charger module contains the power electronics to provide the proper output voltage and current to the battery for charging. The controller module is microprocessor controlled and contains the software for charger control, Built In Test (BIT), and battery monitor functions.

5.1.1 Charger Design

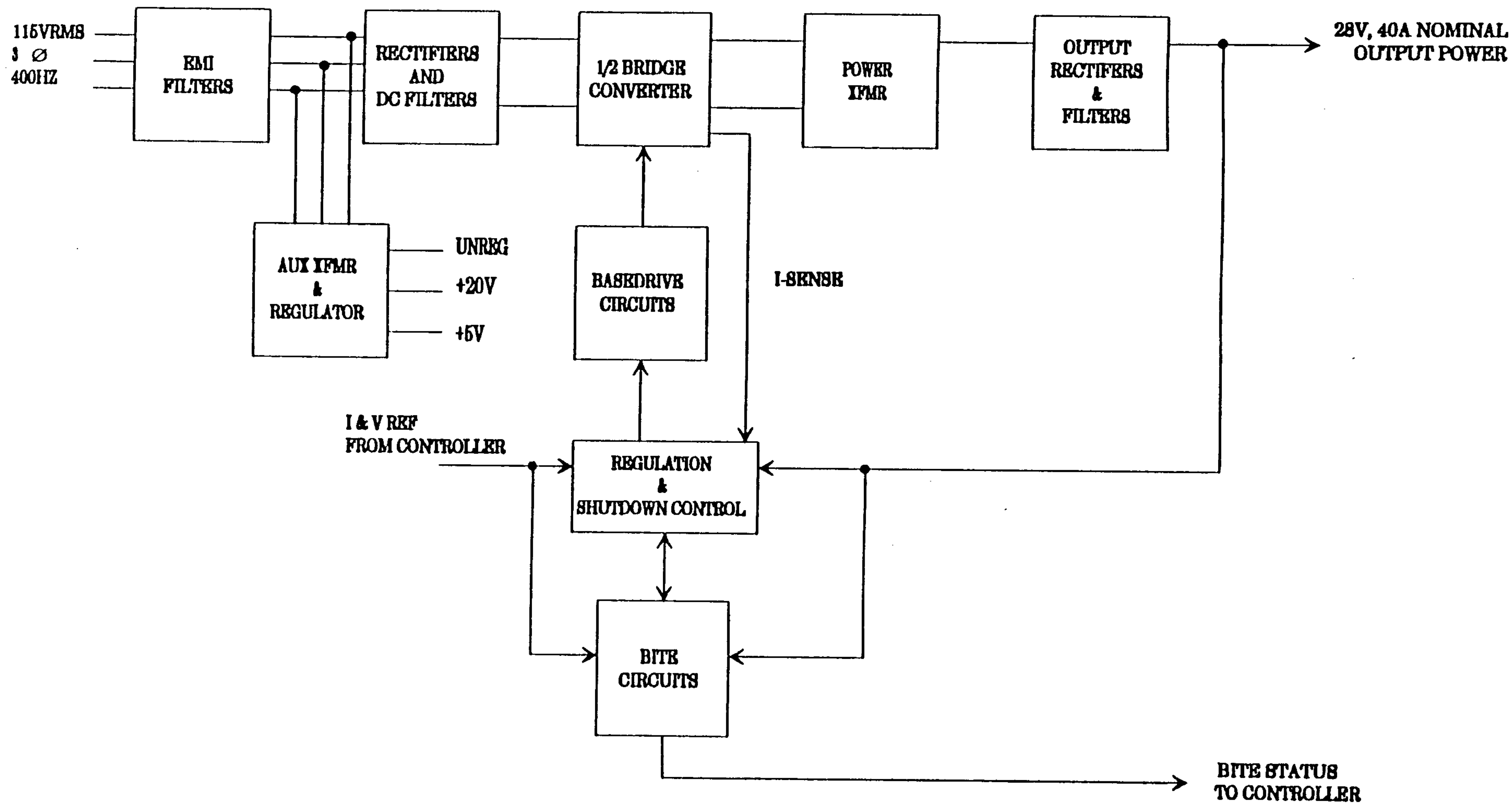
The charger module used for this program is a modified version of a design that ELDEC has been using for aircraft chargers. This design was chosen because it is passively cooled, and covers the power range required by this project (0 to 50A). Design emphasis was on the controller, with goal of control methods and battery monitoring that could be much "smarter" than existing systems. The physical size of the charger is driven by its power capability and the resultant passive cooling techniques described in section 5.2.1.

Figure 5-1 shows a block diagram of the charger module. The input power for the charger is standard aircraft three phase, 115Vrms, 400Hz power. The Electromagnetic Interference (EMI) filters provide filtering to protect both the charger and the input power. The filters provide protection for the charger by filtering input spikes from the main generator lines. The filters also provide attenuation of the switching noise generated by the input rectifiers and the auxiliary regulator. This filtering attenuates noise conducted from those sources.

The input rectifiers convert the 400Hz ac input into a dc input with a 2400Hz ripple component. The dc filters smooth out the 2400Hz ripple component and attenuate the high frequency switching noise from the half-bridge converter. This filtering also provides EMI protection for the input line.

The half-bridge converter segments the input dc voltage and provides an AC high frequency voltage across the power transformer. This method allows the use of smaller power transformers as transformer size is inversely proportional to operating frequency.

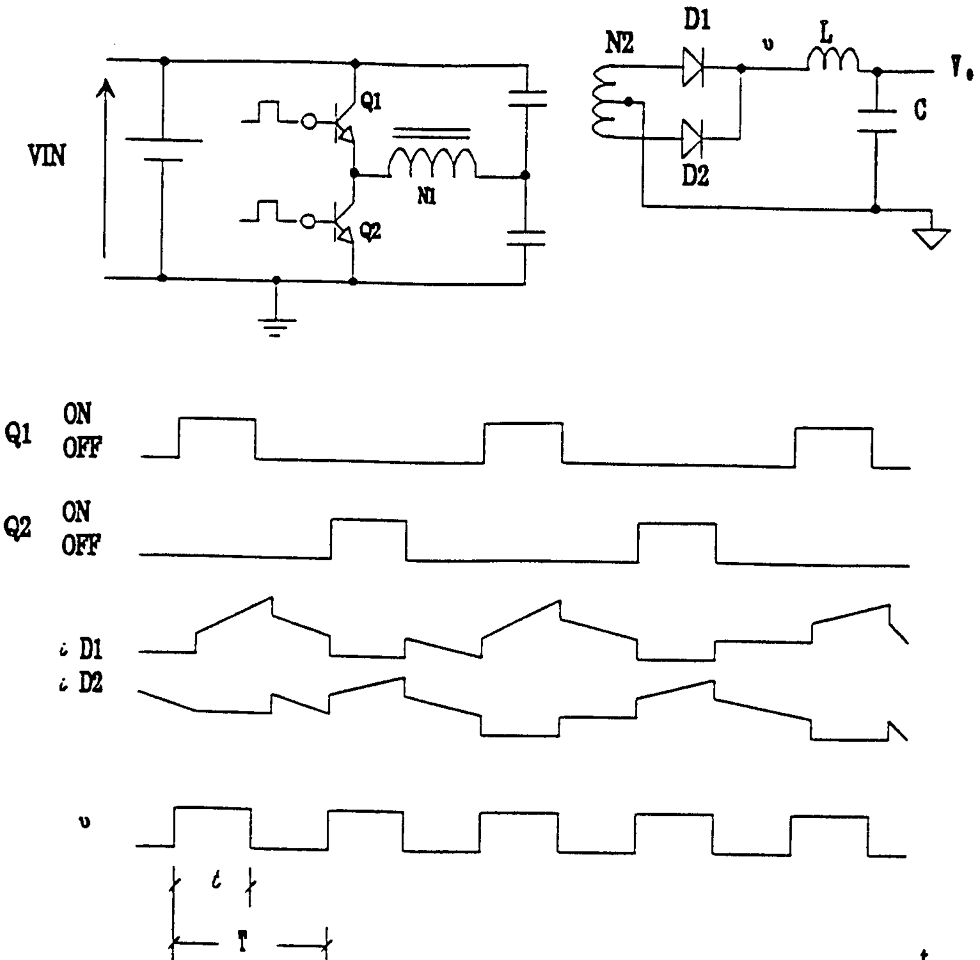
This ac voltage is transformed to a lower ac voltage via the power transformer and then full wave rectified and filtered to provide the final dc voltage and current required by the battery for charging. The half-bridge converter is based on a common buck type regulator topology. Figure 5-2 pictorially describes its operation. As shown in the figure, when either Q1 or Q2 are on there is a voltage applied to the output filter LC. This filter averages the rectified voltage, V, applied to the filter. The resultant output voltage is a function of the input, Vin, the transformer turns ratio, and the duty cycle of the applied waveform. This duty cycle is controlled via the control circuits to be described later. When both transistors are off the two output diodes continue to conduct because there is a dc current in the output inductor, L, which continues to flow. This is the



CHARGER MODULE BLOCK DIAGRAM

JB501.DRW

FIGURE 5-1



DUTY CYCLE $= \frac{t}{T} = D$

$V_o = VIN\left(\frac{N2}{N1}\right)D$

HALF BRIDGE CONVERTER WAVEFORMS

FIGURE 5-2

JB502.DRW

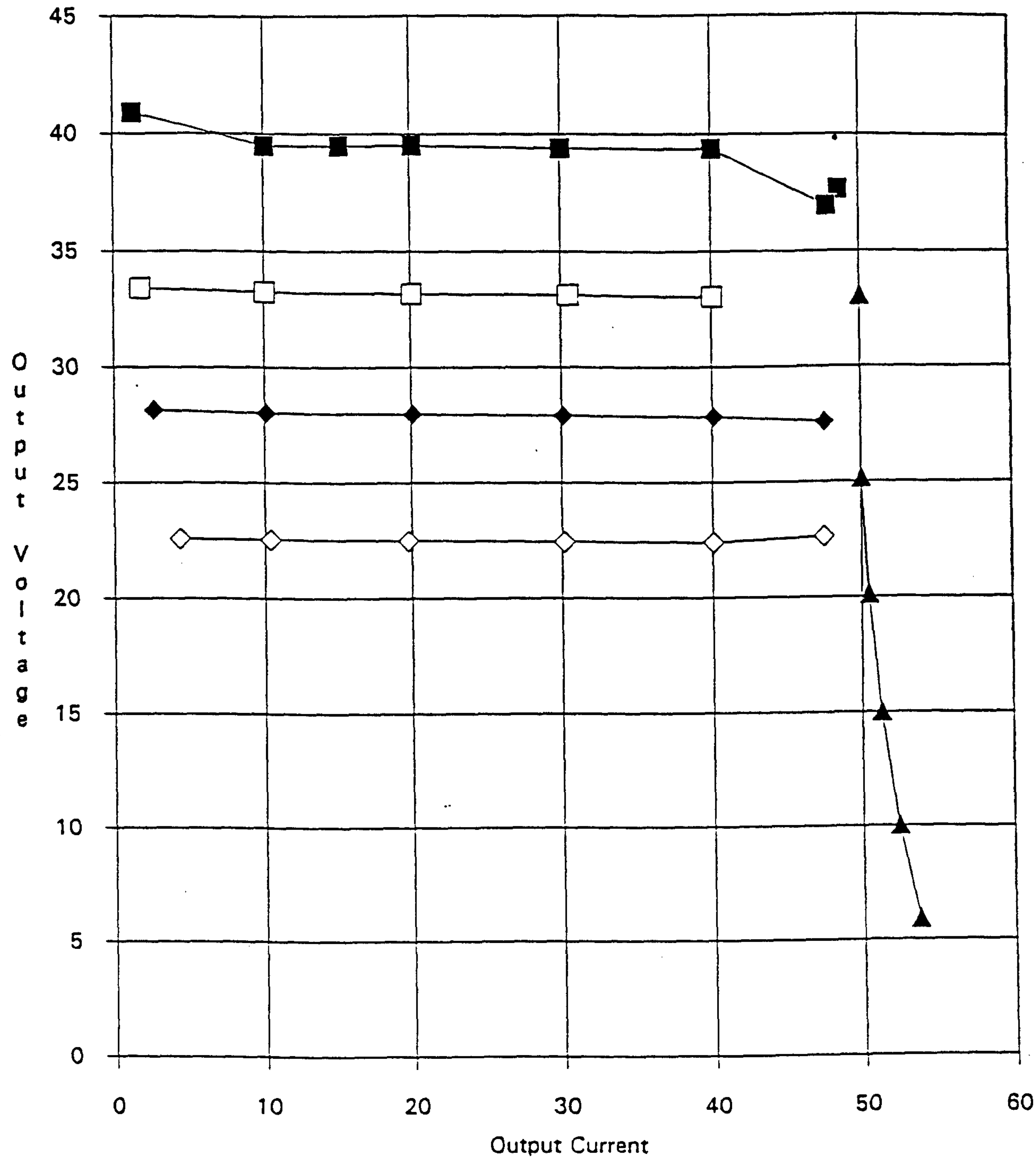
basis of the continuous buck converter, and while the operation remains continuous the control law for the output, Vo, is upheld.

The control circuits monitor the output voltage and current and receive input references from the controller module. The references set the output voltage and current maximums. The control circuits provide the methods to regulate the output voltage or current by comparing these output signals to the input references and then changing the duty cycle of the switching logic that controls the power devices in the half-bridge converter. This technique is known as Pulse Width Modulation (PWM).

The charger control circuits also contain protection circuitry which will turn off the charger if the control circuits cannot control the output voltage or current as commanded. The BIT circuitry can also command a shut-down, as described later. The limits for shut-down are done under hardware control such that a failure in the software cannot cause damage to the battery or the battery charger.

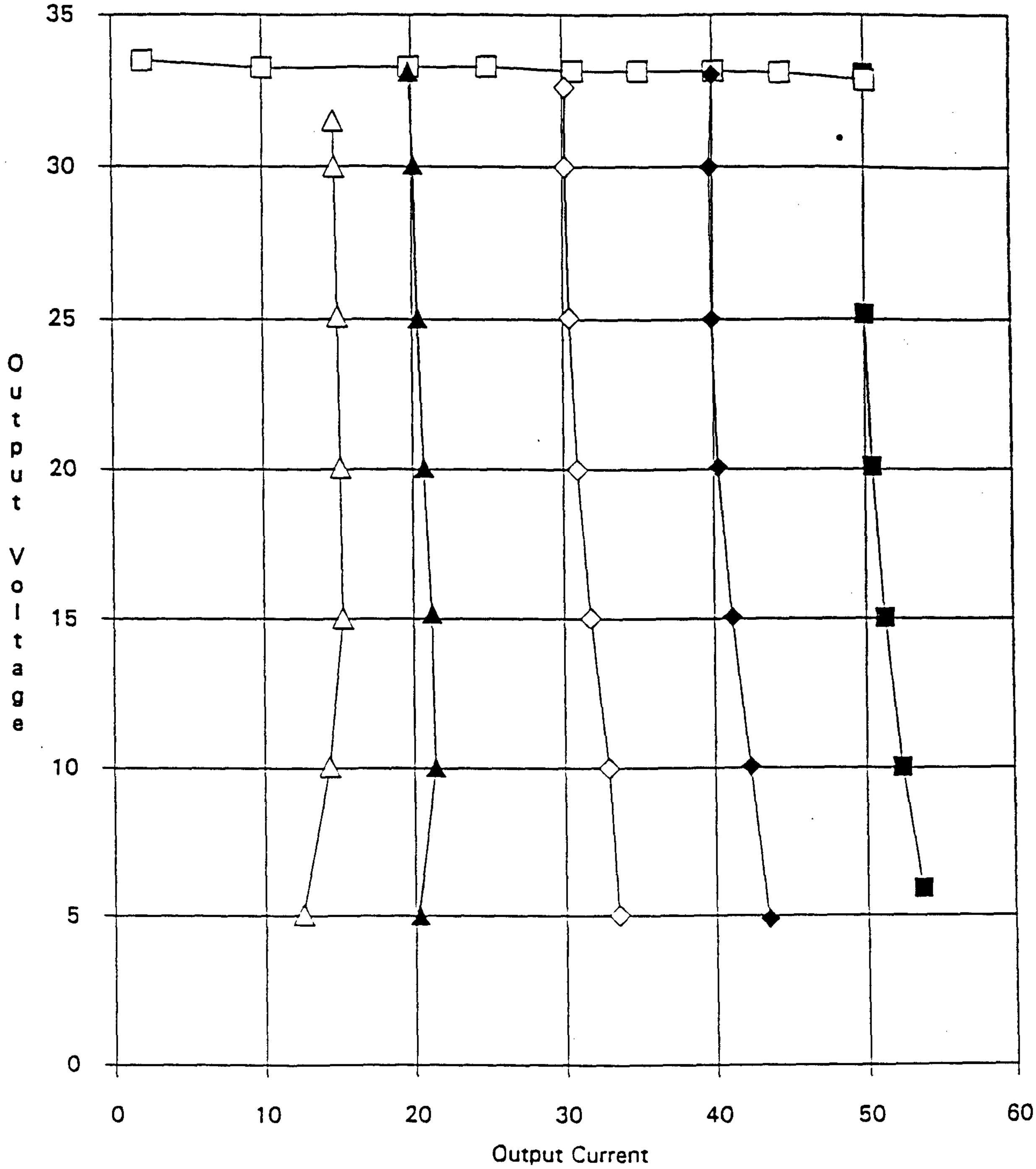
When the charger is operating in the voltage control mode (constant potential) the charger will regulate the output voltage to the level requested by the controller. This is accomplished by controlling the duty cycle. If the charger is in the constant current mode, the charger will regulate the output current to the current requested by the controller. This, too, is accomplished by controlling the duty cycle. These two modes of operation are shown in figures 5-3 and 5-4. Figure 5-3 shows the constant potential mode of operation. This graph shows four different conditions where the output voltage is programmed to regulate between 22 and 38 volts. In each case the output current is varied between zero and 60 Amps. The current maximum for this test was set at 50 Amps. As can be seen, the output voltage remained very constant for varying load conditions in the constant potential mode. This is true until the current reached the maximum (50A), at which time the voltage drops and thus protects the charger as designed.

Figure 5-4 shows the constant current mode of operation. This graph shows five different current curves ranging from 8 Amps to 50 Amps. For all of these conditions a resistor load was varied in order to force the voltage at the output terminals to change. In each case the output voltage maximum was set to 33V. As can be seen from the graph the load regulation is not as precise as the voltage regulation. It is, however, adequate for battery charging because the actual current can be off by several amps and the charging can still be completed in the 60 minute time frame. The maximum voltage however is much more critical for the battery and this function is very tightly regulated even in the constant current mode.



CONSTANT POTENTIAL MODE

FIGURE 5-3



CONSTANT CURRENT MODE

FIGURE 5-4

Both graphs depict the wide operating range of the charger which allows usage for many sizes of batteries. The control circuits provide the PWM signals to the base drive circuits that are used to drive the power devices in the half-bridge converter. The power devices used in this charger are power transistors with low losses. These transistors were selected because of their high gain capabilities over temperature.

The auxiliary regulator converts the ac input voltage after the EMI filters to three dc voltages at low power levels to provide bias power for the controller module and the control and BIT circuits in the charger module. The voltages used are; an unregulated voltage of approximately 26 volts and two regulated voltages at +20 and +5 volts.

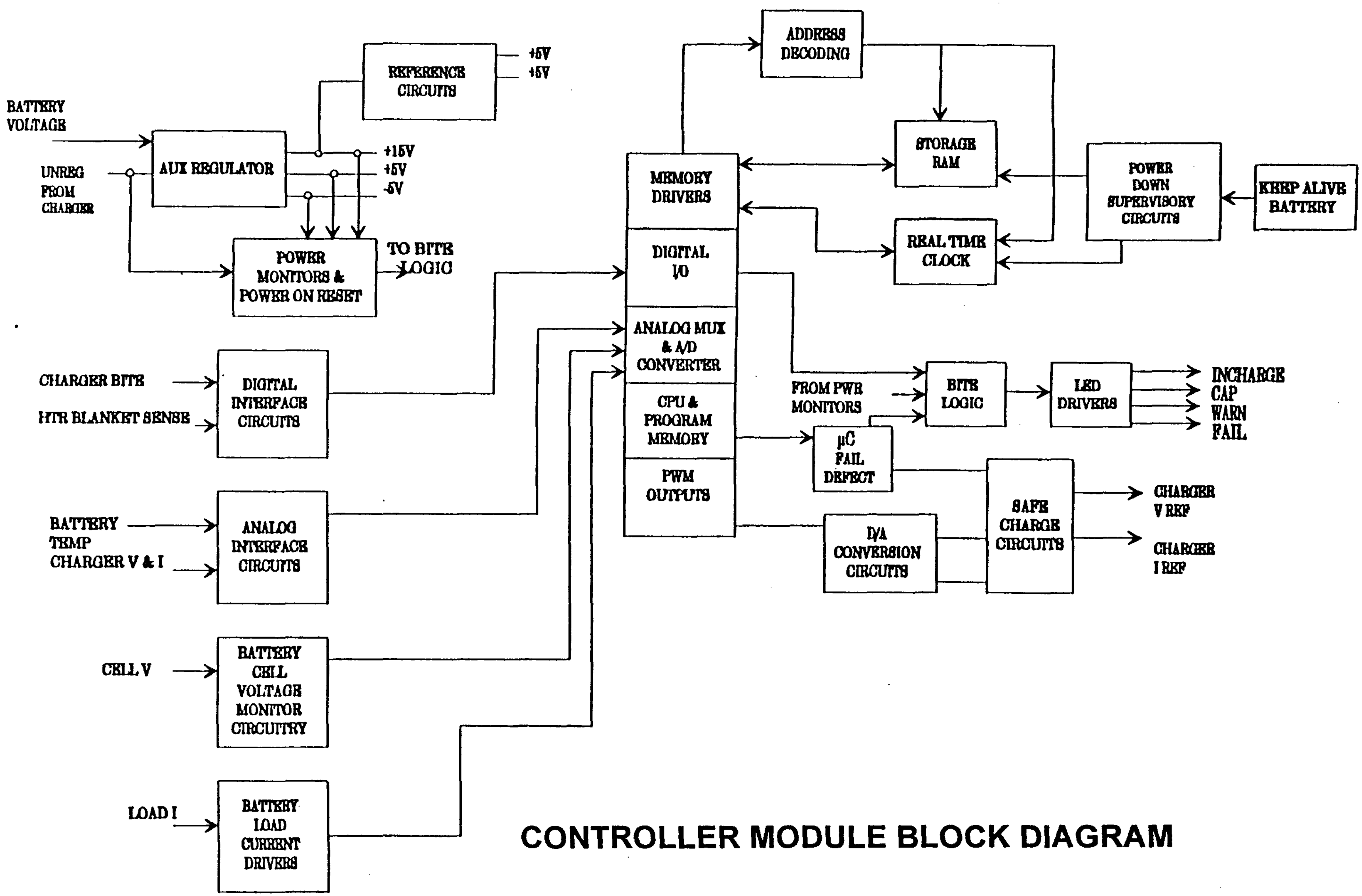
The BIT circuits in the charger monitor the output voltage, output current and the input references and indicate status to the controller. If the charger shuts down, a "charger-off" signal is sent to the controller. The controller can then respond appropriately. This function is described in more detail in both the controller and software sections (5.1.2 and 5.1.3).

5.1.2 Controller Design

The controller module is microprocessor controlled and provides the circuitry and software to control the basic operation for charging the battery, along with the battery system Built in Test capability.

Figure 5-5 is a block diagram of the controller module. The input power for the controller module is taken from either the converter module while powered under aircraft power or the battery for backup operating modes. The unregulated input power is refined to provide three regulated voltages (+15, +5 and -5 volts) for the controller. Separate regulators are used to provide redundancy so that a failure in the controller will not cause a failure in the charger and vis-versa. The +15 volt output also supplies power for two internal references of +5 volts used for the A to D and to set up references for BIT tolerance levels. Each of the unregulated and regulated voltages is monitored by the power monitor circuits. The unregulated voltage from the charger module is representative of the ac input voltage. The power monitor circuits, when ac and dc input power is within operating limits, will issue a power on reset to start the system software which begins the charging sequence.

Digital inputs are processed individually and are made up from the charger BIT inputs and the heater blanket sense circuits. The charger BIT inputs provide information on charger status. If the charger is shut down because of a fault the charger BIT will also indicate if the fault is output voltage or current induced. The heater blanket sense circuit senses the battery heater blanket operation.



CONTROLLER MODULE BLOCK DIAGRAM

FIGURE 5-5

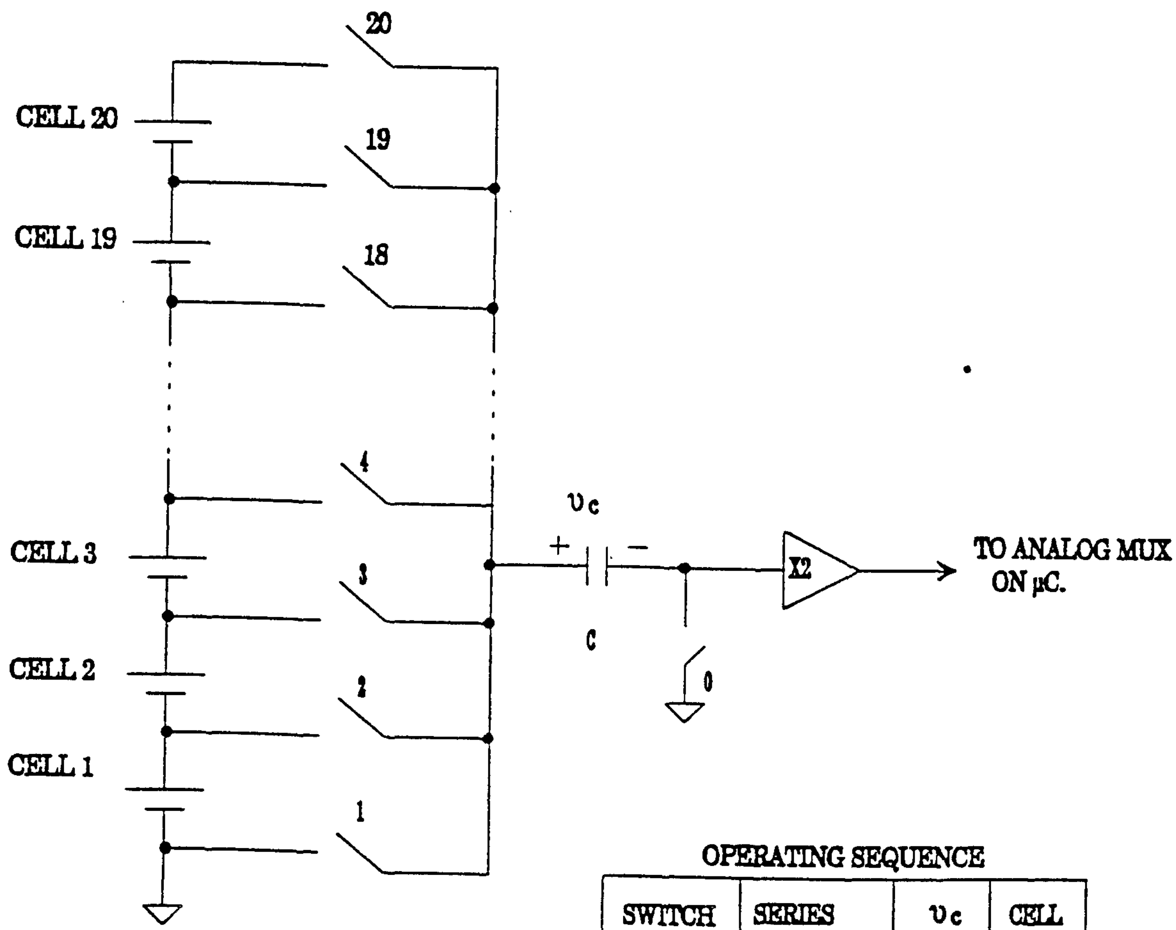
JB505.DRW

There are many analog inputs to the controller module and they are sensed by three different means. The battery temperature and the charger output voltage and current are very straightforward and require simple interface circuits. Once these signals are captured and scaled they are input into the analog multiplexer on the microcontroller.

The battery cell voltages are also monitored as an analog signal. This cell voltage monitor circuitry is more complicated in its operation. Figure 5-6 is a simplified schematic of the circuit. In order to maintain good accuracy in measuring the differential voltages, a switched capacitor type network was utilized. The operating sequence for the circuit can be followed by the table that accompanies the simplified schematic on Figure 5-6. The software controls the operation of the switches in this circuit. During the operation sequence the capacitor C is first discharged by turning both switch 0 and switch 1 on. Next, switches 0 and 1 are turned off and 2 is turned on. At this instant the voltage at the input of the amplifier is equal to the first cell voltage and the system makes the measurement. After the measurement is made switch 0 is turned on and the capacitor charges to the level of the first cell voltage. The next step is the same as before, 0 and 2 are turned off and 3 is turned on. At this point the voltage on the capacitor is equal to the first cell voltage and the circuit is connected to the second cell. Therefore the voltage on the input to the amplifier is equal to the sum of the first two cells minus the first cell, that is to say the value of the second cell. Once again a measurement is made, switch 0 is closed and the capacitor C is now charged to the value of cell 1 plus cell 2. This process repeats until the top of the battery cell string and once cell 20 is measured the capacitor is then shorted out by switches 0 and 1 so the whole sequence can start again. This circuit provides an accurate account of the cell voltages with a better than 4% accuracy level per cell. Table 5-1 indicates the test data for the cell voltage accuracy of the circuit. This table shows the worst case readings, and what cell provided those readings for battery voltages between 18 and 32 volts.

The load current measurements are complex in nature. This circuit only measures one current but it is designed to have high accuracy from 0.1 to 300 Amps. Figure 5-7 is a simplified schematic of the battery load current circuit. This circuit only operates if the charger is shut down. When the charger is operational, it can provide the load current (up to 50A) to the system. The circuit checks the current once per second as shown in the timing diagram in Figure 5-7. The event only takes 2 milliseconds to measure the current out of the battery.

The circuit is a full bridge type drive on a dc current transformer which is located within the battery. The drive circuitry saturates the transformer in the same direction as the dc current flow when switch Q2 and Q3 are turned on. When the 1-second interval occurs, which is provided by an interrupt from the real time clock, then Q2 and Q3 are turned off and Q1 and Q4



OPERATING SEQUENCE

SWITCH 0	SERIES SWITCH ON	υc (V)	CELL #
ON	1	OV	.
OFF	2	0	1
ON	2	1.2	
OFF	3	1.2	2
ON	3	2.4	
OFF	4	2.4	3
ON	4	3.6	'
'	'	'	'
'	'	'	'
'	'	'	'
OFF	18	20.4	18
ON	18	21.6	
OFF	19	21.6	19
ON	19	22.8	
OFF	20	22.8	20
ON	20	24.0	

SIMPLIFIED CELL VOLTAGE MONITOR CIRCUIT

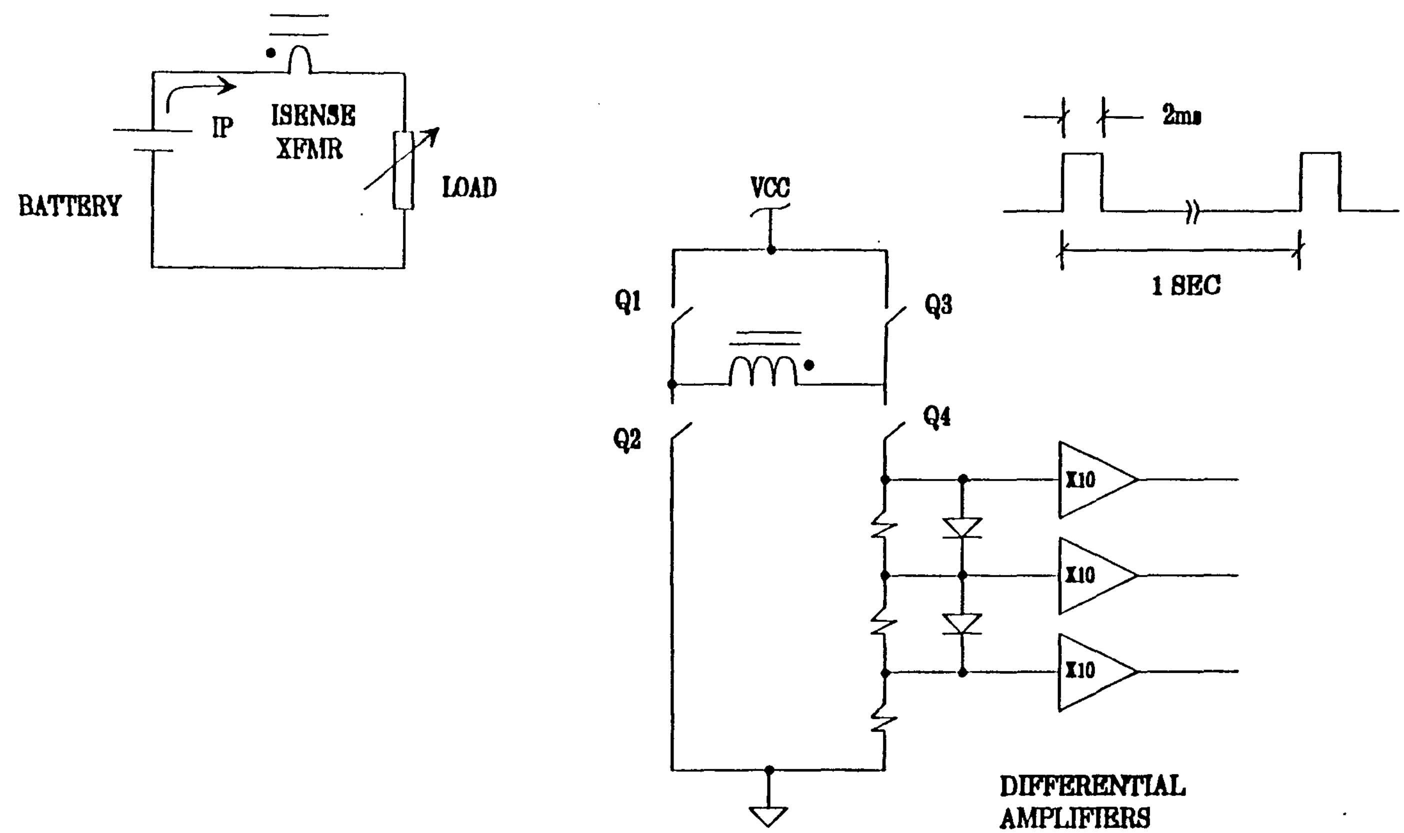
FIGURE 5-6

JB506.DRW

TABLE 5-1

CELL VOLTAGE ACCURACY TEST

TEST "V"	CELL "V"	A/D CNT	MEAS. "V"	LOWEST "V" CELL #	HIGH "V" CELL #	%ERROR
18.000	0.900	89.000	0.873	1		3.050
18.000	0.900	95.000	0.931		19,20	-3.486
20.000	1.000	99.000	0.971	1		2.941
20.000	1.000	105.000	1.029		7,20	-2.941
22.000	1.100	109.000	1.069	1		2.852
22.000	1.100	115.000	1.127		7,20	-2.496
24.000	1.200	119.000	1.167	1		2.778
24.000	1.200	126.000	1.235		7,20	-2.941
26.000	1.300	129.000	1.265	1		2.715
26.000	1.300	136.000	1.333		7,20	-2.564
28.000	1.400	139.000	1.363	1		2.661
28.000	1.400	147.000	1.441		7	-2.941
30.000	1.500	149.000	1.461	1		2.614
30.000	1.500	157.000	1.539		7,14	-2.614
32.000	1.600	158.000	1.549	1		3.186
32.000	1.600	167.000	1.637		7,14,20	-2.328



BATTERY LOAD MEASUREMENT CIRCUIT

JB507.DRW

FIGURE 5-7

turned on. This forces the dc transformer out of saturation and the current that flows thru the resistor string below Q4 is the transformed current from the battery. This current flows thru a weighted resistor string to provide three levels of voltages. The first resistor R1, provides for low ranges of currents up to 3 Amps. At which time the voltage drop across R1 exceeds the diode drop and the diode conducts. R2 then provides the medium range from 3 to 30 Amps of current.

It too has a diode in parallel that conducts for currents greater than 30 Amps. Then the final range that will provide 30 to 300 Amps is provided by R3. Each of these resistors are monitored with a differential amplifier that provides a gain of 10. This output signal is then sent to the analog input of the microcontroller and the reading is taken and stored. The software stores all three readings every second and determines from the values of the readings which range is appropriate. Once this is done it calculates the proper battery current and stores it in memory. By making the measurement on a 1-second interval, the current can be integrated over time to provide the appropriate amp-hours to determine the battery capacity. Table 5-2 shows the battery load current accuracy data measured from the charger controller. As can be seen from the uncorrected measurements, the circuit has an offset error. This is corrected easily in software by subtracting the offset from the measured voltage and the corrected accuracy is within 5% for the entire range of currents.

The heart of the controller module is a microcontroller (uC). The microcontroller used is the Intel 87C196KC. This microcontroller contains not only the main Central Processing Unit (CPU), it also has built in to it the following:

1) Memory Drivers - This function provides address and data lines to provide control for external memory elements.

2) Digital inputs and Outputs - There are two 8-bit ports used for digital inputs and outputs.

3) Analog Multiplexer and A/D Converter - There is an eight channel analog multiplexer with a sample and hold input to a 10-bit A/D converter.

4) 512 Bytes RAM - The internal RAM is used for special function registers, and scratch pad memory.

5) 16K Bytes Program EPROM - The EPROM space contains the operating software. This design utilizes about half of the available memory.

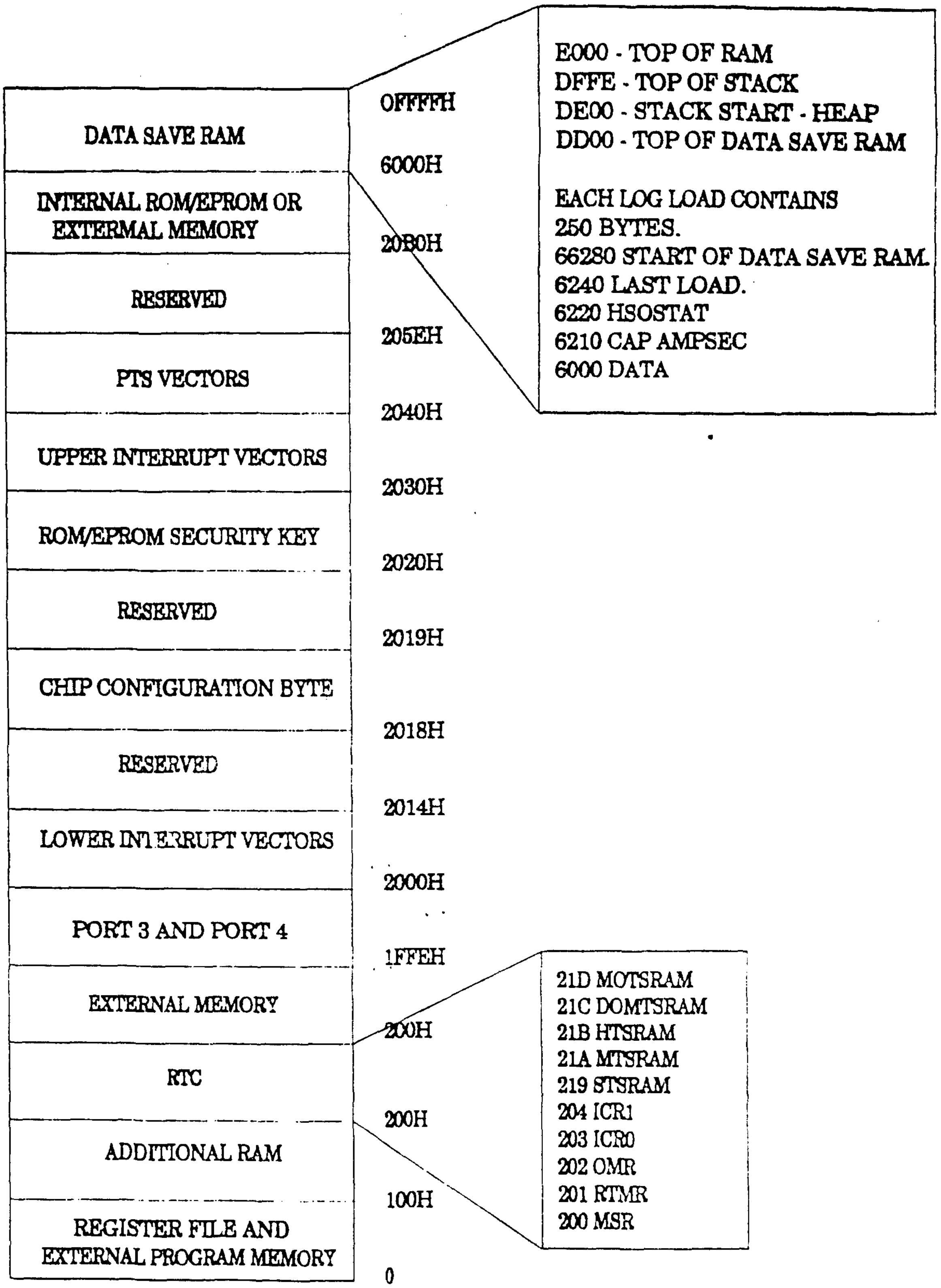
6) PWM outputs - These outputs are used with a simple filter circuit to provide analog outputs to control the charger.

Figure 5-8 contains a memory map which describes the location in memory for each of the functions.

Table 5-2

BATTERY LOAD ACCURACY CHECK

"I" SHUNT	RANGE	ANALOG VOLTAGE	MEASURED "I"	% ACCURACY	CORRECTED VOLTAGE	CORRECTED CURRENT	CORRECTED ACCURACY
0.158	L	0.631	0.380	140.583	0.262	0.158	-0.107
0.282	L	0.860	0.618	83.714	0.491	0.296	4.888
0.62	L	1.434	0.864	39.332	1.065	0.642	3.478
1.08	L	2.190	1.319	22.155	1.821	1.097	1.573
2.05	L	3.765	2.268	10.638	3.396	2.046	-0.206
3.01	L	5.270	3.175	5.472	4.901	2.952	-1.913
4.04	M	0.708	4.265	5.571	0.671	4.043	0.069
6.02	M	1.042	6.277	4.271	1.005	6.055	0.578
8.14	M	1.392	8.386	3.016	1.355	8.163	0.286
10.03	M	1.707	10.283	2.524	1.670	10.061	0.308
12.04	M	2.041	12.295	2.119	2.004	12.073	0.273
14.05	M	2.374	14.301	1.788	2.337	14.079	0.206
16.04	M	2.705	16.295	1.591	2.668	16.073	0.205
18.03	M	3.033	18.271	1.337	2.996	18.049	0.104
20.02	M	3.362	20.253	1.164	3.325	20.031	0.054
25.02	M	4.191	25.247	0.907	4.154	25.025	0.019
30.06	H	0.509	30.663	2.005	0.505	30.440	1.265
35.01	H	0.589	35.482	1.348	0.585	35.260	0.713
40.02	H	0.669	40.301	0.703	0.665	40.079	0.147
45.03	H	0.750	45.181	0.335	0.746	44.958	-0.159
50.02	H	0.832	50.120	0.201	0.828	49.898	-0.244
74.1	H	1.275	76.807	3.653	1.271	76.585	3.353
101.7	H	1.745	105.120	3.363	1.741	104.898	3.145
123.3	H	2.137	128.735	4.408	2.133	128.513	4.228
151.7	H	2.529	152.349	0.428	2.525	152.127	0.282
179.8	H	2.980	179.518	-0.157	2.976	179.296	-0.280
200.9	H	3.314	199.639	-0.628	3.310	199.416	-0.739
227.8	H	3.922	236.265	3.716	3.918	236.043	3.618
252.3	H	4.235	255.120	1.118	4.231	254.898	1.030
278.2	H	4.588	276.386	-0.652	4.584	276.163	-0.732
305.3	H	5.000	301.205	-1.341	4.996	300.983	-1.414



80C 196KC MEMORY MAP

FIGURE 5-8

JB508.DRW

On the output side of the block diagram we have address decoding circuits which decode the address lines from the uC to drive the external memory. External memory consists of the Data Storage RAM and the Real-Time Clock (RTC). The RTC is a memory mapped device that provides real-time information that is used to identify the date and time any events occur. Each of these two elements need to have battery back up to hold the information when disconnected from the main aircraft battery. There are power down circuits and a sealed lithium 5 A-hr primary battery to provide the required back up power and control.

The digital output from the uC along with power monitor circuit outputs are sensed by the BIT logic. The BIT logic takes these inputs and provides the hardware logic to supply the four BIT signals to the aircraft as described in the SCD. The logic circuit outputs are then provided to LED drivers so users need only connect an LED to the output to obtain the BIT light function.

The uC has internal reset capabilities so if the software "gets lost," the uC will automatically reset itself and resume normal operation. If there is a problem where the processor is continually resetting itself, then the uC fail detect circuitry will recognize this and provide input to the BIT logic and the Safe Charge Circuits.

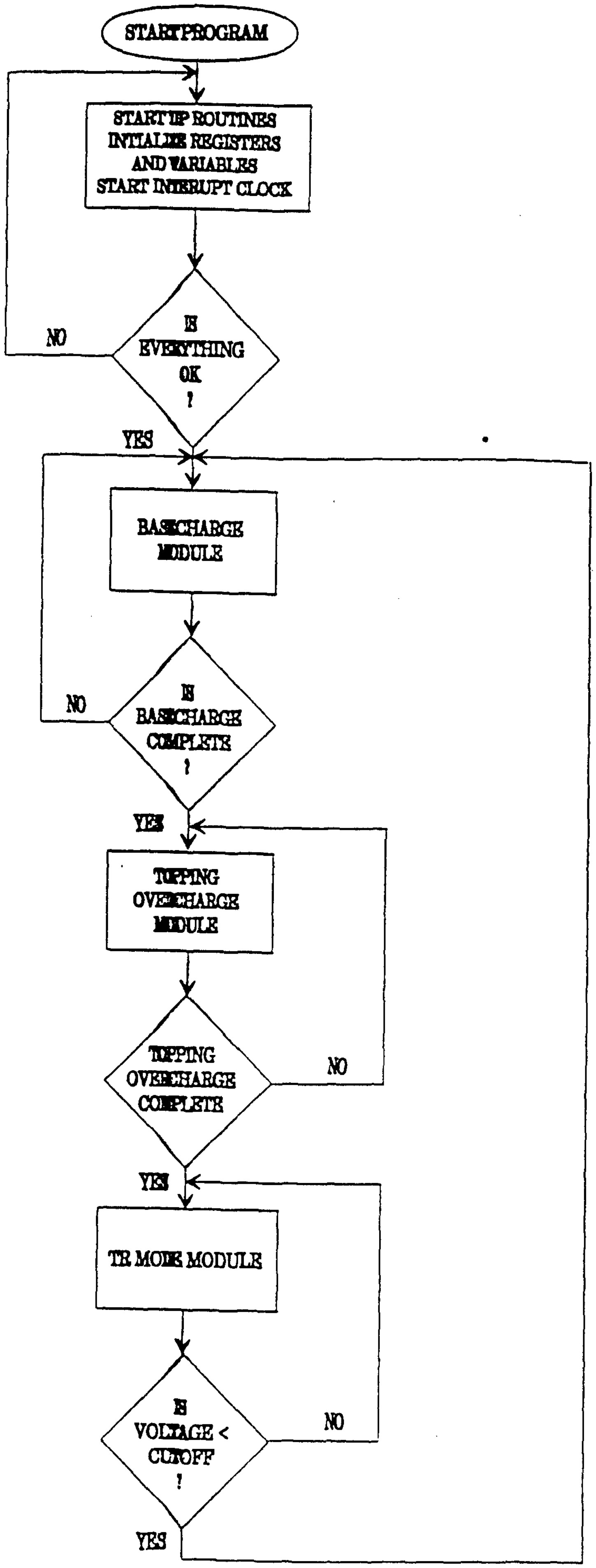
The Safe Charge Circuits provide the analog output drive to the charger module. If the uC is operating properly its PWM outputs provide inputs to a D to A conversion circuit that converts the PWM output to an analog voltage. This voltage is sent thru an analog switch to the charger module. If the uC is upset, the uC fail detection circuitry will force the safe charge circuits to provide a hardware voltage and current reference to safely charge the battery. These signals are buffered and sent via the analog switch circuit.

While operating in this fail safe mode, the charger operates in the constant potential region and the output voltage and current are fixed at a level that will slowly charge the battery without the threat of battery damage even for prolonged charge periods.

5.1.3 Software Design

The charger/controller operates under software control. The software provides the basic control algorithm for charging the battery and it also performs the battery system BIT function. The software is partitioned into two operating modes. The main loop provides the control for charging the battery and the interrupt structure provides updates and tests for the BIT functions.

Figure 5-9 shows the flow chart for the main loop of the software. The program begins execution at the start after any microcontroller reset. A reset can be initiated by any one of the



MAIN LOOP PROGRAM FLOW

FIGURE 5-9

JB509.DRW

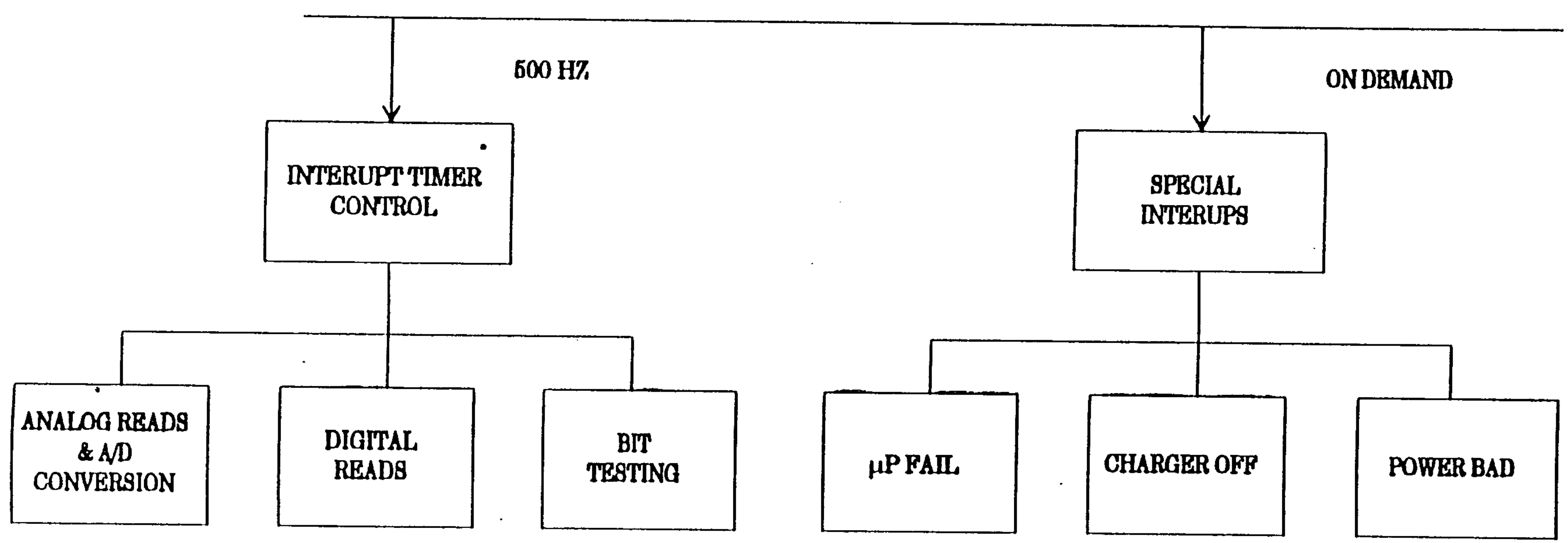
following events; AC power application, aircraft battery connect and uC upset. At initialization the program goes through a start up sequence which initializes variables, sets up all of the special function registers, and starts the interrupt clock. This initialization takes about 3 seconds to check out the entire system. Once the system checks out as functional, the charger commands a constant current base charge mode of operation (approximately 40A). The charger continues to provide the base charge until the battery voltage reaches a temperature compensated cut off voltage or if the battery voltage rolls over and changes to a negative slope. The charger will then command the overcharge constant current (approximately 12.5A). This current is commanded and controlled until the battery voltage reaches another temperature compensated cut off voltage or if the battery voltage rolls over and changes to a negative slope. The next mode of operation is the constant potential mode. During this mode the charger provides a constant voltage output to the battery of approximately 27.5V. The charger remains in this mode of operation until the battery voltage falls to below 23V at which time the base charge mode will resume.

At any time in the operation of the charger if the input power is cycled, any fault, or any reset occurs, then the system will respond accordingly as described below.

Figure 5-10 shows the interrupt structure for the charger/controller. The I/O control and BIT functions operate under interrupt control. The interrupts are time multiplexed with the main loop software. Internal to the microcontroller is a timer interrupt routine that automatically halts execution of the main loop software at a programmable rate. The rate used in the charger/controller is 500Hz. This means that every 2 milliseconds the interrupt timer stops the main loop software and executes the interrupt software. The interrupt software also contains a timer which determines which input port to read or what test to perform. There are 50 different steps in the software timer so that each test and each input read is done 10 times per second. All of the inputs both analog and digital are read and checked to make sure they are within proper operating limits as part of this routine.

Special interrupts for shut down conditions are part of the interrupt routines. These interrupts must be acted upon immediately and are therefore available on demand. Any time there is a charger shutdown or the power to the charger/controller is out of tolerance, the microcontroller responds immediately. The uC then takes appropriate action to protect the battery system, store the failure or shutdown in memory, and report the condition via one of the BIT indications.

If the condition persists, the charger/controller will remain in this mode. If the condition corrects itself then the charger/controller will automatically restart and resume operation.



INTERUPT STRUCTURE

FIGURE 5-10

JB510.DRW

At any operation mode change or for any fault or warning that may occur, the software stores a complete set of data in nonvolatile memory. Figure 5-11 shows the data that are stored in memory for any of the above occurrences. The date, time, and operation mode are stored. If there was a failure, the failure type is also recorded. Then the battery data are stored. These data include battery temperature, overall battery voltage and each individual cell voltage. The charge removed from the battery is stored as amp-seconds and the internal "keep-alive" battery voltage is recorded. Charger information that is stored includes the commanded current and voltage along with the actual current. Several digital signals are stored which are used to further isolate faults for failure conditions.

5.2 Mechanical Design

5.2.1 Packaging Concept

The 4-521-01 Maintenance Free Battery charger was developed as a modification of an existing ELDEC battery charger P/N 4-254. The objective was to provide a quick-turn around development for system verification testing and minimize risk by using a "proven unit." The resulting product was essentially an ELDEC 4-254 with a microprocessor based controller and interface section added to the rear; and retaining the power section of a proven design (see Figure 5-12 "4-521-01 Mechanical Layout").

5.2.2 Chassis Layout

Reference Figure 5-12; which shows an exploded view of the unit. The ELDEC 4-254 (from which the 4-521-01 was derived) is sized to a 6 MCU ARINC format. The 6 MCU ARINC format is 7.5 inches wide, 7.6 inches high and 12.5 inches long. The 4-521-01 is packaged by adding a 1.5 inch extension to the ELDEC 4-254 charger chassis making the total length 14 inches.

The package is formed by using straight fin vertical heatsink extrusions as sides and joining these with sheet metal top, bottom and front. The top and bottom are flat plates which are perforated to allow free convection air flow.

The input filtering capacitors and inductors are mounted to the backside of the front panel. The main power devices (drive and power transformers, inductors, rectifiers and transistors) are mounted to the heatsink sides. The rear of the chassis is a machined plate which serves as a heatsink and thermal conduction path for the controller/interface section.

Machined brackets are added to the front and rear of the unit, allowing it to be mounted at the unit bottom surface.

ELDEC

LOGLOAD SCREEN

DATE: 11/8/89 TIME: 7:49:40

BASE CHARGE NO FAILURES

BATTERY DATA

TEMPERATURE: 24.0°C VOLTAGE: 21.20

CELL VOLTAGES

0:	1.06	1:	1.07	2:	1.05	3:	1.06	4:	1.06
5:	1.07	6:	1.05	7:	1.07	8:	1.07	9:	1.07
10:	1.06	11:	1.05	12:	1.05	13:	1.06	14:	1.06
15:	1.06	16:	1.05	17:	1.06	18:	1.06	19:	1.06

AMP SECONDS REMOVED FROM BATTERY: 115,200

KEEP ALIVE BATTERY VOLTAGE : 3.67

CHARGER INFO

COMMANDED OUTPUT I: 50.73 V: 33.51

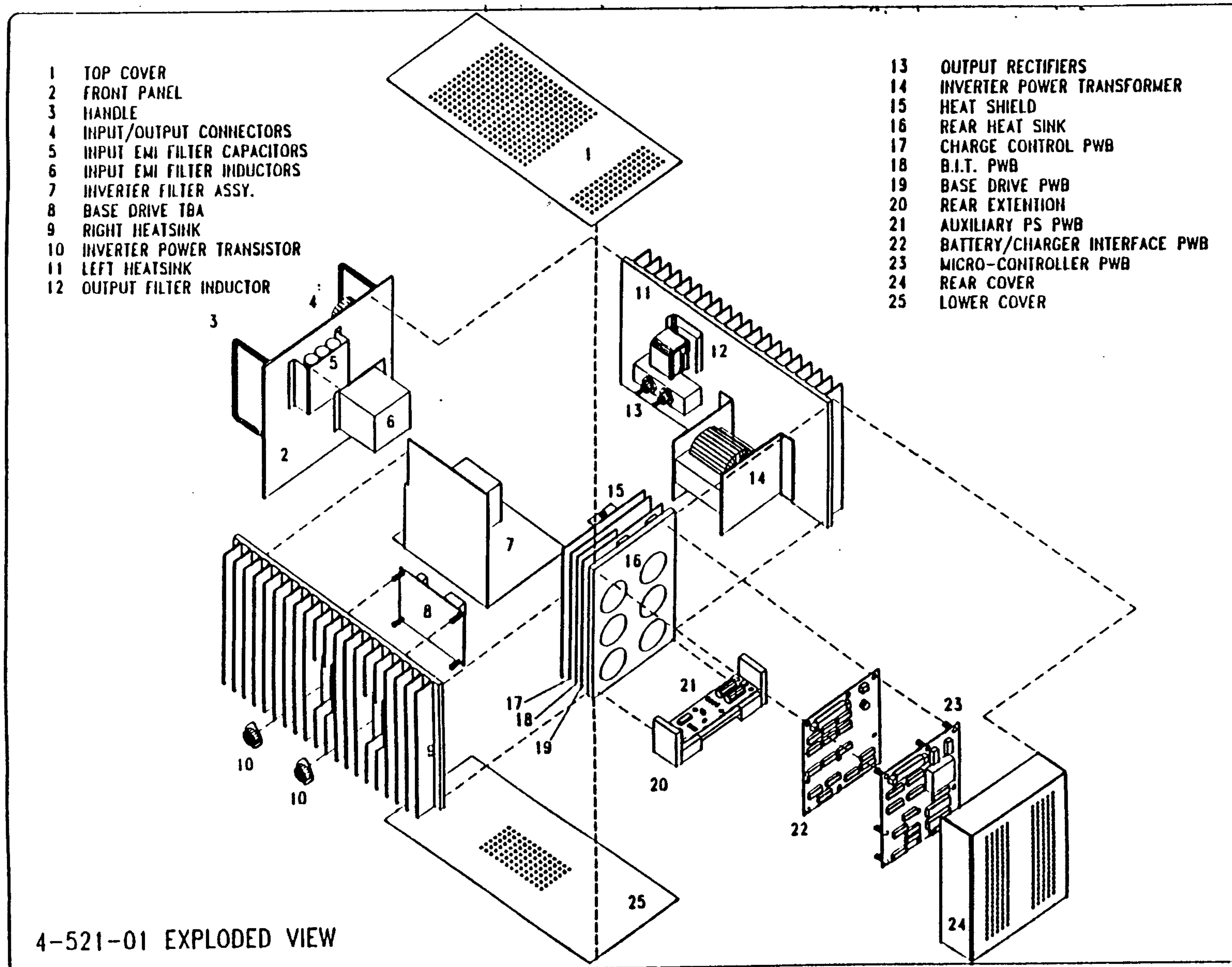
ACTUAL CHARGER OUTPUT I: 50.63

PORT 1 STATES

IERR	VERR	CHRGRCON	CHRGRGOOD	CHRGROC	RMSHTDN	CHGRCNTL	HTRBLKON
1	1	0	1	1	0	0	1

DATA STORED IN MEMORY

FIGURE 5-11



EXPLODED VIEW, CHARGER/CONTROLLER

FIGURE 5-12

5.2.3 Major Sub-Sections

The 4-521-01 consists of the charger power section (from the existing ELDEC 4-254 charger) and a microprocessor based controller/interface section which is mounted to the rear of the unit in a "dog house" configuration.

5.2.3.1 **Charger Section** - Mechanical Design

The charger section is laid out for the primary current loop to move counter clockwise (when viewed from the top) thru the unit beginning with the input connector J1 and ending at the output terminal block, TB1.

All inputs and outputs of the 4-521-01 go thru the front panel. The primary current loop begins with the input filter capacitors and inductors mounted to the front panel.

From the input filter section primary current loop moves to the right side heatsink which mounts the inverter input rectifiers, the auxiliary power supply, base drive transformers and inverter power transformers.

Near the rear of the unit is a heat shield which prevents heat from radiating to the charger circuit boards mounted directly behind it.

On the left side heatsink is mounted the main power transformer, the output filter inductor and output rectifiers.

The microprocessor controlled levels of direct voltage and current necessary to charge the battery pass thru the output rectifiers and terminate at the output terminal studs of the terminal block TB1 on the front panel.

5.2.3.2 **Controller Section** - Mechanical Design

In the rear 1.5 inches of the unit, in the "dog house" is the sensing and control circuitry added to the 4-254 to derive a 4-521-01. The circuitry includes a battery to charger interface circuit board, a microprocessor circuit board and an auxiliary power supply.

The interface and processor boards are vertically mounted in parallel on standoffs. The auxiliary power supply board is horizontally mounted at the bottom of the "dog house" section.

5.2.3.3 Interconnect

Due to the high currents involved and the relative few numbers of required connections, the 4-251-01 is interconnected by hard wire and interconnect harnesses. Mass termination and flexible circuitry are not used.

In the rear of the unit; pin and socket connections are used to join charger control board to the base drive circuit board and to join the charger interface board to the microcontroller board. The connection is affected when the boards are "sandwiched" together in their mounted configuration.

5.2.3.4 Circuit Card Assemblies

Circuit card assemblies are two sided and multilayer types designed per the requirements of Mil-Std-275. The circuit boards are manufactured per Mil-Std-55110 and assembled per Mil-P-28809. The boards are fabricated from material per Mil-P-13949 type FR4. Circuit card assemblies are conformal coated per Mil-I-46058 type XY "Parylene." Circuit board terminations are made with MS55302 connectors or solder terminated.

All circuit card assemblies are stand-off mounted. The modal frequencies of vibration for each circuit card assembly have been analyzed to verify the necessary rigidity to minimize deflection and solder joint stress.

5.2.4 Structural Design

ELDEC has a substantial background of experience with the shock and vibration requirements of aerospace electronics. ELDEC currently provides power supplies, battery chargers and TR units for many Boeing, General Dynamics, and McDonnell Douglas military aircraft.

The chassis pieces are joined with large overlap sheet metal interfaces and tight screw spacing. This provides for efficient joints which meet the structural requirements (shock, vibration, acceleration, handling, etc.) of the unit for its testing, operating, handling and manufacturing environments.

The structural joints have been individually analyzed and custom designed for each application. The modal frequencies of the unit have been tailored to minimize component, fastener and solder joint exposure to transmitted levels of vibration and shock.

The ELDEC 4-254 charger (from which the 4-521-01 was developed) was qualified to a random vibration level of 9.9 G's RMS (3 hours per axis).

5.2.5 Thermal Design

5.2.5.1 Thermal Design Concept/Layout

The 4-521-01 charger/controller is designed for continuous operation in a free convection cooling environment. The left and right side chassis walls have vertical straight-finned heatsinks. The major power dissipating components are mounted to these heatsinks which provide the primary cooling interface for the charger/controller. Internally, the unit is cooled by the bottom to top draw-thru natural convection provided by vent holes located in the top and bottom of the unit (see Figure 5-12 Mechanical Layout).

5.2.5.2 Power Sources

The main power dissipating components in the 4-521-01 are approximately as follows:

Item	Description	Power Diss.
13	Rectifier	48 Watts
14	Power Transformer	65 Watts
21	20V Regulator	3 Watts
10	Transistor Q2	30 Watts
10	Transistor Q1	30 Watts
7	Auxiliary Transformer	3 Watts
7	Input Bridge	15 Watts

The item number corresponds to the item on Figure 5-12.

5.2.5.3 Thermal Design Capabilities

Normal Operating

The 4-521-01 is designed to operate between -55°C and 71°C (@ 40 amps continuous output).

Temperature-Altitude

The high temperature altitude operating capability of the 4-521-01 is as follows:

Altitude	Temperature
Sea Level	71°C
10,000 Ft.	64°C
20,000 Ft.	53°C
30,000 Ft.	41°C
40,000 Ft.	25°C
50,000 Ft.	6°C

5.2.5.4 Thermal Design Similarity

The 4-521-01 thermal design is based on the proven 4-254 which was qualified for operating between -55°C and 71°C. The 4-254 was qualified at 38 amps continuous operation in an 71°C environment without cooling air (and the bottom air holes blocked off).

With the similarity of material parts and processes between the 4-254 and its derivative it is reasonable to expect comparable thermal performance. See the "Safety of Flight Testing" section for the confirmation test data.

5.2.6 Drawing Package

The drawing package for the charger will be submitted under separate cover due to the size and nature of the package. This deliverable will be an ELDEC Level 2 compatible drawing package. Figure 5-13 is the drawing tree for the charger which describes the drawing package breakdown. The items on the left side of the drawing tree represent the drawings that make up the base 4-254 unit from which the 4-521 charger is made. The center section of the drawing tree shows the modification drawings which are used to modify the 4-254 drawings in order to accommodate the new circuits and hardware for the 4-521. The drawings required for the additional hardware to build the 4-521 charger.

6.0 Safety of Flight Testing

Safety of Flight testing was done independently on the battery and the charger/controller. Compatibility testing was done as a system and is described in the next section.

6.1 Battery Testing

The safety of flight testing applicable to the batteries is listed below:

Humidity	Similarity
Salt/Fog	Similarity
Vibration	Test
Temperature Shock	Test
Electromagnetic Interference	Similarity
Performance Testing	Similarity

6.1.1 Similarity Data

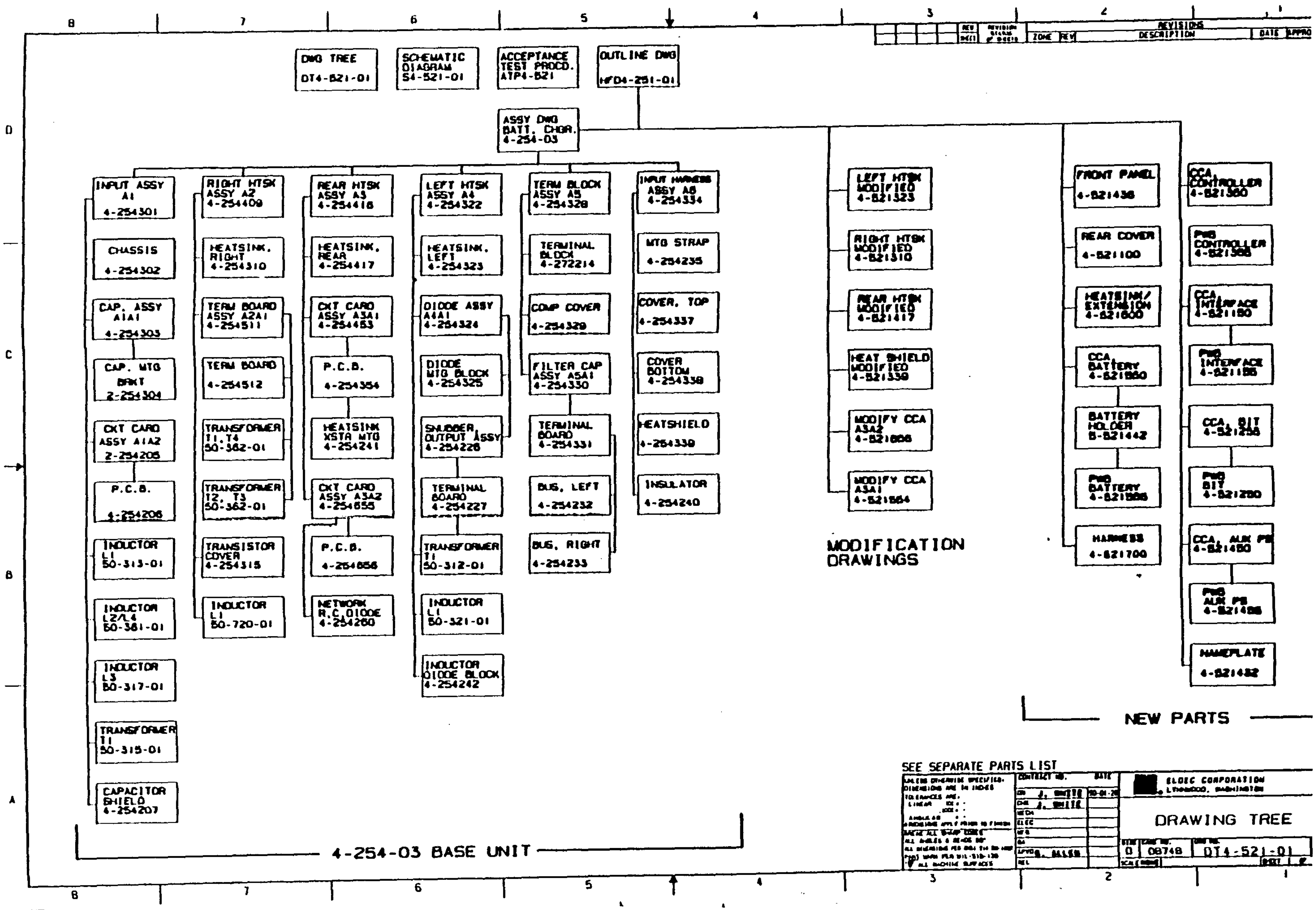
Conditions that are qualified by similarity on Eagle-Picher part numbers 18213 and 18214 are based on Eagle-Picher part number EPI-18164. This is a 20 cell 36 ampere hour nickel-cadmium aircraft starting battery designed for the Bell 214ST helicopter. The batteries will meet all requirements based on the same basic design and development principles used for this battery.

Eagle-Picher part numbers 18216 and 18192 were qualified by similarity based on EPI-18213. These batteries incorporate the same basic design and manufacturing principles, and are subjected to virtually all the same operating circumstances. Based on these conditions, EPI part nos. 18147 and 18192 will meet all requirements.

6.1.2 Vibration Testing

6.1.2.1 Purpose

Vibration testing was performed on all four batteries to ensure they are constructed to withstand dynamic vibrational stresses and that performance degradation or malfunction will not be produced by the operating environment.



DRAWING TREE

FIGURE 5-13

6.1.2.2 Conditions

Eagle-Picher performed sine sweep and random vibration testing on each battery per MIL-STD-810C. The batteries were prepared and tested under simulated operating conditions; discharge representing engine start, and charging representing flight conditions. All units were continuously monitored throughout the vibration test procedures.

6.1.2.3 Results

No operational faults were detected on EPI part numbers 18213, 18214, 18216 and 18192 during the sine sweep vibration testing or on the random vibration testing.

6.1.2.4 Vibration Testing Conclusions

With the prescribed vibration levels, structural integrity and workmanship have been confirmed. Where these units are expected to be mounted in the aircraft, we believe that the separation from normal vibration generation sources is sufficient and that the batteries, having successfully withstood the vibration testing, will meet the need of the program systems evaluation.

6.1.3 Temperature Shock Testing

6.1.3.1 Purpose

Temperature shock testing is conducted to determine the effects on the batteries to sudden changes in temperature and operating environments.

6.1.3.2 Conditions

Temperature shock testing was conducted on the EPI-18213 and EPI-18214 batteries. The units were prepared and tested in accordance with MIL-STD-810, Method 503.1, Procedure I.

6.1.3.3 Results

At the conclusion of the temperature shock testing, the batteries were returned to the standard ambient conditions and allowed to stabilize. The units were then inspected and tested. The batteries showed no signs of loss to structural integrity and workmanship, and no loss of electrolyte was detected. There was also no significant loss of capacity or performance.

6.1.3.4 Temperature Shock Testing Conclusion

Based on the conditions set forth in MIL-STD-810, Method 503.1, Procedure I, and the successful completion of the testing by the batteries, Eagle-Picher has proven that these batteries will meet the needs of the program systems evaluation.

6.2 Charger/Controller Testing

The safety of flight testing applicable to the charger/controller is listed below:

Humidity	Similarity
Salt/Fog	Similarity
Vibration	Test
Temperature	Test
Electromagnetic Interference	Similarity
Performance testing	Test

6.2.1 Similarity Data

Conditions that are qualified by similarity are based on ELDEC part numbers 4-254 Charger, 4-056 Charger, and 4-153 Converter Assembly (regulated). The 4-254 is a battery charger designed for the Boeing 757, 767 aircraft. The basic design approach is also used on the Embraer AMX aircraft and it is the base unit for the charger/controller. The 4-056 is a battery charger used on the Sikorsky Black Hawk Helicopter. The 4-153 is a regulated 28V converter assembly used by General Dynamics on the Tomahawk missile program. The similarity report for the 4-254 covers the following tests:

Explosive Atmosphere
Sand and Dust
Humidity
Fungus
Salt Spray

The charger/controller will meet these requirements based on the similarity in design and performance with the aforementioned test unit and data.

6.2.2 Vibration Testing

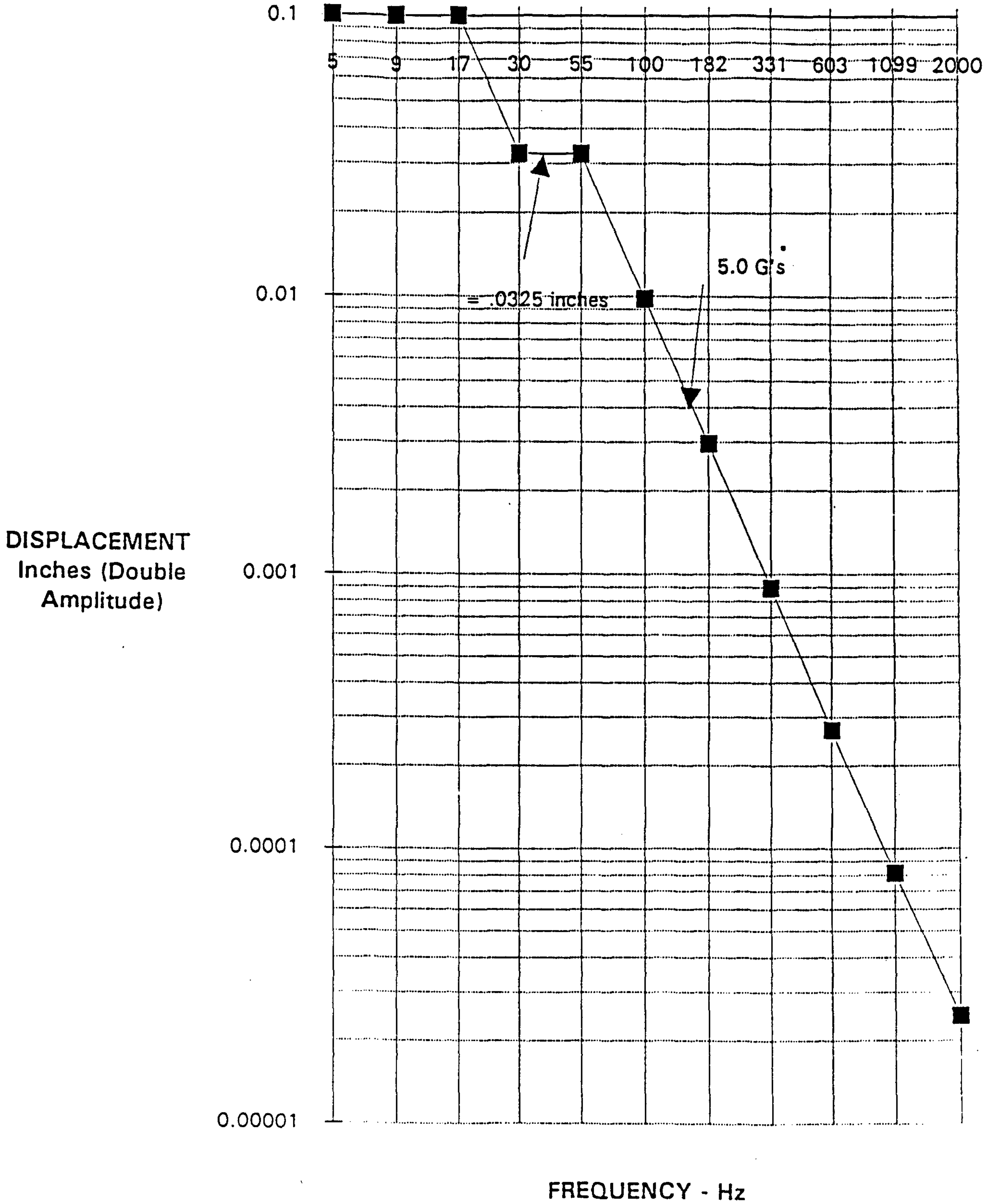
6.2.2.1 Purpose

Vibration *"confidence level testing"* was performed on a 4-521-01 to verify the unit capability and confirm manufacturing workmanship. Raw data was collected in ELDEC Design and Computation Notebook Number 367 issued to ELDEC Electronic Technician Rick Perrault.

6.2.2.2 Conditions

ELDEC performed a sine sweep and random vibration test per Mil-Std-
810C. The unit was powered and output continuously monitored throughout the following vibration test procedure:

1) Sine sweep from 5 to 2000Hz at 5 G's maximum (per Figure 6-1 "Sine Sweep Vibration Test Curve") and identify the four most severe responses.



Sine Sweep Vibration Test Curve

Figure 6-1

2) Dwell for 30 minutes on each of the resonant responses identified as significant.

3) Identify and correct those design elements which exceed the allowable response.

4) Perform a random vibration test (per Figure 6-2 "Random Vibration Test Curve") (4.9 G's RMS). The test was run for one hour per axis.[1]

6.2.2.3 Results

1) No operational faults were detected on the charger/controller unit under test, 4-521-01, SN 00x during the sine sweep vibration testing.

2) No operational faults were detected on the charger/controller unit under test, 4-521-01, SN 00x during the random vibration testing.

6.2.2.4 Vibration Testing Conclusion

With these vibration levels; workmanship and basic structural integrity has been confirmed without needlessly aging the unit. The expected mounting locations for the 4-520-01 during the systems evaluation phase (wheel bay) is substantially isolated from the normal vibration generation sources (engines, gun fire, aerodynamic buffeting, etc.). ELDEC concludes that the vibration test levels indicated will meet the need and intent of the 4-520-01 program for systems evaluation.

6.2.3 Temperature Testing

Thermal confidence testing was performed on a 4-521-01 to verify the unit capability and confirm similarity to the 4-254. Raw data were collected in ELDEC Design and Computation Notebook Number 367 issued to ELDEC Electronic Technician Rick Perrault.

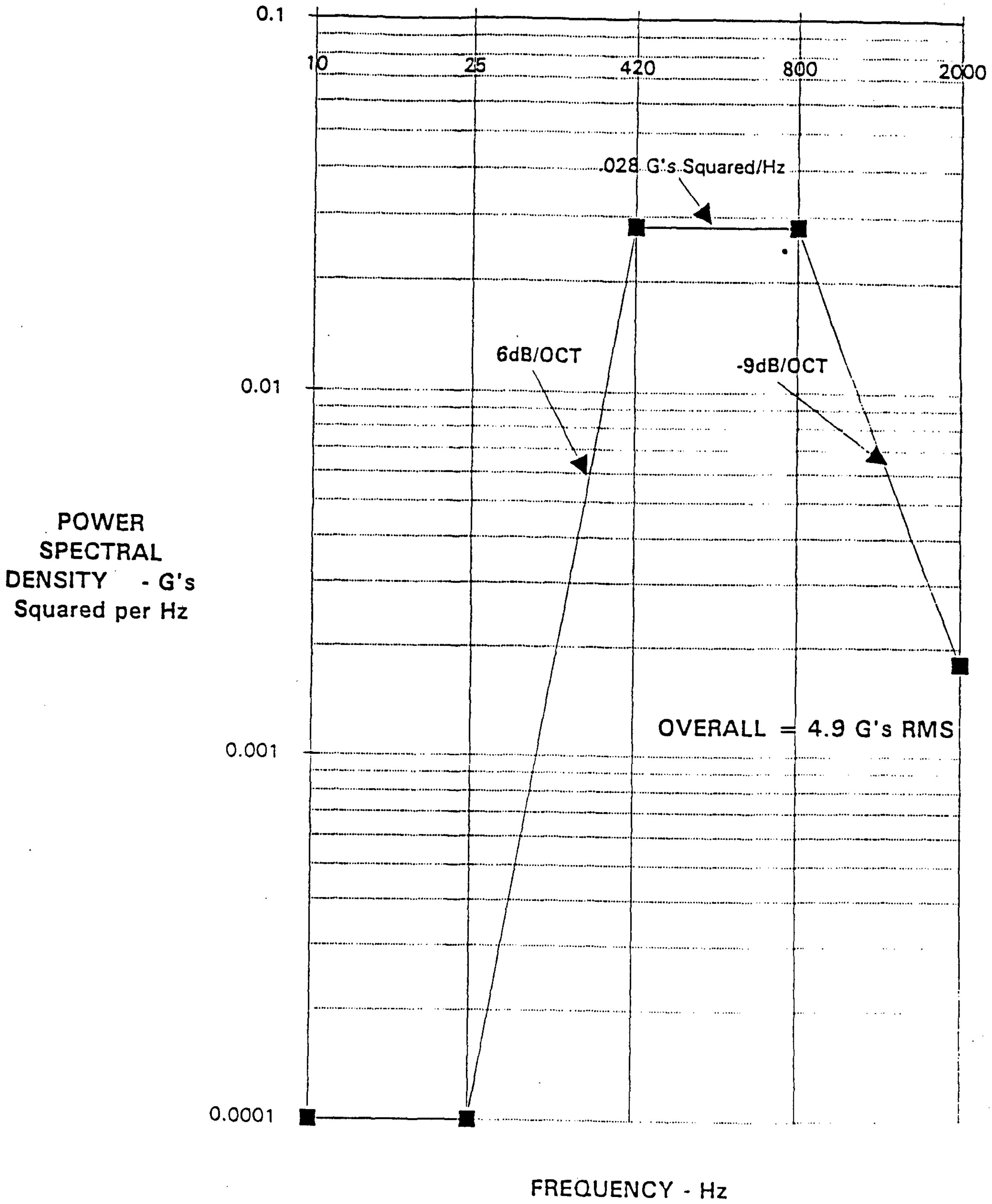
6.2.3.1 Conditions

Thermal testing was performed at room temperature (25°C), 40°C, 50°C, 60°C, and 70°C. In addition, cold start testing was performed at -40° C and -55°C. All testing was conducted at standard pressure.

[1] **Note:** This level represents the equivalent of a six month endurance test at the same level that the 4-254 originally qualified. At this level the unit is expected to remain functional and incur only about 5% of its normal lifetime of aging.

RANDOM VIBRATION TEST CURVE

FIGURE 6-2



6.2.3.2 Setup

1) For all temperature testing, the unit was placed on wood slats (to allow free convection air flow and eliminate conduction affects).

2) Thermal couples were placed on several high power devices, heatsinks and in air stream locations (see thermal map).

3) The unit was powered up to 40 amps output (base charge) for 30 minutes.

4) After 30 minutes, the output was reduced to 13 amps (over charge) with temperature readings continued for an additional 30 minutes (60 minutes total).

6.2.3.3 Results

1) The 4-521-01 successfully completed all room temperature and elevated ambient temperature tests described above.

2) All part temperature readings paralleled the ambient. That is; the 70°C component temperature readings were 10°C higher than the 60°C readings etc.

3) The highest temperature reached (during the 70°C test - after 30 minutes of base charge) was 110°C for the rectifier case temperature. All other part case temperatures were lower.

4) The 4-521-01 successfully completed cold start temperature testing at -40°C and -55°C.

6.2.3.4 Thermal Testing Conclusion

The 4-521-01 will operate in all sea level temperature environments from -55°C to 71°C at all loads up to 40 amps. It has been determined by analysis that the 4-521-01 will operate in all temperature-altitude environments within the envelope described in the thermal design capabilities section (paragraph 5.2.2.3).

6.2.4 Performance Testing

The charger/controller performance is verified by ELDEC Acceptance Test Procedure (ATP), document number ATP4-521. This document specifies test procedures, equipment and acceptance criteria to verify the charger/controller meets all physical and electrical requirements.

7.0 Battery Compatibility Testing

7.1 Test Plan

The battery compatibility testing was designed around the B-52 flight testing that was done as an extension of the original contract. The test plan was designed to simulate a 1-year operation on the B-52. The plan accelerates the testing into a 30- to 40-day test. The B-52 usage was based on the Boeing Wichita, Request for Budgetary Proposal Information document dated 28 March 1989, document number

3-ML1432-02-389-105/J1-389-009. This document has a Figure 5 and an Appendix A which describes the loading and a B-52G/H mission profile.

Table 7-1 shows the accelerated test requirements that were used for the compatibility testing. Requirement A represents accelerated READY status for the aircraft where intermittent unscheduled intervals draw low current from the battery in 20 minute increments. Requirement B represents a cartridge start for the airplane with the power supplied by the battery. Requirement C is basically used to represent a capacity check on the battery and it is done at different intervals to evaluate the battery's capacity as the test proceeds.

Table 7-2 shows the cycle description of the compatibility test. Each cycle represents an approximate 2-week period of operation. The test column describes the load (per Table 7-1) or the mode of operation. The duration is the approximate time for that particular sequence in the test. The description explains what test is run at that time. Because the test is accelerated, the battery is under much greater stress than it will be on the aircraft as far as cycles per day are concerned. In order to accommodate the extra stress in the battery, several rest periods are utilized to bring the battery to a steady-state condition prior to the next test mode within the cycle.

Table 7-3 shows the entire test sequence for the compatibility test. The test column describes the number of cycles or if a capacity check will be done (load per Table 7-1). The duration again is the approximate time for the particular test step. The temperature is the temperature that the battery will be held at during the test step. And the description explains what test is run. This test sequence covers 30 cycles as shown in Table 7-2 and simulates 1-year of accelerated life on the B-52.

7.2 Test Results

A summary of test results for the compatibility testing is shown in Table 7-4. This table covers two sheets, the first shows the charge/discharge data including charge efficiencies. The second sheet shows the battery temperature information at strategic points in the charge cycle during the testing.

TABLE 7-1

ELDEC®

BATTERY COMPATIBILITY TESTING

ACCELERATED TEST REQUIREMENTS.

REQUIREMENT	TIME RATE	CUT-OFF VOLTAGE	DISCHARGE RATE (A)	CAPACITY (A-HRS)
A	35 MIN	20.0	25	14.58
B	30 SEC	18.0	100	0.83
C	1 HR	20.0	22	22

TABLE 7-2

ELDEC

BATTERY COMPATIBILITY TESTING

CYCLE DESCRIPTION

TEST	DURATION	DESCRIPTION
A	35 MIN	STANDBY LOADING
CHARGE	45 MIN *	CHARGE CYCLE
REST	60 MIN	REST CYCLE
A	35 MIN	STANDBY LOADING
B	30 SEC	CARTRIDGE START
CHARGE	60 MIN *	CHARGE CYCLE
REST	120 MIN	REST CYCLE

* APPROXIMATE TIME ONLY. WILL ALLOW FULL RECHARGE OF THE BATTERY.

TABLE 7-3

ELDEC

BATTERY COMPATIBILITY TESTING

TEST SEQUENCE

TEST	DURATION	TEMPERATURE (DEGREES C)	DESCRIPTION
C	2 HRS	24 (75·F)	CAPACITY CHECK
4 CYCLES	16 HRS	24 (75·F)	ROOM TEST
1 CYCLE	4 HRS	50 (122·F)	HOT TEST
6 CYCLES	24 HRS	24 (75·F)	ROOM TEST
C	2 HRS	24 (75·F)	CAPACITY CHECK
1 CYCLE	4 HRS	-18 (0·F)	COLD TEST
6 CYCLES	24 HRS	24 (75·F)	ROOM TEST
1 CYCLE	4 HRS	50 (122·F)	HOT TEST
6 CYCLES	24 HRS	24 (75·F)	ROOM TEST
C	2 HRS	24 (75·F)	CAPACITY CHECK
1 CYCLE	4 HRS	-18 (0·F)	COLD TEST
4 CYCLES	16 HRS	24 (75·F)	ROOM TEST
C	2 HRS	24 (75·F)	CAPACITY CHECK

TABLE 7-4

TEST RESULT SUMMARY

4-520 COMPATIBILITY TESTING
TOTAL TEST SUMMARY
DATE: 3-5-91

CYCLE #	TEMP DEG C	END VOLT 1ST DCHG	END VOLT 2ND DCHG	END VOLT CRTG START	A-H OUT 1ST DCHG	1ST BASE CHARGE A-H	1ST OVER CHARGE A-H	TOTAL 1ST CHG A-H	1ST CYC CHARGE EFFICIENCY	A-H OUT 2ND CHG	2ND BASE CHARGE A-H	2ND OVER CHARGE A-H	TOTAL 2ND CHARGE	2ND CYC CHARGE EFFICIENCY	NOTES / COMMENTS
CAP 1	25	22.00	22.00	N/A	25.25	23.752	1.834	25.586	101.329	N/A	N/A	N/A	N/A	N/A	START OF COMPAT - CAP TEST #1 (NO "WARN" LIGHT ON CAP DCHG)
1	25	24.69	24.48	22.83	11.55	12.420	0.929	13.349	114.484	12.58	12.066	1.718	13.784	109.574	NO FAILURE ON CRTG START
2	25	24.28	24.27	22.59	11.67	12.299	1.734	14.033	120.251	12.59	12.319	2.709	15.028	119.369	NO FAILURE ON CRTG START
3	25	24.09	24.14	22.38	11.67	12.500	2.285	14.785	126.687	12.58	12.106	3.857	15.963	126.395	NO FAILURE ON CRTG START
4	25	23.35	24.08	22.28	11.58	12.780	2.924	15.704	133.596	12.81	11.913	4.466	16.379	129.335	NO FAILURE ON CRTG START
5	50	23.82	23.54	21.79	11.66	7.484	6.720	14.204	121.316	12.80	11.406	6.261	17.667	140.213	1ST SO DEG. C COMPAT CYC (NO FAILURE ON CRTG. START)
6	25	23.29	24.10	22.22	11.57	12.993	5.190	18.183	155.809	12.60	11.279	6.117	17.396	128.064	NO FAILURE ON CRTG START
7	25	23.84	23.95	22.10	11.84	11.552	3.400	14.952	128.020	12.60	11.446	3.997	15.443	123.545	NO FAILURE ON CRTG START
8	25	23.46	23.93	22.00	11.87	12.426	3.425	15.851	135.931	12.60	11.599	3.201	14.800	117.459	NO FAILURE ON CRTG START
9	25	23.77	23.79	21.90	11.88	10.999	2.216	13.215	113.138	12.52	11.806	2.187	13.993	111.230	NO FAILURE ON CRTG START
10	25	23.46	23.82	21.34	11.57	11.993	2.901	14.894	127.825	12.31	11.899	2.632	14.531	115.239	NO FAILURE ON CRTG START
11	25	23.55	23.90	21.79	11.57	11.526	2.064	13.590	116.450	12.59	11.879	2.340	14.219	112.945	NO FAILURE ON CRTG START
CAP 2	25	22.00	22.00	N/A	20.30	19.590	2.671	22.261	109.652	N/A	N/A	N/A	N/A	N/A	2ND CAP TEST (WARN LIGHT "ON" BATV-22.O Vdc)
12	-19	23.89	24.11	22.04	11.67	10.539	1.626	12.165	104.240	12.50	10.899	1.321	12.220	97.752	1ST -18 DEG. C COMPAT CYC (NO FAILURE ON CRTG. START)
13	25	23.74	23.94	22.00	11.57	12.106	2.072	14.178	121.489	12.59	11.969	1.999	13.968	110.366	NO FAILURE ON CRTG START
14	25	23.69	23.34	21.35	11.68	11.779	1.949	13.728	117.524	12.60	11.959	2.047	14.006	111.159	NO FAILURE ON CRTG START
CAP 3	25	22.00	N/A	N/A	19.41	18.529	2.141	20.670	105.492	N/A	N/A	N/A	N/A	N/A	3RD CAP TEST (NO "WARN" LIGHT ON DCHG)
CAP 4	25	22.00	N/A	N/A	20.89	18.636	2.281	20.917	101.598	N/A	N/A	N/A	N/A	N/A	12 MIN. O/CHG TIME LIMIT ADORD (PRIOR TO 4TH CAP TEST)
15	25	23.99	24.18	22.38	11.57	13.127	2.596	15.723	134.725	12.51	11.946	2.304	14.250	113.005	NO FAILURE ON CRTG START
16	25	23.90	23.99	22.14	11.66	12.153	2.181	14.334	122.922	12.58	11.906	2.179	14.065	111.965	NO FAILURE ON CRTG START
17	25	23.74	23.90	22.04	11.66	12.106	2.277	14.383	123.355	12.50	11.733	2.229	13.962	111.393	NO FAILURE ON CRTG START
18	25	23.84	23.35	21.93	11.57	12.199	2.272	14.471	124.016	12.59	11.373	2.012	13.385	110.284	NO FAILURE ON CRTG START
19	50	23.61	22.91	20.35	11.57	7.684	2.246	9.930	85.092	12.49	11.399	2.143	13.542	108.421	2ND SO DEQ. C COMPAT CYCLE (NO FAILURE ON CRTG. START)
20	25	21.96	23.90	21.95	11.68	15.448	2.208	17.656	151.162	12.59	12.052	2.287	14.339	113.395	NO FAILURE ON CRTG START
21	25	23.51	23.76	21.72	11.66	12.279	2.281	14.560	124.875	12.80	11.799	2.225	14.024	111.392	NO FAILURE ON CRTG START
CAP 5	25	22.00	N/A	N/A	14.84	15.394	2.018	17.412	116.938	N/A	N/A	N/A	N/A	N/A	CAP TEST #5 (DCHG "1" ONLY @ 16A POM 1/2 OF TEST)
CAP 6	25	22.00	N/A	N/A	17.26	16.076	2.311	18.387	109.418	N/A	N/A	N/A	N/A	N/A	CAP TEST #6 (NO WARN LIGHT DURING DCHG)
22	25	24.30	24.10	22.20	11.67	11.425	2.312	13.737	117.716	12.55	11.506	2.173	13.679	103.998	NO FAILURE ON CRTG START
23	25	23.67	23.87	21.91	11.67	12.279	2.246	14.525	124.472	12.51	11.745	2.266	14.011	112.002	NO FAILURE ON CRTG START
24	25	23.85	23.79	21.34	11.23	11.372	3.138	14.510	114.796	13.80	11.225	3.227	14.452	112.390	FIX S.W. FOR SMOOTHER TR MODE TRAINING FAIL ON CRTG START
25	25	23.32	23.70	21.30	11.37	12.533	2.231	14.764	125.312	12.57	11.399	2.271	13.670	111.142	NO FAILURE ON CRTG START
CAP 7	25	22.00	N/A	N/A	14.78	15.454	2.233	17.687	119.833	N/A	N/A	N/A	N/A	N/A	CAP TEST #7 (NO WARN LIGHT DURING DCHG)
26	-19	22.91	23.76	21.48	11.68	10.825	2.122	12.947	110.343	12.51	10.345	1.720	12.065	96.447	2ND-18 DEG. C COMPAT CYC (NO FAILURE ON CRTG. START)
27	25	23.22	23.73	21.68	11.57	12.507	2.244	14.751	126.401	12.60	11.819	2.252	14.071	111.675	NO FAILURE ON CRTG START
28	25	23.27	23.63	21.49	11.67	11.993	2.131	14.124	121.028	12.59	11.886	2.246	14.132	112.248	NO FAILURE ON CRTG START
29	25	22.70	23.72	21.51	11.68	13.407	2.189	15.596	133.519	12.59	11.773	2.246	14.019	111.360	NO FAILURE ON CRTG START
30	25	23.15	23.56	21.37	11.66	12.093	2.173	14.266	122.360	12.60	11.813	2.227	14.040	111.429	NO FAILURE ON CRTG START
CAP 8	25	22.00	N/A	N/A	14.01	15.021	2.244	17.265	123.233	N/A	N/A	N/A	N/A	N/A	CAP TEST #8 (NO WARN LIGHT DURING DCHG)

The Engineering battery used in the test had one "weak" cell that was watched closely during the testing for evidence of degradation. As such the information in the notes column in Table 7-4 shows a "WARN" light indication where this cell dropped below 1V during discharge. The cell did not degrade appreciably different than the other cells in the battery, therefore, the battery performance was considered to be valid as if the "weak" cell did not exist.

During testing several parameters were modified in the charger software to better tailor the charging profile. These required modifications came from examination of the test data and battery/charger performance during the testing phase.

The two major changes in the software were modifications to the overcharge and TR mode of operation. The overcharge mode was modified to include, in addition to a cut off and roll over termination indication, a 12-minute time limit such that the overcharge will be limited in time was incorporated. This modification was incorporated after Cycle 14 just prior to the fourth capacity test. The second change was incorporated at Cycle 22 which reduced the TR mode voltage level at the battery to 26.5V and modified the transition from overcharge to TR mode for a smoother transition without excessive current draw from the battery.

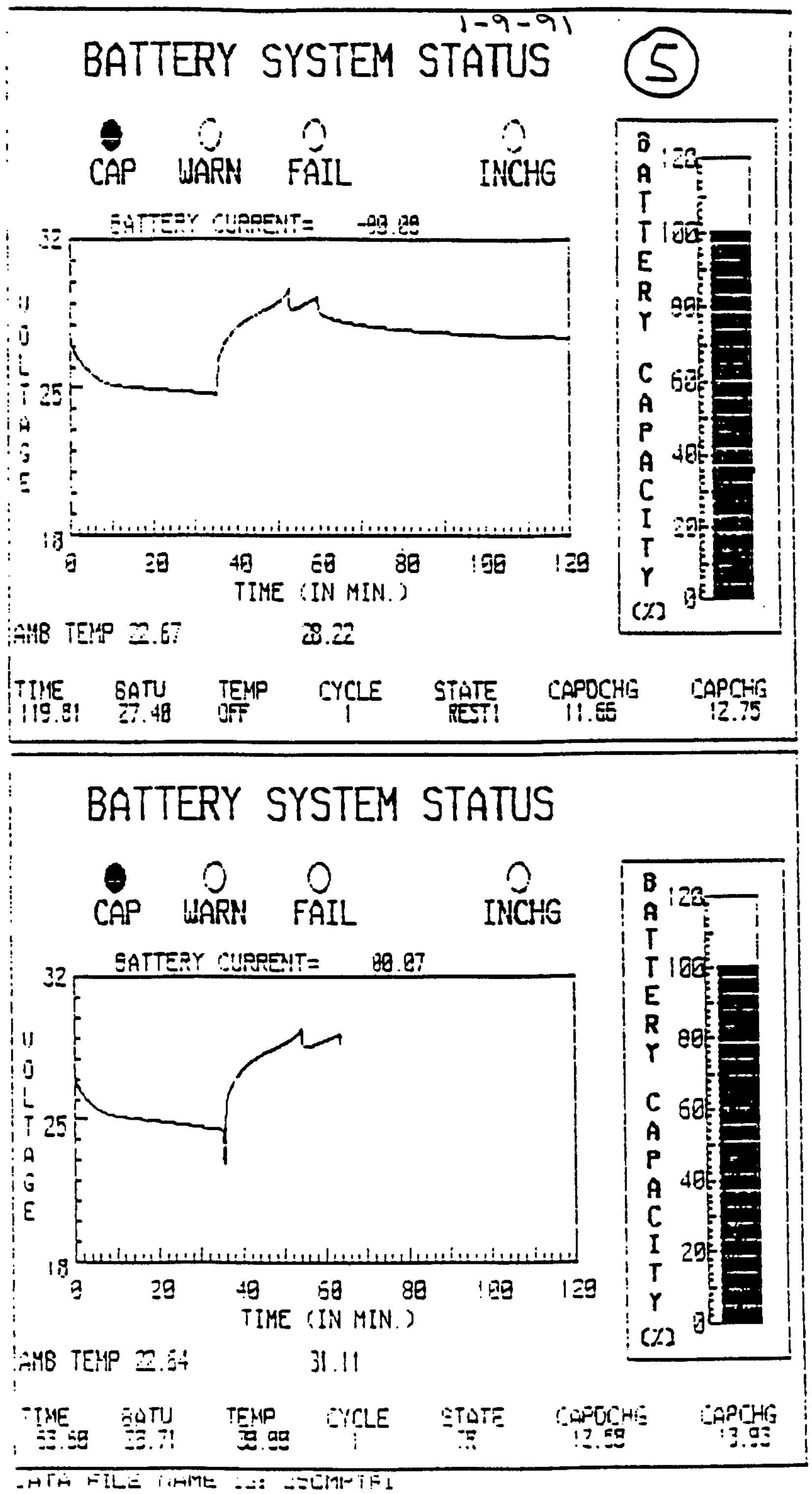
Several battery performance curves are summarized below:

Figure 7-1 Screen Dump from test station

This figure is a screen dump from the computer controlled test station showing one complete test cycle. The upper view shows the first discharge, charge and rest sequence. The lower view shows the second discharge with a cartridge start load of 100A at the end of the discharge (evidenced by the abrupt voltage drop) and then the final charge. One cycle was performed each day and then the battery was allowed to rest for 24 hours before the next cycle was run.

Figure 7-2 Temperature Comparisons

This figure shows three curves for a cartridge start discharge and charge subcycle. The curves are for -18, +25, and +50 degrees battery temperature. The figure shows about 1V of depression from the room temperature baseline to the hot temperature during discharge. The cold temperature performance during discharge is virtually identical to the room temp. During the cartridge start, there is only 0.5V difference between the temperatures. During the charge subcycle the cold temperature yielded the highest voltage, and at hot temperature, the voltage rolls over during overcharge. These curves also show the charger cutoff voltage as it is compensated to ensure adequate charging at the temperature extremes.



SCREEN DUMP

FIGURE 7-1

4-520 COMPATABILITY TEST HOT, COLD, AND ROOM TEMP COMPARISONS OF CARTRIDGE START SUBCYCLES

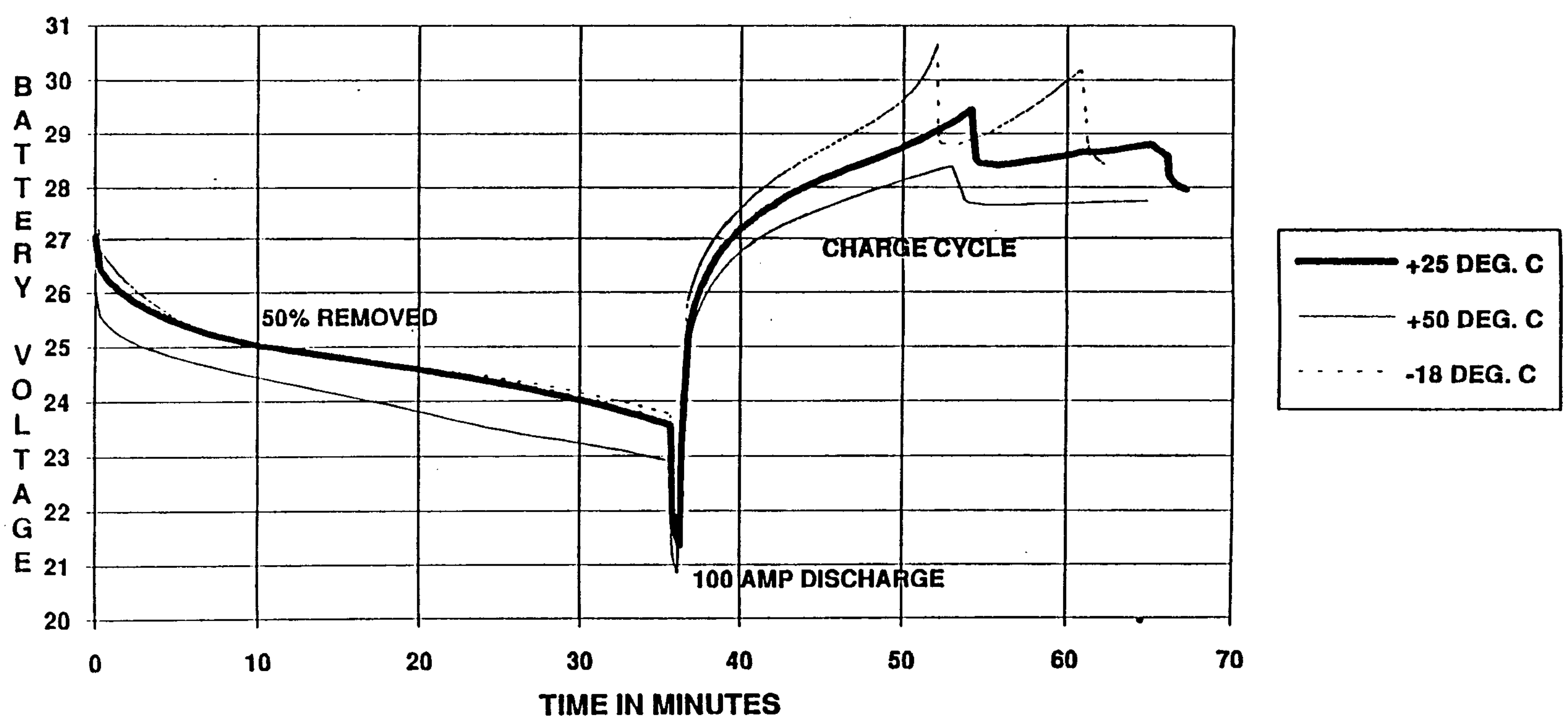


FIGURE 7-2

Figure 7-3 Discharge End Voltages

This figure shows the voltage of the battery vs. compatibility cycles at the end of each discharge subcycle and at the end of the cartridge start. The curve for the first discharge (DCHG1) shows a large dip at cycle 20 which was caused by a long rest period (after a weekend) just after a hot cycle. However, the voltage came back in alignment after a few additional cycles. These data show that the end voltage dropped about 1V during the entire test sequence. The cartridge start data basically follows the DCHG2 curve only it is another 1.5V below due to the higher current discharge.

Figure 7-4 Start and End Comparison

This figure shows the first and last cartridge start subcycles which shows the voltage depression during discharge. Of note here is the slope change during discharge which indicates a capacity degradation in the battery. The charge cycle looks the same for the base charge region; however, the voltage is depressed for the overcharge region.

Figure 7-5 Capacity Fade Data

The voltage drop indications are caused by a capacity fading effect in the battery. This figure shows the capacity as a function of cycles where cycle 1 was performed prior to the compatibility testing and cycle 8 was performed after the compatibility testing. These data indicate considerable fading in the battery as a result of this test sequence. The initial drop in capacity is believed to be caused by overcharging of the battery in the overcharge region, and the charge regime was altered to correct for this as mentioned earlier. However, the capacity continued to fade further as the testing progressed with a final capacity of around 14 Ahs. This test was quite extreme with a 50 to 75% depth of discharge drained from the battery on each cycle which was to represent an accelerated life on the B-52. However, in reality the battery will typically only see a 10 to 20% depth of discharge between cycles and they will be extended considerably in time. Other data on the battery show with shallower depths of discharge that the capacity fading is not severe, in fact it is very slight; therefore, we believe that the battery will provide good performance for the 3-year time frame based on that observation.

4-520 COMPATABILITY TEST DISCHARGE END VOLTAGES

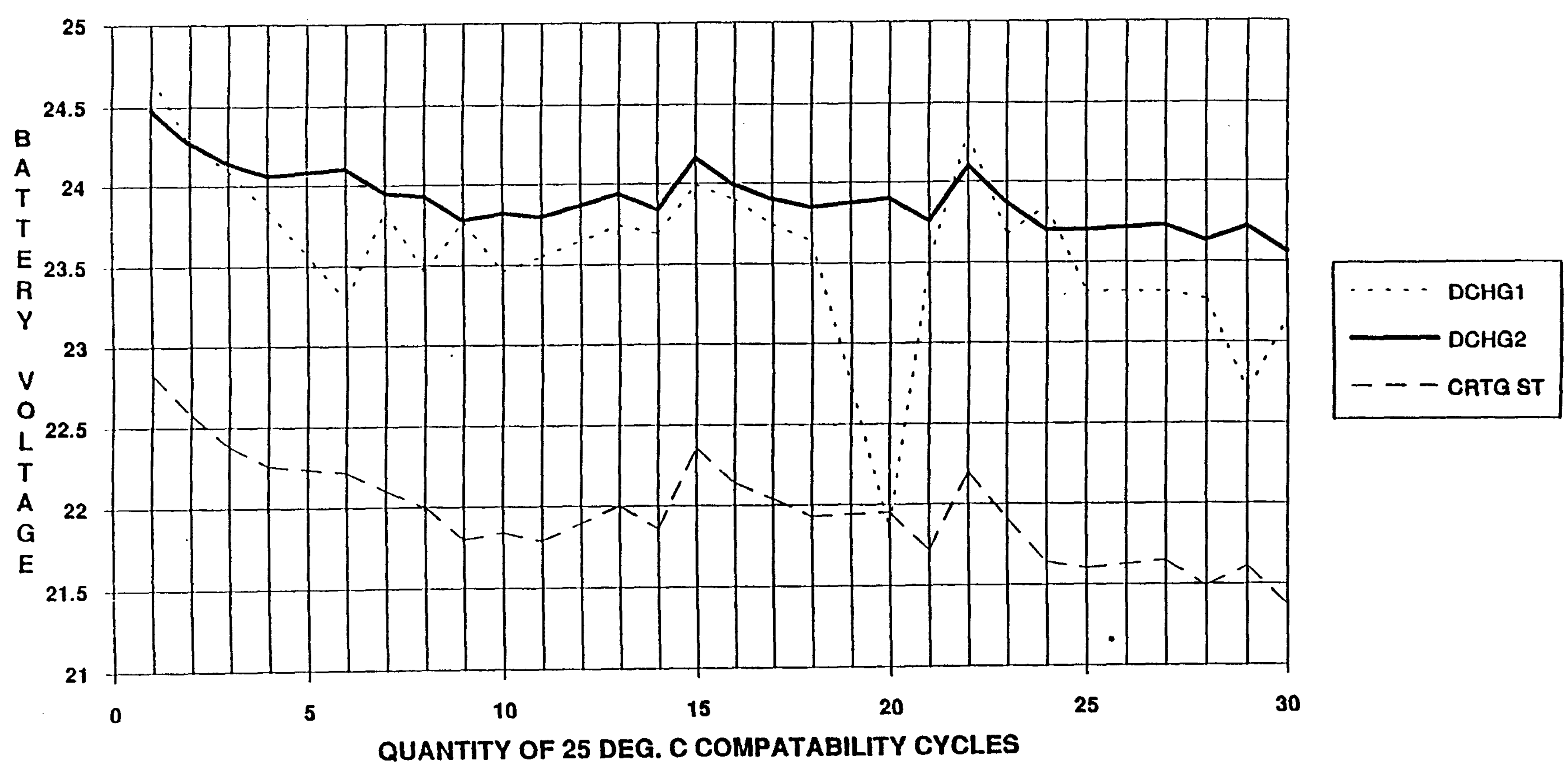


FIGURE 7-3

4-520 COMPATABILITY TEST 1ST AND 30TH CYCLE COMPARISONS FOR CARTRIDGE START SUBCYCLES (START AND END COMPARISON)

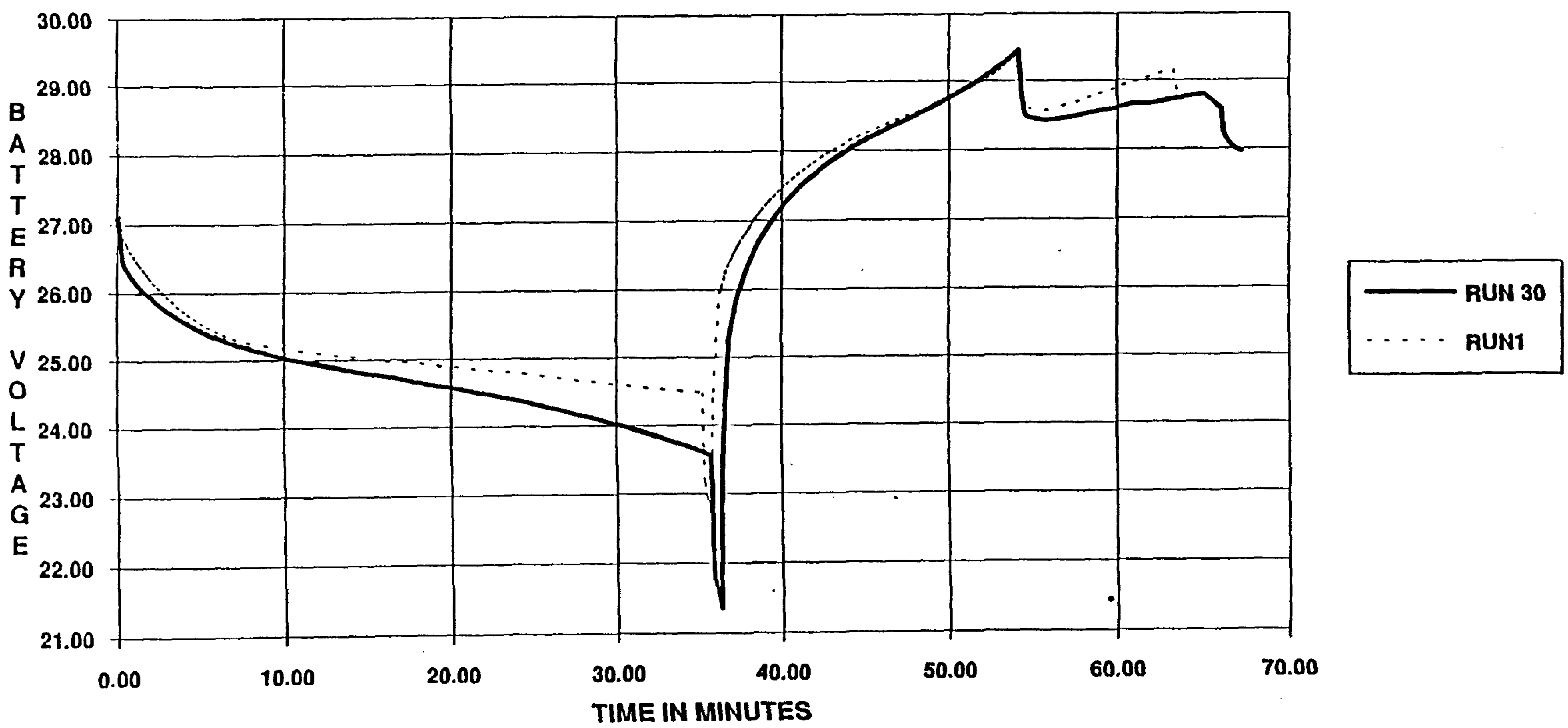


FIGURE 7-4

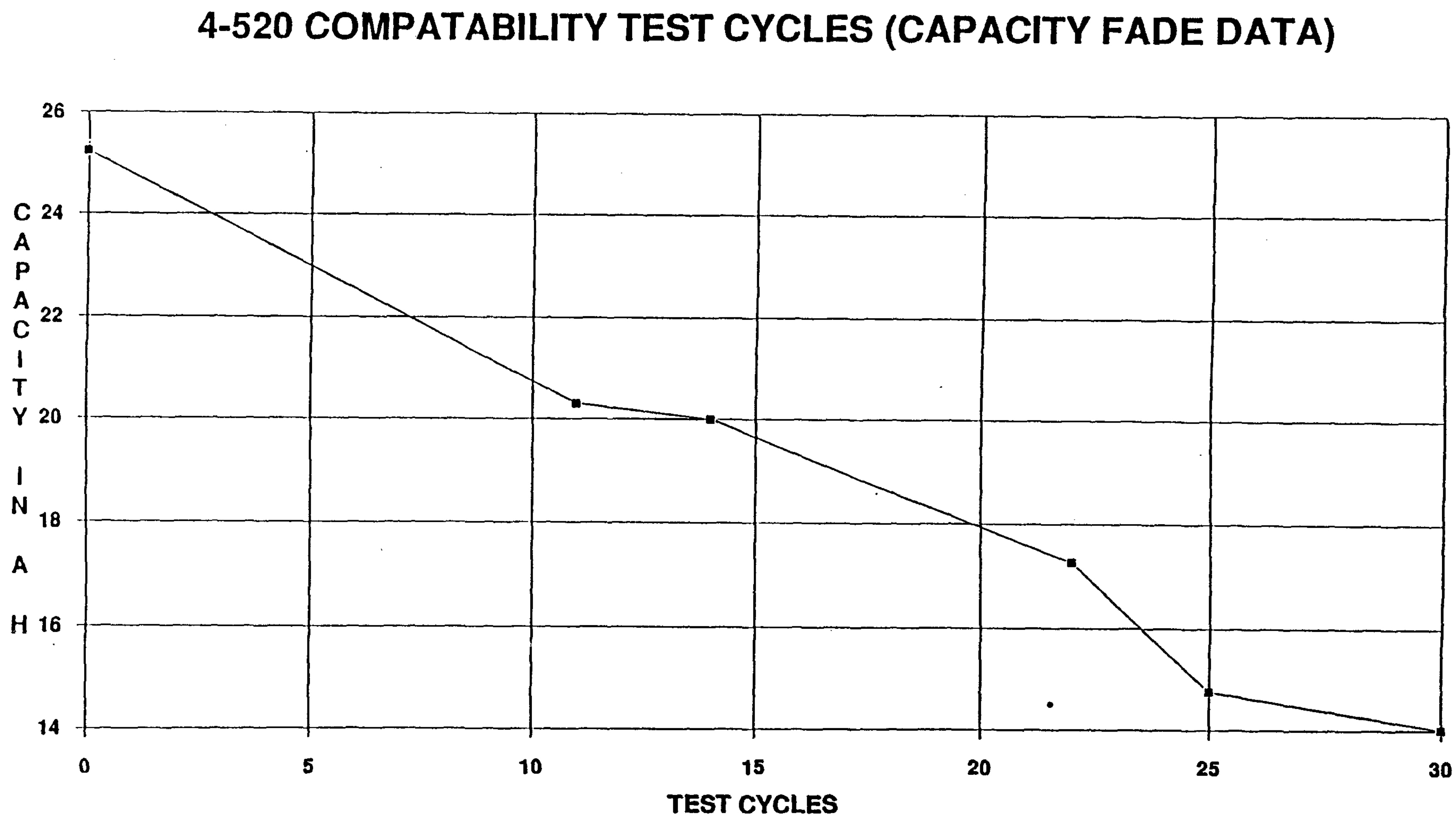

4-520 COMPATABILITY TEST CYCLES (CAPACITY FADE DATA)
26
24
22
20
18
16
14
CAPACITY IN AH
0
5
10
15
20
25
30
TEST CYCLES

FIGURE 7-5

Appendix A

B-52 Flight Test Report

FINAL REPORT

ADVANCED BATTERY SYSTEM for AIRCRAFT

B-52 FLIGHT TEST

WRIGHT LABORATORIES

WRIGHT PATTERSON AIR FORCE BASE, OHIO

CONTRACT NO. F33615-86-C-2678

EAGLE-PICHER INDUSTRIES, INC.
and
ELDEC CORPORATION

JULY 1992

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1 INTRODUCTION

This report summarizes the events and observations from the B-52H flight testing that was performed by replacing the existing 2 each per aircraft vented nickel-cadmium battery systems with the Eagle-Picher/ELDEC sealed nickel-cadmium Advanced Battery System for Aircraft (ABS). This flight test was performed by ELDEC and Eagle-Picher Industries (EPI) for the U.S. Air Force under contract Number F33615-86-C-2678. The ABS is comprised of an EPI sealed nickel-cadmium battery, part number EPI-18213, and an ELDEC battery charger/controller, part number 4-521-01. The testing was conducted over a one year period (April 1991 to April 1992) over which there was approximately 8 months of actual flight time.

2 SUMMARY

The ABS was successfully tested for approximately 277 flight hours plus an additional 1274 non-flight operational hours for a total of approximately 1551 hours without needing battery maintenance. The large amount of data collected by the battery charger's microprocessor has enabled us to create a daily profile of the ABS usage and to estimate actual usage ratios which may be helpful in battery system predictions. For example, if the usage experienced during these test flights are typical, it can be estimated that the average yearly flight time of a B-52 is approximately 400 hours and the approximate average operational time would be 2240 hours. The lessons learned during this program can be directly applied to the design and manufacture of other highly reliable battery systems such as the AMFABS, AC-130, E-3, (K)C-135, and others.

3 GENERAL OBSERVATIONS

The following are observations made during the flight test phase of this contract.

3.1 BATTERY CHARGER BITE

The ability of the charger to sense, collect, store, and down load system performance and status data has proven invaluable. On more than one occasion the battery charger BITE circuitry was able to determine an aircraft system fault. In the first installation a loose ground wire was found. In the final de-mod of the aircraft "Sky Wolf" a loose wire on the power diode was discovered which may have caused a flashing cockpit display anomaly discovered at Norton AFB. The BITE circuitry also was very beneficial at ELDEC for isolating faults and system anomalies by reviewing the down loaded data and using it as a troubleshooting aid. An inadequately strain relieved wire that had pulled loose was discovered by reviewing the down loaded data.

3.2 LESSONS LEARNED/HARDWARE & SOFTWARE OPTIMIZATION

3.2.1 BITE SENSITIVITY

It was quickly discovered that the BITE circuitry was initially too sensitive, resulting in a large amount of "nuisance" data being generated. Corrective action was taken to filtered the data in both hardware and software. In addition, the charger shutdown circuitry was also desensitized.

3.2.2 AIRCRAFT POWER USAGE/MODIFIED CHARGING ALGORITHM

During the numerous data down loading reviews, it was very apparent that the battery charging system was used often. The data shows that the AC power on the airplane is cycled quite often. This caused some over charging problems at first. However the charging algorithm was modified to protect the battery from overcharge during these frequent power up and power downs of the AC power on the airplane.

4 DATA ANALYSIS

4.1 USAGE RATIOS

ELDEC analyzed the data collected during the month of February in order to estimate the relationship between flight hours and total operational hours, and between amp-hours used and available battery hours. This reduced data is shown in Table 4 of attached Appendix A. The resulting ratios are shown in Table 1, Usage Summary, below. These ratios were then used to predict system usage during the remaining of the test period by utilizing the actual recorded flight hours, also shown in Table 1.

TABLE 1

USAGE SUMMARY

	FLIGHT HOURS (1)	CHARGER TOTAL OPERATIONAL HOURS (1)	OPERATIONAL HOURS/ FLIGHT HRS. RATIO (1)	AMPERE HOURS USED (3)	AVAILABLE BATTERY HOURS (2)	TOTAL HOURS IN TIME PERIOD (4)	AMP-HR USED/ AVAILABLE BATTERY HRS. RATIO (3)
FEBRUARY DATA	41	229	5.6	183	491	720	0.37
PROJECTED 6 MONTH PERIOD	198	1109	5.6 ref	1610	3211	4320	0.37 ref

Note 1: Projected 6 month data is based on actual flight hours x actual Operation Hours usage ratio.

Note 2: Available battery hours = total hours in the calendar time period minus charger total operation hours.

Note 3. Projected amp-hours used is based upon total hours in time period x actual amp-hours usage ratio.

Note 4: Total hours in the time period = number of days x 24.

4.2 DAILY USAGE PROFILE

The February data also allowed us to graphically portray the actual usage profile which is shown in Figure 1, Page 4. This figure is useful to gain understanding of the daily use of the system and the relationships between flight hours, operational hours, and ampere-hours used. If this profile is judged to be typical, it may also be used to gain insight into reliability prediction of the aircraft battery and system.

4.3 DATA

Although significant amounts of good data was retrieved from the microprocessors in the chargers, there was also a large amount of unusable data. One reason is that the flight test chargers used on the B-52 were commercial hardware modified for use in an engineering laboratory environment. The microprocessor in the chargers is mounted in a commercial grade socket to enable data down loading. As a result of the commercial grade hardware and the engineering environment in which the work was done, one of the microprocessor sockets was damaged preventing it from collecting adequate data. In another instance a wire was not adequately strain relieved which caused it to pull loose from its connection. This caused the charger to interpret a faulty battery condition when there was none, thereby shutting down the charger. These problems will be solved for subsequent systems (ie AC130 and the AMFABS program).

5 BATTERY PERFORMANCE

Generally, the batteries met all mission requirements. However, there were incidents of batteries being in a discharged state due system anomalies. The incident of May 28, 1991, indicates that the aft battery was in a discharged state due a charger failure. The battery was recharged on the aircraft with the on-board system once the charger had been replaced and AC power was applied to the aircraft. On March 31, 1992, it was reported that there was a problem with the system with the aircraft on the ground at Norton AFB, California. Analysis of the exact condition of the batteries was not possible due to attempts by Air Force personnel to charge the batteries locally. Subsequent analysis of this incident and the demodification of the aircraft on April 23, 1992, indicated both a broken wire in the charger and a loose connection in the aircraft wiring.

During the data down load and charger swap on February 28, 1992, EPI removed the batteries to the Fairchild battery shop and a capacity check was done on the batteries. Discharge curves from this capacity check are included as Figures 2 and 3, Page 5 of this report. Following removal of the batteries from the aircraft at the demodification, capacity was again checked. Discharge curves from this capacity check are depicted in Figures 4 and 5, Page 6. Battery capacity is well over the minimum 18 ampere hour, end of test life expected.

DAILY USAGE PROFILE

B-52H - "SKYWOLF" - No. 1036

JANUARY/FEBRUARY 1992

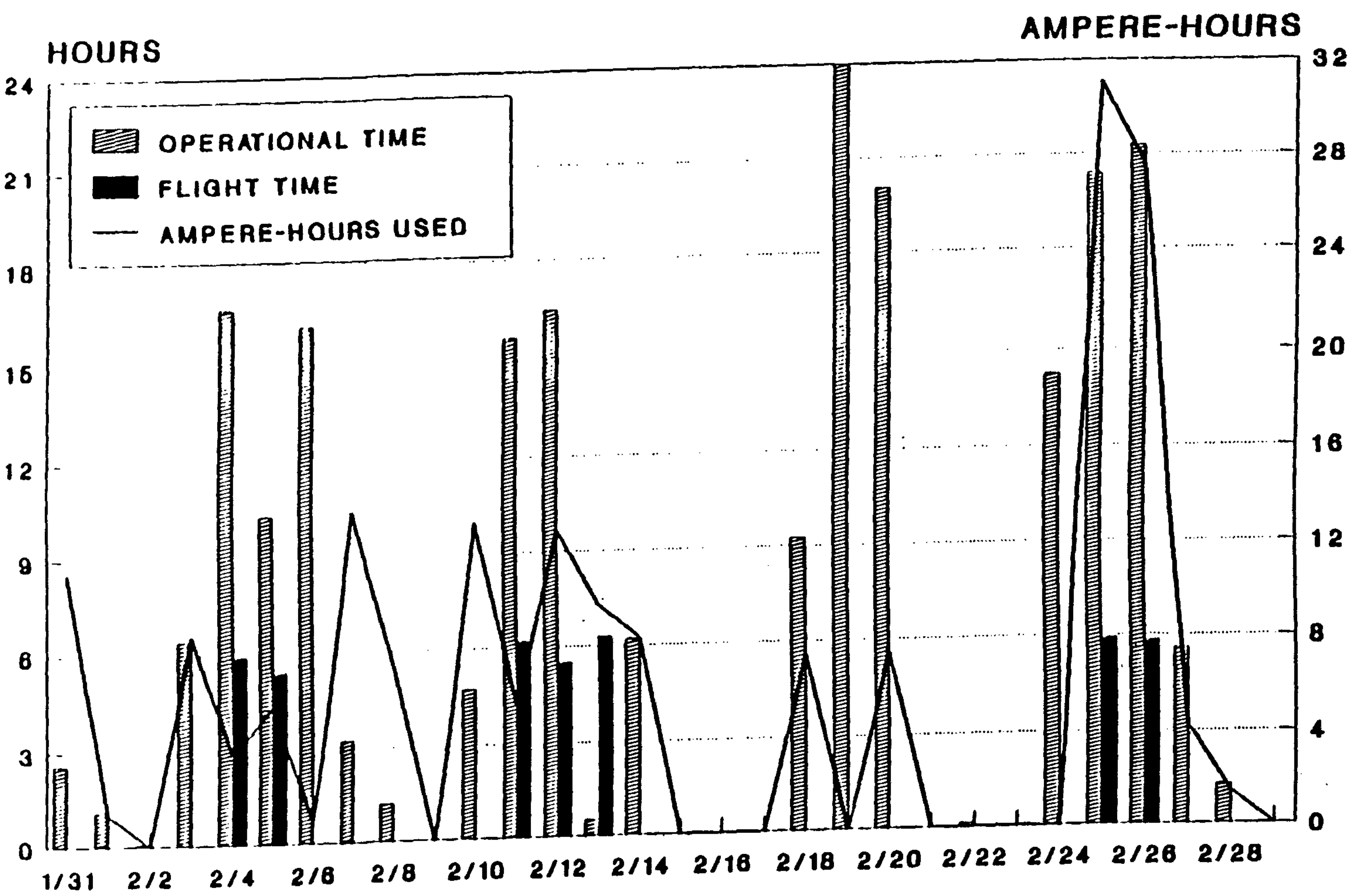

FIGURE 1

CAPACITY DISCHARGE
AFT BATTERY
B-52 FLIGHT TEST - 28 FEB 92

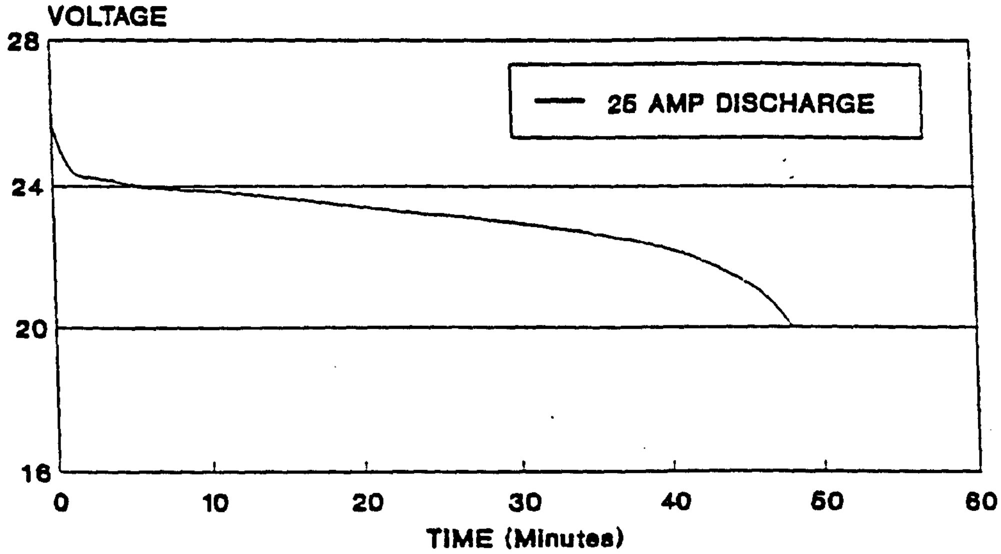

FIGURE 2

C9203008

CAPACITY DISCHARGE
FORWARD BATTERY
B-52 FLIGHT TEST - 28 FEB 92

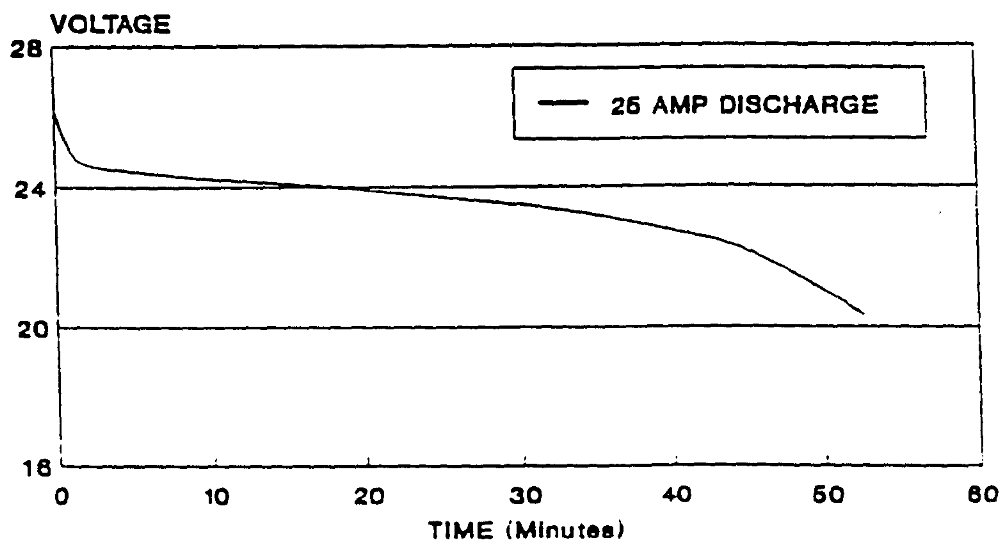

FIGURE 3

C9203009

CAPACITY DISCHARGE
AFT BATTERY
B-52 FLIGHT TEST - 29 APR 92

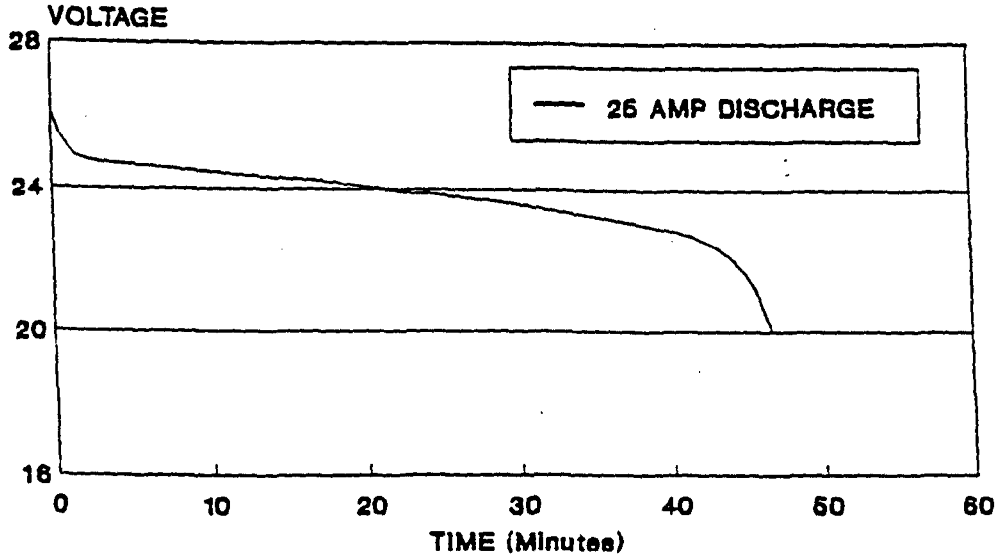

FIGURE 4

C9206025

CAPACITY DISCHARGE
FORWARD BATTERY
B-52 FLIGHT TEST - 29 APR 92

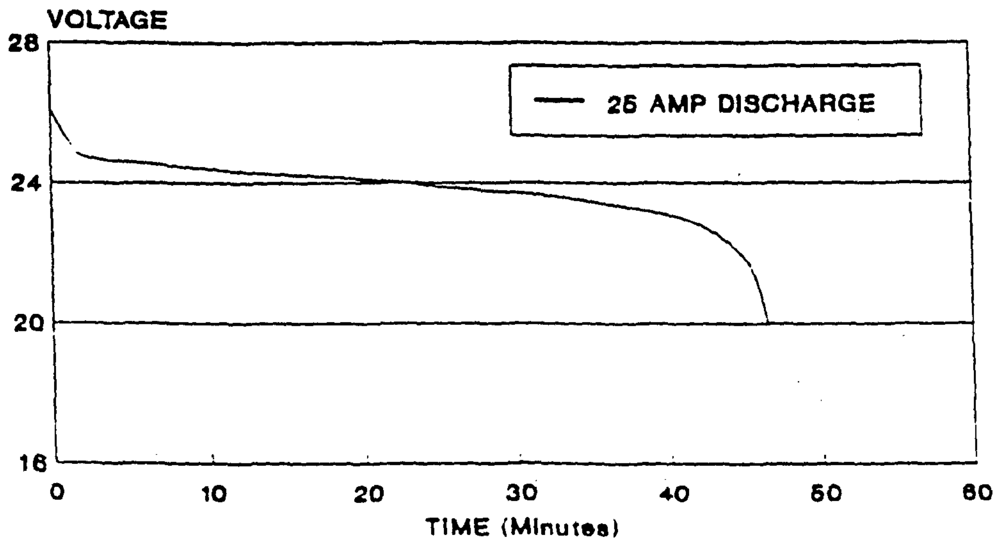

FIGURE 5

C9206026

6 FLIGHT LOG DATA

TABLE 2

FLIGHT TEST HOURS LOGGED - FAIRCHILD AFB

Date	Duration, Hours
10/22/91	12.8
10/23/91	12.5
10/31/91	7.8
11/04/91	6.9
11/05/91	9.0
11/07/91	2.7
11/12/91	5.0
11/13/91	4.8
11/18/91	6.9
11/19/91	9.3
11/20/91	10.8
11/25/91	7.4
11/26/91	4.6
12/04/91	5.8
12/09/91	6.9
12/10/91	7.3
2/4/92	5.9
2/5/92	5.4
2/11/92	6.2
2/12/92	5.5
2/13/92	6.3
2/25/92	5.9
2/26/92	5.8
3/2/92	6.4
3/2/92	2.6
3/3/92	4.6
3/4/92	5.8
3/9/92	5.4
3/11/92	6.3
3/26/92	2.9
3/31/92	2.5
Total	198.0

Table 2 data does not include the approximately 2 months of flight time conducted at Minot Air Force Base in North Dakota during the months of April, May, and June of 1991. If we estimate those hours as the monthly average of the above hours, the total flight time of the Advanced Battery System was approximately 277 hours.

7 FLIGHT TEST EVENTS

Table 3, Page 8, summarizes the key flight test events from April 1, 1991 to April 23, 1992. Each event is documented by a detailed report or memo on file at ELDEC.

8 CONCLUSIONS

The B-52 flight test program accomplished its objective of demonstrating the successful performance of the ELDEC/EPI Advanced Battery System in a real life rugged environment. The program also yielded several valuable lessons learned which we will incorporate in to our on-going ABS design and development efforts. Many system and user requirements were refined based on actual usage of the battery system installed on an active aircraft. Based on actual usage data, we have learned to refine our charging algorithms to better match actual system usage. Data filtering and collection techniques have also been refined to give more accurate and consistent results. The profiling of the daily use of the system not only yields useful ratios of total operating hours to flight hours, but also gives insight to the actual demands place on the charger and battery system. This type of data will enable ELDEC and EPI to better understand how to optimize our designs to enhance the reliability of the system. Most important to note however, is the fact that the battery performed flawlessly through out the entire test program without damage or maintenance.

9 ACKNOWLEDGEMENTS

We like to take this opportunity to offer our special thanks to all of the people too numerous to mention in this report by name who went well beyond their normal call of duty to initiate and support the Advanced Battery System design and development, and its subsequent flight test evaluation on the B-52H aircraft. The overall support that we experienced was nothing short of excellent especially when you consider the already heavy work loads of the individuals involved. Our special thanks go out to the base commanders at both Minot Air Force Base, and Fairchild Air Force Base for allowing us to use their aircraft for the flights, and to the Program Manager Richard Flake out of Wright Laboratories located on Wright Patterson Air Force Base who was not only our sponsor, but also a driving force in the success of the program. Our special thanks also to Capt. Anthony Romano and MSGT Kent Morris from HQ SAC/LGME, Offutt Air Force Base, which without their understanding of B-52H requirements and their frequent extra efforts during all of the phases of the program, this success would not be possible. Finally, thanks to SMSGT David Holbrook at Fairchild Air Force Base, who always made time available to us on our very frequent trips to Spokane to retrieve data from the ABS memory.

Appendix A-1

Reduced Data for the Month of February 1992

FINAL REPORT
B-52 FLIGHT TEST

Appendix A

Reduced Data for the month of February 1992

APPENDIX A

DATA

START-UP DATE	START-UP T-O-D	SHUT-DOWN DATE	SHUT-DOWN T-O-D	OPERATING TIME	OPERATING HOURS	AMP HRS REPLACED
1/31/92	12:35:28		13:30:50	0:55:22		10.45
	13:31:14		13:36:44	0:05:30		
	13:37:06		13:42:27	0:05:21		
	16:09:16		16;24:10	0:14:54		
	19:07:56		19:22:50	0:14:54		0.99
	19:27:47		19:37:49	0:10:02		
	19:40:24	1/31/92	20:28:22	0:47:58		
DAILY TOTAL:					2.57	11.44
2/01/92	7:45:10		7:47:10	0:02:00		
	8:30:01		9:28:04	0:58:03		1.34
	12:38:00		12:38:45	0:00:45		
	12:55:39	2/01/92	12:59:50	0:04:11		
DAILY TOTAL:					1.08	1.34
2/02/92	11:08:54	2/02/92	11:10:44	0:01:50		
DAILY TOTAL:					0.03	0.00
2/03/92	0:16:33		0:28:55	0:12:22		
	2:17:30		3:15:27	0:57:57		7.21
	3:47:03		3:52:40	0:05:37		
	4:40:26		5:01:30	0:21:04		
	12:30:23		14:26:53	1:55:53		
	14:24:24		14:46:32	0:22:06		
	14:47:00		14:53:57	0:06:57		
	14:54:19		15:40:39	0:46:20		
	16:17:35		16:24:13	0:06:38		
	17:21:39		17:38:18	0:16:39		
	19:26:45		19:28:50	0:02:05		
	20:07:46		20:13:42	0:05:56		1.56
	20:38:04		21:10:16	0:32:12		
	21:25:10	2/03/92	21:56:17	0:31:07		
DAILY TOTAL:					6.38	8.77

APPENDIX A (Continued)

DATA

START-UP DATE	START-UP T-O-D	SHUT-DOWN DATE	SHUT-DOWN T-O-D	OPERATING TIME	OPERATING HOURS	AMP HRS REPLACED
2/04/92	0:02:52		4:23:46	4:20:54		
	4:44:49		5:22:22	0:37:33		
	5:51:26		6:06:03	0:14:37		
	6:08:54		6:11:31	0:02:31		
	10:32:07		10:39:05	0:06:58		
	10:45:02		10:46:37	0:01:35		1.54
	10:47:26		10:50:33	0:03:07		
	11:27:25		11:28:33	0:01:08		
	11:28:55		11:30:40	0:01:45		
	11:31:19		11:39:16	0:07:57		
	11:39:39		11:43:23	0:03:44		1.79
	11:49:25		19:10:57	7:21:32		
	19:11:05		21:50:02	2:38:57		
	21:50:39	2/04/92	22:50:40	1:00:01		0.51
DAILY TOTAL:					16.71	3.84
2/05/92	8:56:50		9:13:10	0:16:20		
	9:16:49		9:21:31	0:04:42		
	9:26:40		10:06:15	0:39:35		
	10:06:23		10:06:24	0:00:01		
	10:41:02		10:41:08	0:00:06		
	11:20:23		11:28;11	0:07:48		
	11:28:10		11:55:31	0:27:12		0.97
	13:29:59		13:39:17	0:09:18		
	13:57:28		14:00:53	0:03:25		
	14:08:13		14:08:36	0:00:23		
	14:46:15		14:47:15	0:01:00		
	14:47:43		21:28:19	6:40:36		
	22:04:51		23:34:15	1:29:24		1.74
	23:40:49	2/05/92	23:59:59	0:19:10		3.10
DAILY TOTAL:					10.32	5.81
2/06/92	0:00:00		3:04:25	3:04:25		
	6:04:44		6:12:44	0:08:00		
	6:13:49		12:58:27	6:44:38		
	13:38:21		14:52:57	1:14:36		
	15:25:38		15:36:25	0:10:47		
	17:19:37		17:48:39	0:29:02		
	18:17:52	2/06/92	22:36:30	4:18:38		1.02
DAILY TOTAL:					16.18	1.02

APPENDIX A (Continued)

DATA

START-UP DATE	START-UP T-O-D	SHUT-DOWN DATE	SHUT-DOWN T-O-D	OPERATING TIME	OPERATING HOURS	AMP HRS REPLACED
2/7/92	0:47:46		0:55:27	0:07:27		
	0:56:04		1:12:04	0:16:50		
	9:12:54		10:19:08	1:06:14		8.23
	13:26:16		14:49:32	1:23:16		3.09
	17:19:18		17:20:19	0:01:01		
	17:20;47		17:21:07	0:00:20		
	19:34:54		19:34:57	0:00:03		
	19:35:23	2/7/92	19:54:47	0:19:24		2.60
DAILY TOTAL:					3.25	13.92
2/08/92	10:04:49		10:22:40	0:17:51		
	10:26:56		10:39:05	0:12:09		7.52
	11:51:18	2/08/92	12:34:44	0:41:26		
DAILY TOTAL:					1.19	7.52
2/10/92	2:04:14		2:24:39	0:20:25		5.13
	2:25:23		5:57:19	3:31:56		
	21:56:51		22:13:56	0:17:05		
	22:15:15	2/10/92	22:51:27	0:36:12		8.20
DAILY TOTAL:					4.76	13.33
2/11/92	0:57:21		1:16:32	0:19:11		
	2:09:22		2:59:52	0:50:30		
	5:50:02		5:46:59	0:56:57		1.59
	6:23:06		7:46:23	1:23:17		
	7:49:09		7:55:39	0:06:30		
	8:13:52		8:17:17	0:03:25		
	8:17:32		8:17:58	0:00:26		
	8:18:13		8:18:48	0:00:35		
	8:19:06		8:20:10	0:01:04		
	9:01:39		9:29:17	0:27:38		
	9:29:25		16:10:16	6:40:51		
	16:24:45		16:26:45	0:02:00		
	16:26:49		16:33:24	0:06:35		
	17:32:47		18:13:58	0:41:11		4.03
	18:14:09		18:14:40	0:00:31		
	18:14:49		18:20:57	0:06:08		
	19:57:11		19:57:41	0:00:30		
	20:05:49	2/11/92	23:59:59	3:54:10		
DAILY TOTAL:					15.69	5.62

APPENDIX A (Continued)
DATA

START-UP DATE	START-UP T-O-D	SHUT-DOWN DATE	SHUT-DOWN T-O-D	OPERATING TIME	OPERATING HOURS	AMP HRS REPLACED
2/12/92	0:00:00		1:50:15	1:50:15		
	2:36:39		4:53:27	2:16:48		
	5:07:15		6:06:13	0:58:58		10.20
	8:23:25		11:19:46	2:56:21		
	11:40:56		11:50:34	0:09:38		1.41
	13:31:10		13:39:56	0:08:46		
	14:00:11		14:28:54	0:28:43		
	14:50:56		15:56:34	0:05:38		1.32
	15:28:07		15:57:55	0:29:48		
	15:58:03		22:10:44	6:12:41		
	22:10:53		22:33:02	0:22:09		
	23:31:49	2/12/92	23:59:59	0:28:10		
DAILY TOTAL:					16.48	12.93
2/13/92	0:00:00		0:23:26	0:23:26		
	0:27:40		1:43:23	1:15:43		
	1:47:40		2:16:07	0:28:27		
	6:40:59		6:42:32	0:01:33		
	8:13:58		8:16:00	0:02:02		
	10:00:19		10:37:21	0:37:02		
	10:37:42		17:24:16	6:46:34		5.85
	17:25:48		18:02:06	0:36:18		
	18:07:17		18:07:21	0:00:04		
	18:39:10		19:11:13	0:32:03		
	19:24:41		20:47:12	1:34:31		3.86
	20:49:13		20:15:19	0:02:06		
	23:59:19	2/13/92	23:59:59	0:00:40		
DAILY TOTAL:					12.35	9.71
2/14/92	0:00:00		0:04:22	0:04:22		
	0:12:03		0:23:22	0:11:19		
	2:48:35		3:15:54	0:27:19		
	4:01:06		5:16:41	1:15:35		4.03
	9:32:55		9:46:20	0:13:25		
	9:46:37		10:36:43	0:50:06		
	11:11:11		11:16;52	0:05:41		2.79
	11:17;13		11:48:55	0:31:42		
	14:16:12		14:16:19	0:00:07		
	15:43:07		15:43:12	0:00:05		
	15:43:22		15:45:45	0:02:23		
	15:58:55		16:00:50	0:01:55		
	16:01:07		16:02:52	0:01:45		1.48
	16:02:56		16:04:54	0:01:58		
	16:07:22		16:20:53	0:13:31		
	16:21:02	2/14/92	18:30:12	2:09:10		
DAILY TOTAL:					6.17	8.30

APPENDIX A (Continued)

DATA

START-UP DATE	START-UP T-O-D	SHUT-DOWN DATE	SHUT-DOWN T-O-D	OPERATING TIME	OPERATING HOURS	AMP HRS REPLACED
2/18/92	0:02:59		0:20:19	0:17:20		6.51
	0:22:21		0:39:26	0:17:05		
	0:39:52		2:22:33	1:42:41		
	2:24:24		2:25:18	0:00:54		
	3:26:56		3:28:42	0:01:46		
	3:30:25		3:42:50	0:12:25		
	7:48:00		9:25:31	1:37:00		
	9:26:45		9:26:51	0:00:06		
	9:27:15		11:39:18	2:12:03		1.02
	21:06:38	2/18/92	23:59:59	2:53:21		
DAILY TOTAL:					9.25	7.53
2/19/92	0:00:00	2/19/92	23:59:59	23:59:59		
DAILY TOTAL:					24.00	0.00
2/20/92	0:00:00		19:04:59	19:04:59		7.56
	20:50:35		20:56:54	0:06:19		
	21:02:33	2/20/92	21:52:03	0:49:30		
DAILY TOTAL:					20.01	7.56
2/22/92	12:00:02	2/22/92	12:07:31	0:07:29		
DAILY TOTAL:					0.12	0.00
2/24/92	9:45:49		23:59:59	14:14;10		
DAILY TOTAL:					14.24	0.00
2/25/92	0:00:00		11:07:31	11:07:31		
	11:12:19		11:29:06	0:16:47		
	11:53:13		12:05:42	0:12:29		
	12:28:31		12:43:44	0:15:13		28.02
	13:14:55		13:15:38	0:00:43		
	13:15:53		13:31:52	0:15:59		
	15:30:39		22:53:00	7:22:21		1.58
	23:08:20	2/25/92	23:59:59	0:51:39		1.52
DAILY TOTAL:					20.38	31.12

APPENDIX A (Continued)

DATA

START-UP DATE	START-UP T-O-D	SHUT-DOWN DATE	SHUT-DOWN T-O-D	OPERATING TIME	OPERATING HOURS	AMP HRS REPLACED
2/26/92	0:00:00		0:25:57	0:25:57		
	0:28:01		1:32:52	1:07:51		
	2:45:54		3:50:25	1:04:31		1.63
	5:22:02		18:04:28	12:42:26		25.98
	18:04:36	2/26/92	23:59:59	5:55:23		
DAILY TOTAL:					21.27	27.61
2/27/92	0:00:00		0:44:38	0:44:38		
	0:46:13		1:47;41	1:01:28		
	3:21:14		4:27:02	1:05:48		0.93
	5:45:26		6:03:23	0:17:57		
	11:29:55		12:18:12	0:48;17		3.37
	16:21:45	2/27/92	17:58:20	1:36:35		
DAILY TOTAL:					5.58	4.30
2/28/92	1:47:36		1:52:36	0:05:00		
	1:55:47	2/28/92	3:06:35	1:10:48		1.40
DAILY TOTAL:					1.26	1.40
MONTHLY TOTAL:					229.27	183.07

Appendix B

E-3 Flight Test Final Report

E-3 FLIGHT TEST FINAL REPORT

ADVANCED BATTERY SYSTEM FOR AIRCRAFT

JULY 1994

CONTRACT NUMBER: F33615-86-C-2678
WRIGHT LABORATORIES
Wright Patterson Air Force Base, Ohio

Eagle Picher Industries, Inc.
Electronics Division
3820 South Hancock Expressway
Colorado Springs, CO 80911

Prepared by: [signature]
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Program Manager

Approved by: [signature]
Darren Scoles
Product Manager

EAGLE PICHER

Table of Contents

1.0 Introduction

This report summarizes the events, observations, and performance data from the E-3 flight testing that was performed by replacing the current vented Nickel Cadmium battery system with an "Eagle Picher Industries/ELDEC Corporation" High Reliability Maintenance Free Battery (HRMFB) System. The flight test was performed by ELDEC and Eagle Picher Industries (EPI) for the U. S. Air Force under Contract Number F33615-86-C-2678. The HRMFB system was comprised of an EPI sealed nickel cadmium battery, part number EPI-18214, and an ELDEC battery charger/controller, part number 4-521-02. The actual flight test was conducted for a period of approximately 1 year (Sept 92 to Sept 93), using an E3 stationed at Tinker AFB, OK (aircraft tail #1607).

2.0 System Identification

2.1 Current Charger/Battery System

The E-3B/C currently uses 4 batteries (NSN 6140-01-020-7288) along with 2 chargers (NSN 6139-01-027-0261) to provide power to the Main Forward System and the Emergency Light System. These batteries are currently on a 90 day maintenance cycle. This constant maintenance is required for cell equalization and replacement. SCD 204-13038 is the Specification Control Drawing for this charger/battery system.

The 90 day maintenance cycle is a costly and unnecessary (based on flight test) requirement. It is this cost that the HRMFB System is intended to eliminate. Scheduled and unscheduled maintenance requirements are a direct contributing factor to airframe down time, in worse case scenarios this maintenance requirement can effect the worldwide capabilities and versatility required for today's fleet. The HRMFB System will eliminate maintenance cycles and reduce battery shop requirements to a minimum.

2.2 High Reliability Maintenance Free Battery System

The following parts where used for this flight test:

Part	Part #
Batteries, 55 amp hour (4ea)	EPI 18214
Chargers (2ea)	ELDEC 4-521-02
Mounting Tray (1ea)	ELDEC TBD
Cables (2ea)	ELDEC TBD
Adapter Plates (2ea)	ELDEC TBD

There would be no maintenance cycle for this system. The system is intended to fly one to three years without any maintenance. The HRMFB System would upgrade the E-3B/C to an airframe system compatible with any worldwide commitments up to and including remote station type missions.

2.3 System Weight Comparison

The Temporary Modification added a total weight of 111 lbs to the aircraft. Approximately 60% of this weight would be excluded from future modifications because it would not be necessary to leave the original charging systems in place as was done for the flight test. Incorporation of the HRMFB System on the E-3B/C would add less than 50 lbs to the total Charger/Battery system weight

3.0 Flight Test

3.1 System Integration

The HRMFB System was designed to fully integrate with the current aircraft structure and electrical system. The new batteries where installed using existing battery equipment with no modification required to the airframe or support structure. The new charging system was supplied with cabling and mounting provisions. The charging system was installed using a mounting tray attached to the E-1 Flight Essential Avionics rack in the forward lower lobe.

3.2 Flight Test Requirement

The requirement for this system was for it to be installed on an E-3, and to operate under normal system demands with no maintenance operation being performed on the HRMFB System. The flight test time period was originally for three to six months. This period had been extended to a 9 month flight test prior to system installation. An additional requirement was for the aircraft to be refueled from a normal landing load to 120,000 lbs of fuel using the batteries for power (this is an alternative procedure used for bare base operations/T.O. 1E-3A-2-7). This refueling exercise was to be performed sometime during the flight test. Other than the refueling the HRMFB System was exposed to "normal operational mission requirements".

The flight test was considered a success if the system met the refueling demands along with all the other power demands during the flight test period, without requiring any maintenance operation on the HRMFB system.

4.0 Discussion

4.1 Charger

The ability of the charger to sense, collect, store and download historical data, system status and system performance was an invaluable source of information.

The chargers that were originally installed, were chargers that were transferred to this program from the B52 flight testing. These chargers were using the wrong resistor value in the sensing of the battery temperature and consequentially were causing the batteries to be overcharged. This condition was not discovered until the first data download (2-4-93). Upon discovery of this problem, arrangements were made to correct the charging system. The installation of the correct hardware transpired 2-11-93. At the time it was decided to change the batteries to ensure that there were no long term effects from the over charging (see battery discussion). For further discussion and analysis of this situation and the corrective action please see the quarterly report submitted for this contract 3/93.

The flight test was completed using the correct hardware, with great success. The chargers were able to provide a historical record of the battery performance and system demands along with providing data attesting to the ability of the chargers to maintain the batteries in an optimum charge status. Other than the temperature sensing problem, which was discovered by ELDEC, there were no recorded problems with this part of the system during the flight test.

4.2 Battery

As discussed in the previous paragraph, for approximately the first 5 months of the flight test (9/30/92 - 2/11/93) the batteries were receiving an excessive overcharge everytime the system was used. After discussions with the Air Force and ELDEC it was decided to replace the batteries for the completion of the flight test. Although the available data indicated the batteries had met or exceeded performance expectations, EPI had no supporting data to ensure the constant overcharging had not induced long term damage on the batteries. Discharge information already provided (Quarterly report 3/93) showed the batteries ability to provide the required 55 amp hours comfortably, upon their removal from the airplane.

The flight test was completed with 4 new batteries provided by EPI. These batteries were on the system long enough to provide over 6 months of complete data showing system and battery reliability. The batteries were subjected to discharge rates from 10 amps to a maximum rate of 60 amps, with Depth of Discharges (DOD) being anywhere from 5% to 95% of full battery capacity. Beyond being able to handle scheduled tasks under worst case scenarios, such as the refueling exercise using the batteries, the batteries were also used for unscheduled maintenance activities, with no adverse impact on regular mission demands. All batteries were comfortably able to provide 55 amp hours upon their removal from the aircraft. There was no noticeable drop in battery performance from when they went on the plane to when they were removed.

4.3 System Compatibility

The modification of the aircraft was accomplished with minimum airframe downtime and in less time then originally allowed for the mod. The battery appears to be capable of handling expected and unexpected system demands. The average DOD was only 15% of the battery capabilities, but system demands were such that at times the battery was used to 95% of its rated capacity with no effect on the battery/charger system. This type of DOD profile from this long of a time period would be an indication that the 55 amp hour Eagle Picher battery (EPI-18214) along with the ELDEC charger (ELDEC 4-521-02) is the optimum system for this application.

5.0 Data Analysis

Attachments 1-6 are incorporated from a Technical Design Review, ELDEC performed for Wright Laboratory (USAF) Feb 2, 1994. Attachments 7-8 are sample discharges from the batteries that were removed from the aircraft at the completion of the program. Analysis of all the supporting data has increased our confidence in the compatibility of this application (E-3 flight system) and the EPI/ELDEC HRMFB System. The batteries were able to comfortably provide 55 amp hours along with a high degree of battery and cell balance. This would attest to the compatibility of the charging system and the batteries. Visual examination of the HRMFB System components revealed no signs of usage, except for some paint missing from the bottom of the battery containers.

6.0 E-3 - High Reliability Maintenance Free Battery System/Flight Test Review

September 1992
System installed on E-3 (Tail #1607)

February 1993
1st data download-discover system error, system corrected, new batteries installed

June 1993
2nd data download-no problems, over 900 pages of system historical data produced

Sept 1993
1 year Flight Test Successfully completed....
System removed.

7.0 Conclusions

The flight test program successfully accomplished its objective of defining a power system that would be capable of supplying (Maintenance Free) "all" of the real life demands necessary for the normal operation of the E-3B/C flight system. The ELDEC/Eagle Picher Ind. High Reliability Maintenance Free Battery System was designed for applications such as the E-3 where a Long Term - No Maintenance battery system would increase mission confidence along with the added benefit of lowering maintenance cost. As stated previously, at times the battery will be expected to deliver up to 95% of its rated capacity, but on a normal basis the DOD is only 15% of rated battery capacity. Thus, we believe that through the successful teamwork exhibited by ELDEC Corp, Eagle Picher Ind and the U S Air Force, we were able to provide the most optimum system for this application. The chargers ability to sense data, store data, then retrieve data has proven invaluable to documenting the actual system usage. This information has increased the confidence of everyone involved that the ELDEC/EPI "High Reliability Maintenance Free Battery" System is a proven answer to the Air Force needs for this application and probably should be already on board. The other flight tests (a similar HRMFB system flew for a year on the B52) associated with this program were able to help ELDEC and Eagle Picher refine their knowledge of the HRMFB System to where we feel that this flight test was provided with an optimized battery charger and support system. It should be pointed out again that this is inclusive of scheduled and unscheduled maintenance type operations. All three systems performed flawlessly

8.0 Acknowledgments

We would like to take this opportunity to offer our special thanks to all the individuals that provided the invaluable support to this flight test. Although there were too many to mention by name in this report, we would like to specifically mention Lt Chris Beverly (ALC/LAKRB) and Sgt Jeff Schradle (552ACW/MAQY) for being the "hands on" foundation for Air Force support to this program. We would also like to acknowledge the unit commanders for supplying the aircraft, along with an experience support crew, from engineers to hands on maintenance people, that made this part of the program a complete success.

Chronology

9/18/92
Air Combat Command
Temporary Modification Directive for E-3B/C HIGH RELIABILITY MAINTENANCE FREE BATTERY (HRMFB) SYSTEM
Modification left original charge equip and wiring on plane (only old batts to be removed)
2 systems referred to as Main Battery System and Emergency light System
replace 4 existing batteries
new charger weight 23lbs
charger requires mounting tray on E-1 Flight Essential Avionics rack in forward lower lobe
batts use existing batt equip, no mod to airframe or support structure
estimated Net weight change (lbs)

chargers and tray		57lbs+
batteries (4)		44lbs+
cabling		10lbs+
	total	111lbs+ this includes leaving old charging system on plane

SCD 204-13038 specification control drawing for original charger/battery systems

Battery passed mech. shock and vibration

Summary of items to be removed during mod
4ea batts NSN 6140-01-020-7288

Summary of items to be added during mod
4 ea batts EPI 18214
2 chargers ELDEC 4-521-02
1 mounting tray ELDEC TBD
cables (2ea) ELDEC TBD
2 adapter plates ELDEC TBD

9 month flight test - perform normal mission requirements
In addition an aircraft refuel under batt power required (altematives procedure T.O. 1E-3A-2-7) to simulate bare base operations (from normal loading load to 120,000lbs

Test considered successful if aircraft completes 9 month test period w/o requiring maintenance actions on HRMFB system

Maintenance currently 90 days for cell equalization and replacement
Significant cost savings potential

9/30/92
Install system on tail #1607
left spare set of batt and 1 extra charger at Tinker
3-6 month original flight test - contract extended for 9 month flight test
only problems with aircraft mod was 2 broken circuit breakers
recommended algorithm review
Batt s/n 3a + b emergency light system charger s/n 003
4a +b main aircraft system 004
2a +b left in battery shop
Battery part # EPI 18214
Charger part # 4-521-02

10/30/92
EPI does follow-up trip to visually inspect system - no problems

2/4/92

data download perform. system (on board) verification took place for emer batts, cannot do main batts, perform as expected

2/8/93 - ELDEC discovers charger error
2/11/93 SYSTEM swapped Batt sn 6a,b emer light charger 004
5a,b main 003
2a,b left in batt shop
batt sets 3 and 4 returned to EP, batteries gave over 55 ah (approx 50 off plane) on 1st charge

3/1/93
No system anomalies reported thru 2/1/93
Download 2/4/93 - data review shows charger error, is using B52 flight test ware, wrong temp sensor resistor

Battery currently goes thru 90 day inspection for equalization and replacement replace with maintenance period of 1 to 4 years (AF Form 1067)

Current battery NSN 6140-01-020-7288
charger 6139-01-027-0261

6/24/93
ELDEC ltr

6/18/93-data download from Emer system at Tinker, charger remained on plane. main system replaced w/flight test back-up. download performed at ELDEC/downloaded

batt sn 6a+b emer lights charger sn 004
5a+b main fwd 005 replaces 003

6/23/93

4 trips
10 30/92 -visual
2/4/93 download
2/11/93 system swap
6/18/93- download over 900 pages generated from download
initial analysis;
1- batts being maintained fully charged
2 - systems functioning as designed
2 - recharge cycles appear normal
4 - charges behave normal
5 - reasonable batt temps recorded
6 - cell volt balance reasonable
final report due approx 8/93 from download

8/24/93
ELDEC fax
Demod to be 9/8/93 w/o EPI
EP to bring batts back to EP for final capacity

ADVANCED BATTERY SYSTEM (6.2 PROGRAM)
FLIGHT TEST ACTIVITIES

- E-3 Flight Test
  - Test Period — September 1992 to September 1993
  - 2 Battery Systems — 1 Main & Auxiliary
  - Capacity Requirements — 55 Amp-hrs
  - Discharge Rates
    - Normal Rate — 10 - 25 Amps
    - Maximum Rate — 60 Amps
    - Typical Discharge — 15 - 20 Amp-hr
  - Both Batteries Used for Maintenance Operations

ADVANCED BATTERY SYSTEM (6.2 PROGRAM)
FLIGHT TEST ACTIVITIES

- E-3 (AWACS) Flight Test
  - September 1992 through September 1993
    - 1100 Flight Hours Per Year
    - 3200 Operational Hours Per Year
  - System Considerations
    - Battery Overcharge Anomoly
    - Battery System Usage Data

ADVANCED BATTERY SYSTEM (6.2 PROGRAM)
FLIGHT TEST ACTIVITIES

E-3 USAGE SUMMARY

DOWLOAD DATE	SYSTEM	FLIGHT HOURS	CHARGER OPERATIONAL HOURS	OPERATIONAL HOURS/FLIGHT HOURS RATIO	AMP-HOURS REMOVED
2/4/93	MAIN	85.6	237	2.8	115
	EMERGENCY	85.6	156	1.8	93
6/18/93	MAIN	103.7	290	2.8	117
	EMERGENCY	103.7	231	2.2	130
9/8/93	MAIN	83.9	270	3.2	126
	EMERGENCY	83.9	164	1.9	179
PROJECTED OPERATION	MAIN	1100	3188	2.9	1432
12 MONTH PERIOD	EMERGENCY	1100	2204	2.0	1608

ELDEC

EAGLE PICHER

E-3 DEPTH OF DISCHARGE ANALYSIS

11-SORTIES, 85.6 FLIGHT HOURS

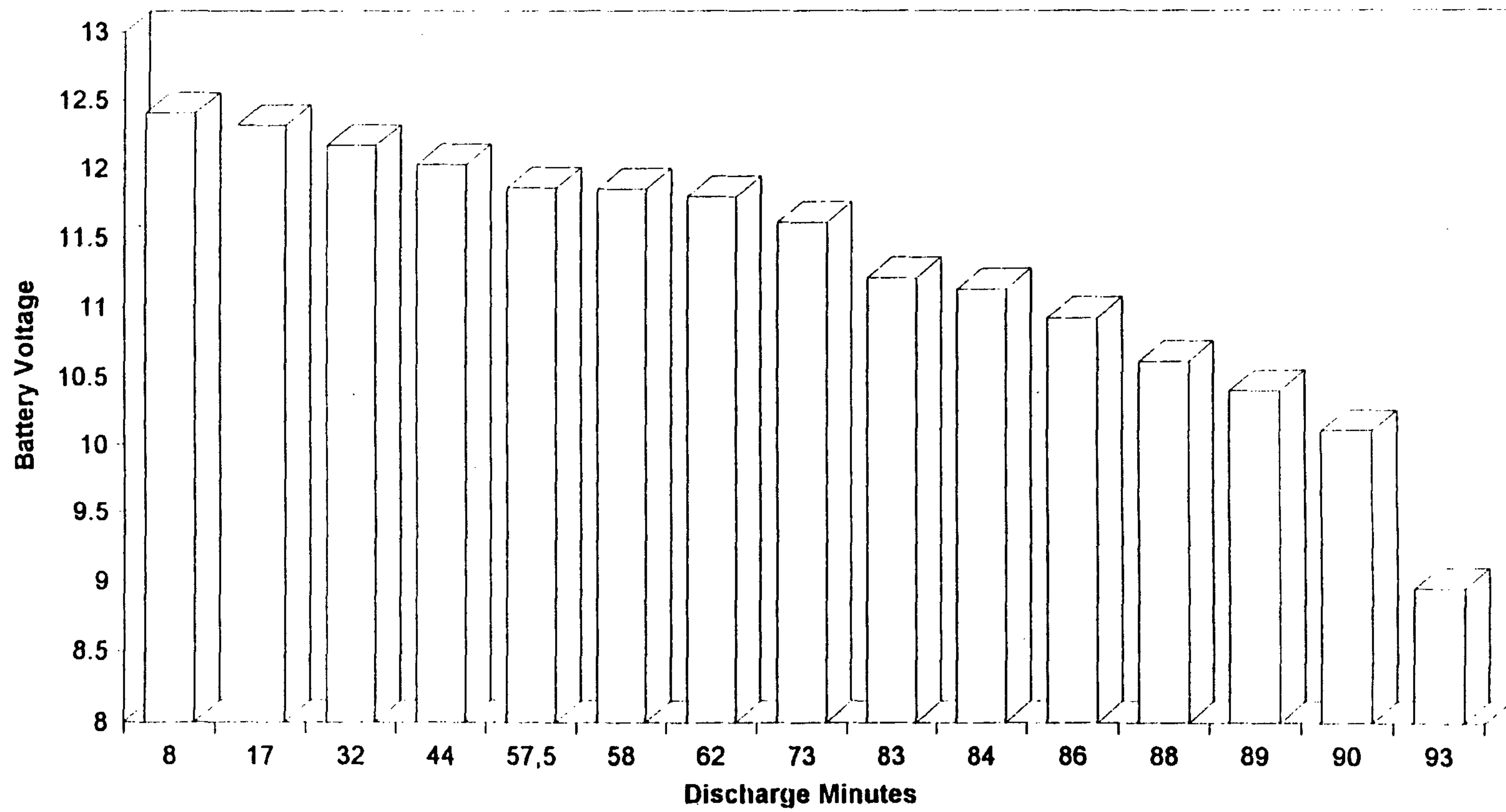
DATE	SYSTEM	CHARGE/ DISCHARGE CYCLES	MINIMUM DOD	MAXIMUM DOD	AVERAGE DOD
Jan-93	MAIN	15	5%	45%	13%
	EMERGENCY	18	7%	45%	15%

DATE	SORTIES	FLT HRS	SYSTEM	CHARGE/DISCHARGE CYCLES	MAXIMUM DOD	AVERAGE DOD	NOTES
Jan-93	11	85.6	MAIN	15	46%	13%	Maintenance Performed on Aicrcraft this period
			EMERGENCY	21	95%	16%	
May-93	13	103.7	MAIN	17	36%	11%	
			EMERGENCY	19	35%	12%	
Aug-93	11	83.9	MAIN	16	20%	13%	Maintenance Performed on Aicrcraft this period
			EMERGENCY	19	44%	16%	
Projected Operation	140	1100	MAIN	192		12%	
12 Month Period			EMERGENCY	236		15%	

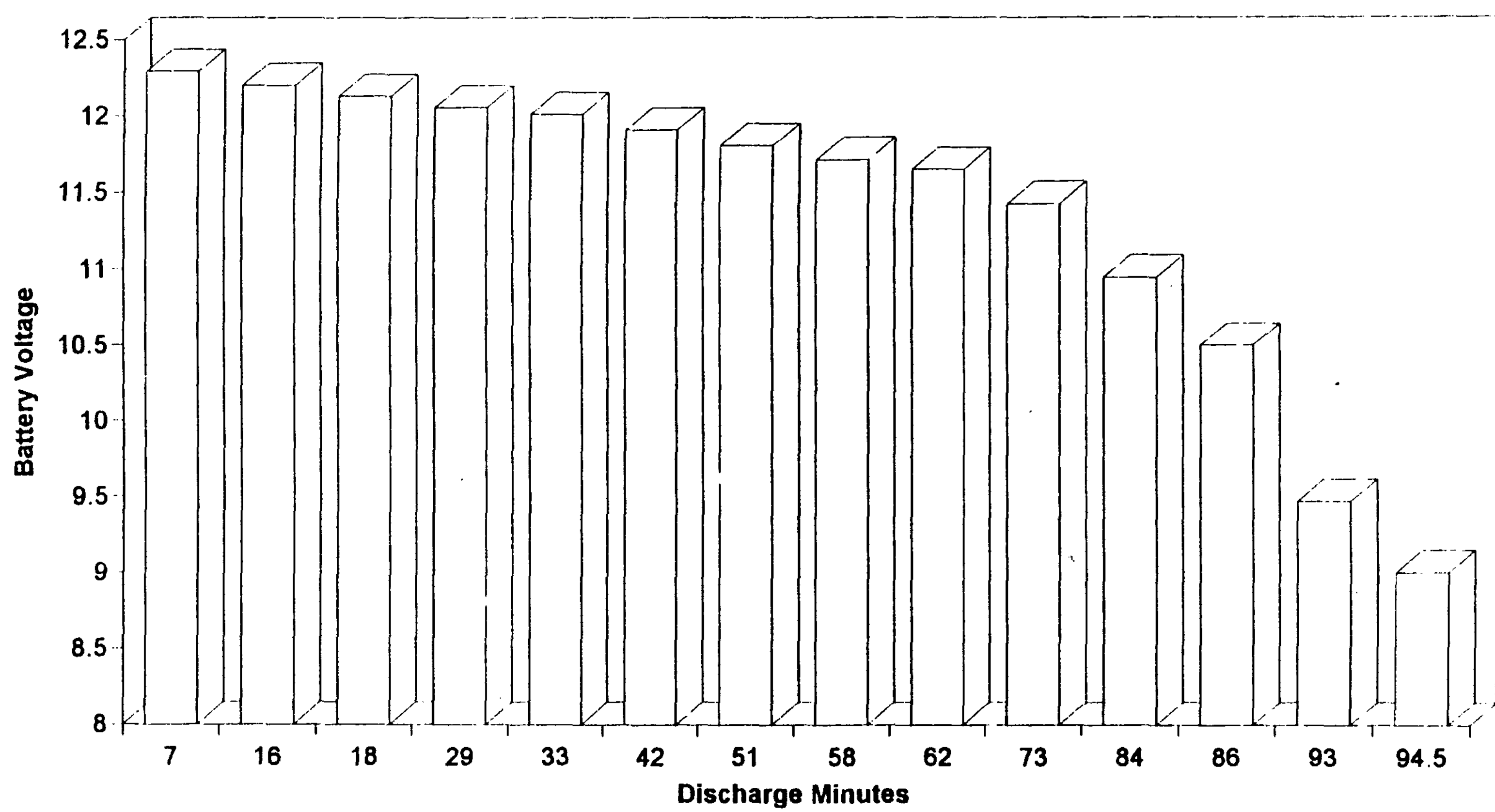
ADVANCED BATTERY SYSTEM (6.2 PROGRAM)
FLIGHT TEST ACTIVITIES

- E-3 (AWACS) Flight Test Results
  - Maintenance Free Operation
    - Battery Maintenance Not Required During Test Program
  - Results
    - Successful Completion of Test Program
    - Determined Battery Safety Margin
    - Capacity Checks on Batteries in Excess of 55 Amp-hrs

40 Amp Discharge EPI 18214 (s/n 006A)



40 Amp discharge EPI 18214 (s/n 005A)



TEST REPORT

From: G.R. Burns

To: Za Johnson, EPI
Tim Edgar, EPI
Lee Dahle, EPI
Richard Flake, WL/POOS-2
Gordon Allen, ELDEC Corporation
Jeff Dees, WR-ALC/LUFHT
CMSGT Barry Wilkins, SMOTEC/FW

Date: 26 May 1992

Subject: Flight test of Nickel-Cadmium battery on AC-130H 20MM Gun System.

Background

Because the previous flight test had not been successful due to the failure of the SMOTEC instrument pallet Loral SSA-100A computer, it was decided to again flight test EPI batteries. However, since some manual data had been taken that indicated that a battery of less capacity and therefore less weight and volume might be acceptable, it was decided to test both a 40 ampere hour and a 24 ampere hour high rate batteries.

Test Plan

a. Flight of 4 May 1992

Battery 1 (24 AH nickel-cadmium)/Gun 1 - 1500 rounds
Battery 2 (40 AH nickel-cadmium)/gun 2 - 1500 rounds

b. Flight of 5 May 1992

Battery 1 (40 AH nickel-cadmium)/Gun 1 - 1500 rounds
Battery 2 (24 AH nickel-cadmium)/Gun 2 - 1500 rounds

c. Flight of 6 May 1992

Backup if either of previous flights were cancelled or test failed.

d. Test data to be accumulated by Loral SSA-100A computer.

Test Results

Data was taken during the flights at approximately 1 millisecond intervals. However, it was found that the voltage and current response was such that eight consecutive data points were the same in each case. The data was further reduced to eliminate this redundancy. Summaries of the gun fire events for 4 and 5 May are enclosed as Attachments A and B.

The attached figures depict the current and battery voltage during gun bursts. All figures are annotated with the flight date, the gun number and battery type and number of that burst. A summary of the available data from each flight is also included. Current and voltage readings fluctuated widely during each firing as shown on the graphs. This may be a result of the high data sample rate when used with a DC electric motor.

The most complete data is from the flight of 4 May during which Gun 1 was fired with the EPI 24 AH battery and Gun 2 was fired using the EPI 40 ampere hour battery. Each gun was fired for a total of approximately 30 seconds. Gun 2 was fired for 21 bursts of durations from 0.807 to 2.572 seconds. Gun 1 was fired for 10 bursts of durations of 0.830 to 8.062 seconds. However, the current readings for each gun/battery combination differed greatly. Gun two current draw was recorded with peaks of less than 200 amperes and average currents of approximately 100 amperes. Gun one current draw was recorded with peak current in excess of 600 amperes and an average current of greater than 200 amperes. 1.3612 ampere hours were removed from battery 2 and 1.5518 ampere hours were removed from battery 1.

On 5 May, The EPI 40 ampere hour battery was assigned to Gun 1 and the 24 ampere hour battery assigned to Gun 2. This data indicates that the actual firing time for Gun 1 for 1500 rounds was 22.121 seconds in 15 bursts. There are two very short bursts included in this data, one burst of which may be a dry fire event. A very short burst was fired to clear the final two rounds from the gun. The longest burst was of 3.451 seconds duration with the shortest normal event being 0.528 seconds.

Peak current was measured at 767 amperes with the voltage depressed to 15.10 volts during these events. Current draw was reduced to less than 350 amperes in less than 0.2 seconds and the voltage recovered to greater than 18 volts.

A total of 1.9858 ampere hours was removed from the battery during these firing events.

Because of a loose connection, Gun 2 could not be fired with battery 2. Therefore, battery 1 was connected to Gun 2 and firing was resumed with Gun 2. Data from these firings is not usable (see sample data enclosed as Attachment C). However, the gun operated normally during this time.

SUMMARY OF FIRING EVENTS

DATE	GUN	BATTERY	DURATION	TOTAL FIRING TIME	AMPERE HOURS REMOVED
4 MAY	2	40 AH	60:43.639	0:30.750	1.3612
4 MAY	1	24 AH	24:33.776	0:30.276	1.5518
5 MAY	1	40 AH	18:14.742	0:22.121	1.9858

Conclusions

a. A normal combat load of 20mm ammunition is 1500 rounds per gun. However, this may be increased due to mission requirements.

b. Maximum capacity removed to fire 1500 rounds is approximately 2 ampere hours.

c. Maximum firing duration for 1500 rounds is approximately 30 seconds with a 24 volt nickel cadmium battery.

d. Gun fire rate is a function of battery voltage. The higher voltage can be maintained during firing, the better the gun fires.

e. Gun performance varies widely.

f. A single battery must be capable of firing both guns during a mission.

g. The on-board charging system is on-line whenever the gun is not being fired.

h. A 20 ampere charger would restore capacity removed from firing 1500 rounds in approximately 6 minutes.

i. Performance of the guns was virtually the same with both the EPI 24 ampere hour battery and the EPI 40 ampere hour battery.

j. The EPI 24 ampere hour low impedance nickel-cadmium battery meets the mission requirements of the AC-130 20mm guns at an approximate weight saving of 27 pounds per battery (54 pounds per ship set).

k. EPI recommends that a sealed, maintenance free, 24 ampere hour nickel-cadmium battery be used with the AC-130 20mm guns.

ATTACHMENT A

AC-130 20mm GUN FIRE TEST
HURLBURT FIELD, FL

4 MAY 1992 (GMT)

		TIME						DURATION	AMPERE	ROUNDS FIRED
		START			END				HOURS	(@ 49
GUN	BURST	HR	MIN	SEC	HR	MIN	SEC	(SECONDS)	REMOVED	rounds/sec)
2	1	3	26	17.207	3	26	18.014	0.807	0.8070	40
2	2	3	27	2.696	3	27	3.847	1.151	0.1590	56
2	3	3	28	1.749	3	28	2.916	1.167	0.0168	57
2	4	3	29	49.059	3	29	50.635	1.576	0.0198	77
2	5	3	30	36.263	3	30	37.980	1.717	0.0251	84
2	6	3	31	51.275	3	31	53.188	1.913	0.0234	94
2	7	3	49	52.011	3	49	54.342	2.331	0.0305	114
2	8	3	50	50.535	3	50	51.569	1.034	0.0138	51
2	9	3	51	41.519	3	51	42.899	1.380	0.0199	68
2	10	3	52	13.684	3	52	14.723	1.039	0.0159	51
2	11	3	53	10.090	3	53	10.906	0.816	0.0134	40
2	12	3	53	56.258	3	53	58.023	1.765	0.0246	86
2	13	3	54	33.076	3	54	35.648	2.572	0.0334	126
2	14	3	56	9.061	3	56	11.242	2.181	0.0279	107
2	15	3	58	57.716	3	58	59.293	1.577	0.0215	77
2	16	4	6	29.521	4	6	31.398	1.877	0.0250	92
2	17	4	14	2.022	4	14	3.343	1.321	0.0183	65
2	18	4	22	40.719	4	22	41.671	0.952	0.0149	47
2	19	4	24	57.025	4	24	57.989	1.004	0.0147	49
2	20	4	25	38.078	4	25	39.511	1.423	0.0206	70
2	21	4	26	52.699	4	26	53.846	1.147	0.0157	56
								30.750	1.3612	1507
1	1	4	43	15.960	4	43	16.790	0.830	0.0491	41
1	2	4	43	47.455	4	43	48.511	1.056	0.0250	52
1	3	4	44	28.853	4	44	29.888	1.035	0.0610	51
1	4	4	45	15.020	4	45	15.873	0.853	0.0494	42
1	5	4	45	40.355	4	45	44.277	3.922	0.2840	192
1	6	4	46	56.102	4	47	2.643	6.471	0.2859	317
1	7	4	48	16.266	4	48	24.328	8.062	0.3771	395
1	8	4	49	23.351	4	49	24.269	0.918	0.1105	45
1	9	4	53	52.463	4	53	53.294	0.831	0.0442	41
1	10	5	7	43.338	5	7	49.636	6.298	0.2656	309
								30.276	1.5518	1484

FILE: ACM04SUM

ATTACHMENT B

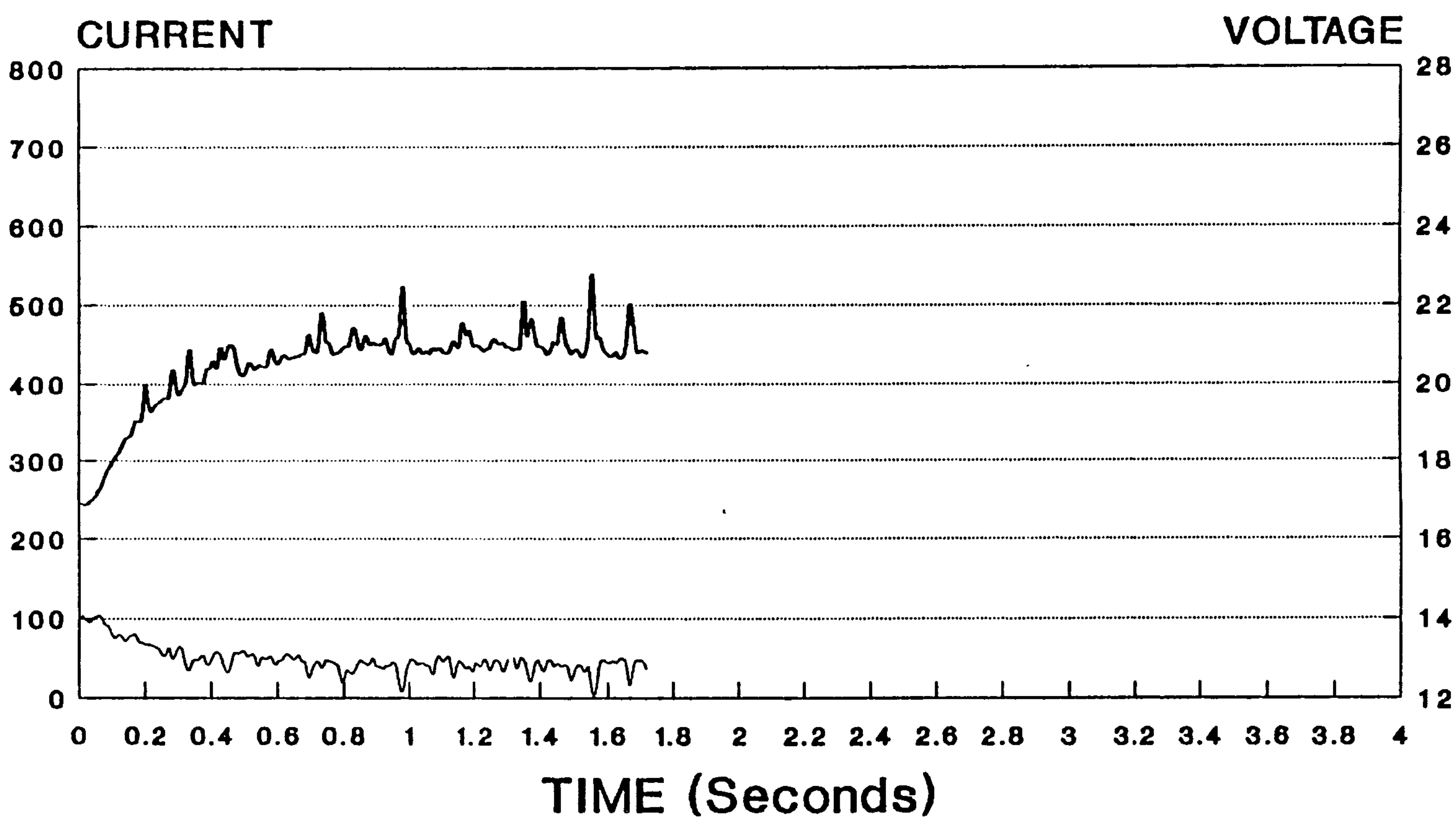
AC-130 20mm GUN FIRE TEST
HURLBURT FIELD, FL

5 MAY 1992 (GMT)

GUN	BURST	START HR	START MIN	START SEC	END HR	END MIN	END SEC	DURATION (SECONDS)	AMPERE HOURS REMOVED	ROUNDS FIRED (@ 68 rounds/sec)
1	1	2	13	13.366	2	13	14.269	0.903	0.0953	61
1	2	2	14	2.066	2	14	3.077	1.011	0.1028	69
1	3	2	14	51.921	2	14	52.889	0.968	0.0942	66
1	4	2	23	54.515	2	23	55.669	1.154	0.1107	78
1	5	2	24	26.677	2	24	27.847	1.170	0.1083	80
1	6	2	25	13.318	2	25	16.769	3.451	0.3123	235
1	7	2	25	37.502	2	25	39.898	2.396	0.2112	163
1	8	2	25	56.754	2	25	58.668	1.914	0.1731	130
1	9	2	27	45.419	2	27	45.947	0.528	0.0383	36
1	10	2	29	50.322	2	29	51.504	1.182	0.1068	80
1	11	2	30	4.289	2	30	6.696	2.407	0.2096	164
1	12	2	30	19.362	2	30	22.356	2.994	0.2640	204
1	13	2	30	31.986	2	30	33.956	1.970	0.1563	134
1	14	2	31	1.854	2	31	1.886	0.032	0.0013	2
1	15	2	31	28.067	2	31	28.108	0.041	0.0016	3
								22.121	1.9858	1504.23

NOTE: DATA FOLLOWING THIS POINT IS NOT USABLE.

AC-130 BATTERY PROGRAM
20mm GUN FIRE TEST
BURST 4 - 4 MAY 92

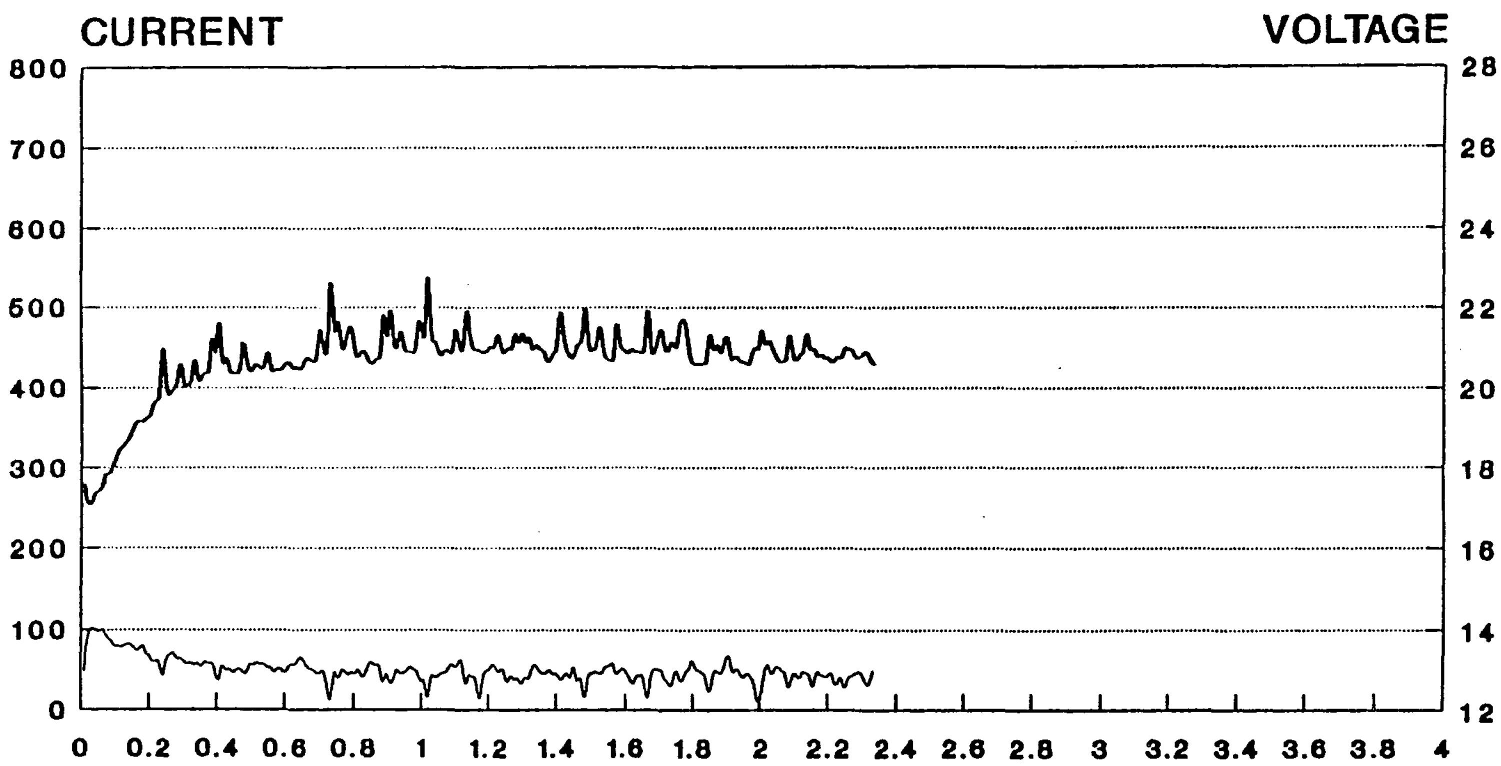


40 AH/24 VOLT BATTERY
BATTERY 2/GUN 2

C9205024

EAGLE PICHER

AC-130 BATTERY PROGRAM
20mm GUN FIRE TEST
BURST 7 - 4 MAY 92

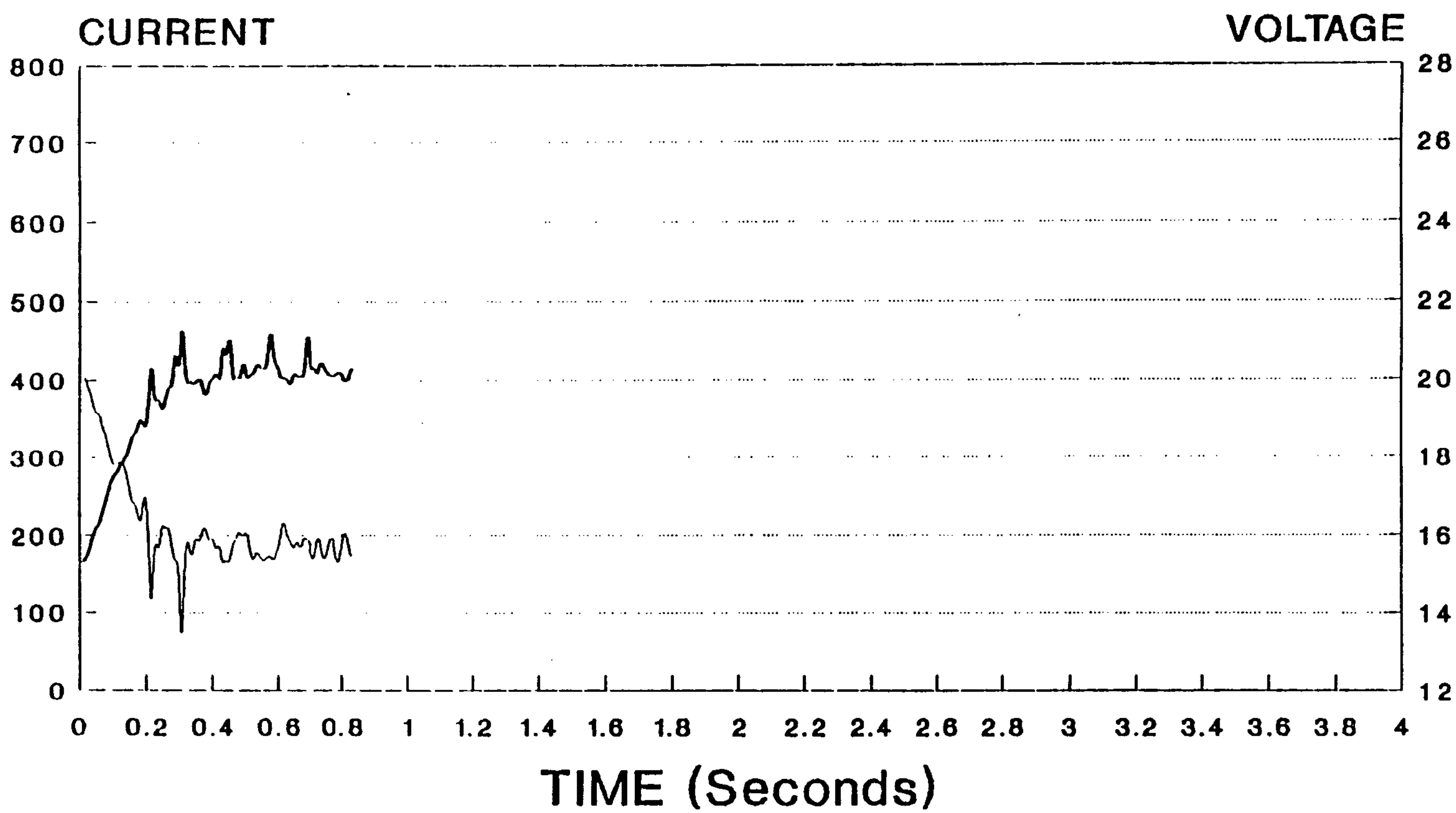


40 AH/24 VOLT BATTERY
BATTERY 2/GUN 2

C9205027

EAGLE Ep PICHER

AC-130 BATTERY PROGRAM
20mm GUN FIRE TEST
BURST 22 - 4 MAY 92

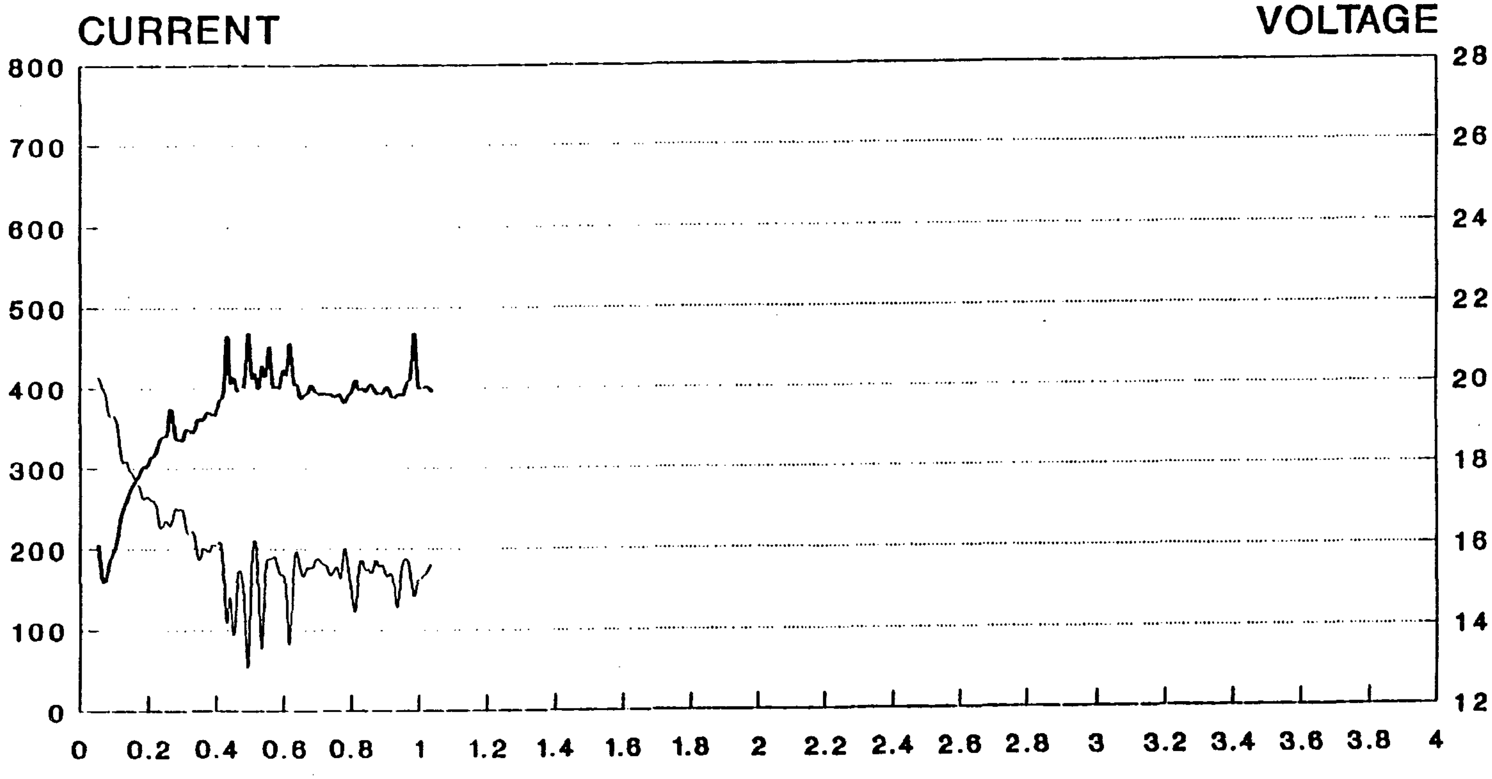


24 AH/24 VOLT BATTERY
BATTERY 1/GUN 1

C9206042

EAGLE PICHER

AC-130 BATTERY PROGRAM
20mm GUN FIRE TEST
BURST 24 - 4 MAY 92



24 AH/24 VOLT BATTERY
BATTERY 1/GUN 1

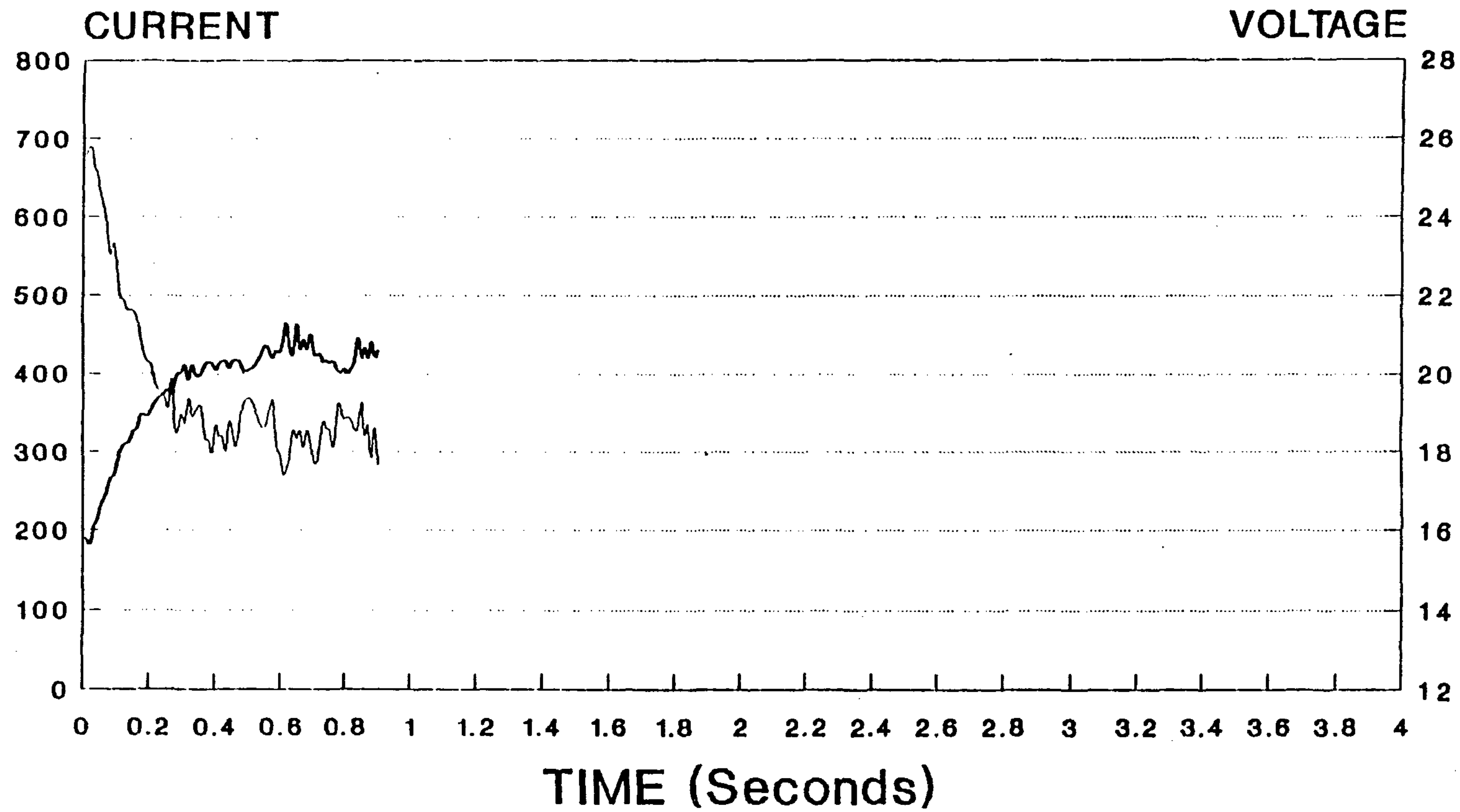
C9205044

EAGLE PICHER

AC-130 BATTERY PROGRAM

20mm GUN FIRE TEST

BURST 1 - 5 MAY 92

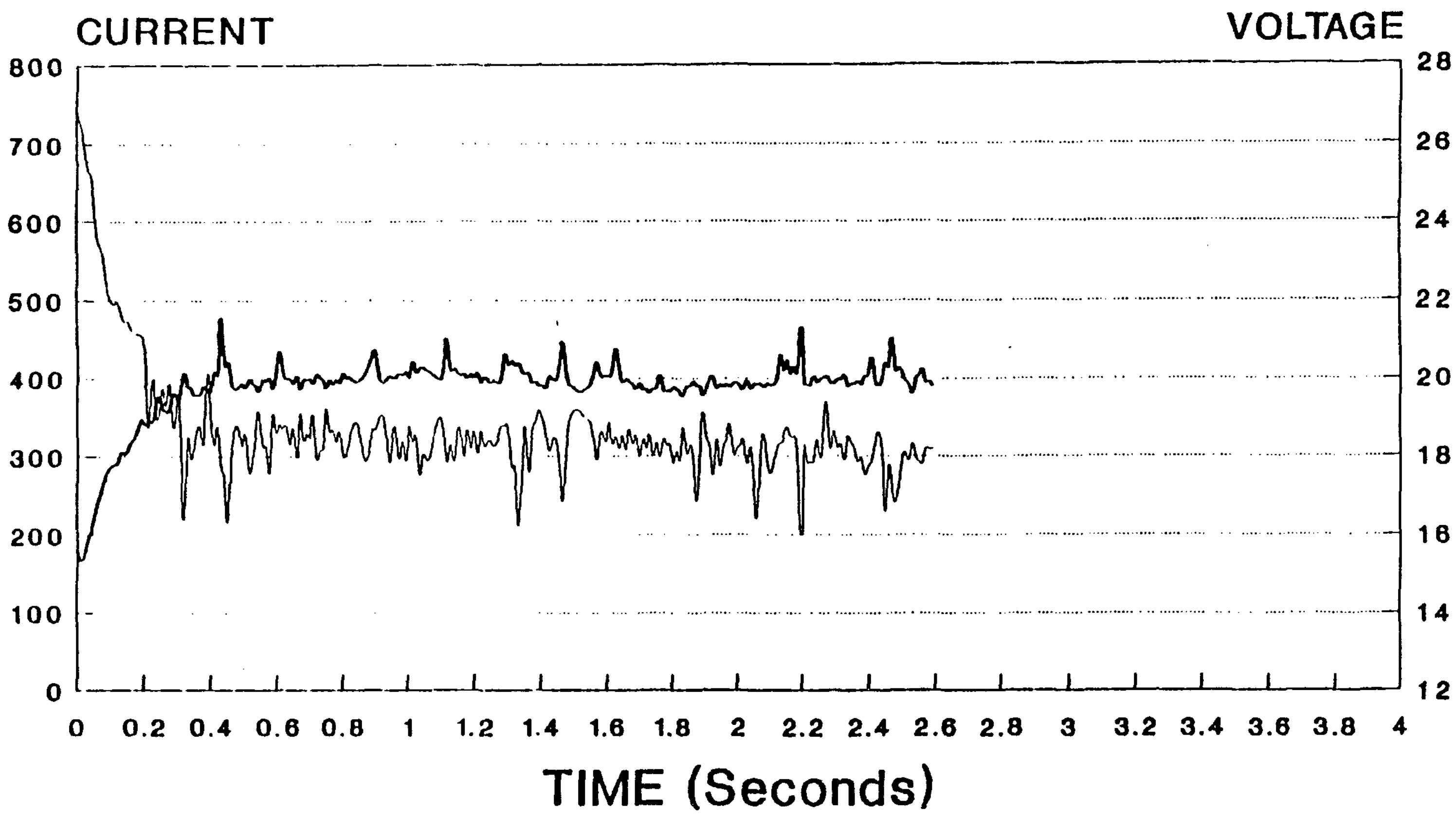


40 AH/24 VOLT BATTERY
BATTERY 1/GUN 1

C9205001

EAGLE PICHER

AC-130 BATTERY PROGRAM
20mm GUN FIRE TEST
BURST 6 - 5 MAY 92



40 AH/24 VOLT BATTERY
BATTERY 1/GUN 1

C9205006

EAGLE PICHER

ATTACHMENT C

AC-130 GUN TEST
5 MAY 1992 (GMT)

BATTERY 1 = 40
BATTERY 2 = 24

HR	TIME MIN	SEC	GUN 1: BATT 1 CURRENT	VOLTS	AMP HOURS	GUN 2: BATT 2 CURRENT	VOLTS	AMP HOURS	TIME PER BURST
2	43	8.354	0	26.70					0
2	43	8.356	103	26.20	0.0001	103	26.90	0.0000	0.002
2	43	8.368	129	26.20	0.0004	129	26.90	0.0000	0.014
2	43	8.378	193	26.30	0.0005	193	26.90	0.0000	0.024
2	43	8.388	449	26.50	0.0012	449	26.80	0.0000	0.034
2	43	8.398	583	26.70	0.0016	583	26.80	0.0000	0.044
2	43	8.409	532	26.70	0.0016	532	26.80	0.0000	0.055
2	43	8.419	171	18.40	0.0005	171	26.90	0.0000	0.065
2	43	8.429	159	18.50	0.0004	159	26.90	0.0000	0.075
2	43	8.439	154	18.70	0.0004	154	26.90	0.0000	0.085
2	43	8.451	176	17.60	0.0006	0	27.20	0.0000	0.097
					0.0073			0.0000	

ACTUAL GUN 2 DATA WITH BATTERY 1

HR	TIME MIN	SEC	GUN 1: BATT 1 CURRENT	VOLTS	AMP HOURS	GUN 2: BATT 2 CURRENT	VOLTS	AMP HOURS	TIME PER BURST
2	43	28.609	0	26.30	0.0000	0	26.90	0.0000	0.000
2	43	28.612	120	17.10	0.0001	0	27.10	0.0000	0.003
2	43	28.621	125	17.00	0.0003	0	27.10	0.0000	0.012
2	43	28.631	122	17.10	0.0003	0	27.10	0.0000	0.022
2	43	28.642	93	17.50	0.0003	0	27.10	0.0000	0.033
2	43	28.652	222	17.00	0.0006	0	27.20	0.0000	0.043
2	43	28.662	190	17.30	0.0005	0	27.20	0.0000	0.053
2	43	28.672	198	17.30	0.0006	0	27.20	0.0000	0.063
2	43	28.682	176	17.60	0.0005	0	27.20	0.0000	0.073
2	43	28.693	181	17.70	0.0006	0	27.20	0.0000	0.084
2	43	28.703	168	17.80	0.0005	0	27.20	0.0000	0.094
2	43	28.713	127	18.70	0.0004	0	27.10	0.0000	0.104
2	43	28.723	156	18.10	0.0004	0	27.10	0.0000	0.114
2	43	28.734	151	18.30	0.0005	0	27.10	0.0000	0.125
2	43	28.744	142	18.40	0.0004	0	27.10	0.0000	0.135
2	43	28.754	81	21.10	0.0002	0	27.00	0.0000	0.145
2	43	28.764	134	18.50	0.0004	0	27.10	0.0000	0.155
2	43	28.775	120	18.70	0.0004	0	27.10	0.0000	0.166
2	43	28.786	154	18.60	0.0005	0	27.10	0.0000	0.177
2	43	28.795	129	19.00	0.0003	0	27.10	0.0000	0.186
2	43	28.805	132	18.80	0.0004	0	27.10	0.0000	0.196
2	43	28.816	110	19.20	0.0003	0	27.10	0.0000	0.207
2	43	28.826	120	19.30	0.0003	0	27.10	0.0000	0.217
2	43	28.836	112	19.10	0.0003	0	27.10	0.0000	0.227
2	43	28.847	83	19.40	0.0003	0	27.10	0.0000	0.238
2	43	28.856	110	19.40	0.0003	0	27.10	0.0000	0.247
2	43	28.867	120	19.30	0.0004	0	27.10	0.0000	0.258
2	43	28.877	107	20.00	0.0003	0	27.10	0.0000	0.268
2	43	28.887	93	19.60	0.0003	0	27.10	0.0000	0.278
2	43	28.897	85	19.70	0.0002	0	27.10	0.0000	0.288

ATTACHMENT C (continued)

ACTUAL GUN 2 DATA WITH BATTERY 1

2	44	19.653	0	26.00	0.0000	0	27.00	0.0000	0.000
2	44	19.654	0	26.00	0.0000	100	26.90	0.0000	0.001
2	44	19.674	0	26.10	0.0000	212	26.90	0.0012	0.021
2	44	19.686	0	26.40	0.0000	496	26.80	0.0017	0.033
2	44	19.695	0	26.50	0.0000	574	26.80	0.0014	0.042
2	44	19.705	0	26.50	0.0000	586	26.80	0.0016	0.052
2	44	19.716	0	18.20	0.0000	430	26.80	0.0013	0.063
2	44	19.725	0	17.80	0.0000	359	26.80	0.0009	0.072
2	44	19.736	0	17.60	0.0000	251	26.80	0.0008	0.083
2	44	19.746	0	17.00	0.0000	0	27.00	0.0000	0.093
2	44	19.756	149	16.40	0.0004	0	27.10	0.0000	0.103
2	44	19.766	61	16.60	0.0002	0	27.00	0.0000	0.113
2	44	19.777	68	16.50	0.0002	0	27.10	0.0000	0.124
2	44	19.787	76	16.50	0.0002	0	27.10	0.0000	0.134
2	44	19.797	68	16.50	0.0002	0	27.00	0.0000	0.144
2	44	19.808	76	16.50	0.0002	0	27.10	0.0000	0.155
2	44	19.818	59	16.50	0.0002	0	27.00	0.0000	0.165
2	44	19.828	51	16.50	0.0001	0	27.00	0.0000	0.175
2	44	19.839	59	16.50	0.0002	0	27.00	0.0000	0.186
2	44	19.848	73	16.50	0.0002	0	27.10	0.0000	0.195
2	44	19.859	125	16.20	0.0004	0	27.10	0.0000	0.206
2	44	19.870	134	16.20	0.0004	0	27.10	0.0000	0.217
2	44	19.879	66	16.50	0.0002	0	27.00	0.0000	0.226
2	44	19.889	39	16.50	0.0001	0	27.00	0.0000	0.236
2	44	19.900	54	16.50	0.0002	0	27.00	0.0000	0.247
2	44	19.910	34	16.60	0.0001	0	27.00	0.0000	0.257
2	44	19.920	29	16.60	0.0001	0	27.00	0.0000	0.267
2	44	19.930	56	16.50	0.0002	0	27.00	0.0000	0.277
2	44	19.941	56	16.50	0.0002	0	27.00	0.0000	0.288
2	44	19.951	54	16.40	0.0002	0	27.00	0.0000	0.298
2	44	19.961	27	16.50	0.0001	0	27.00	0.0000	0.308
2	44	19.971	103	16.20	0.0003	0	27.10	0.0000	0.318
2	44	19.981	129	16.20	0.0004	0	27.10	0.0000	0.328
2	44	19.992	42	16.50	0.0001	0	27.00	0.0000	0.339
2	44	20.002	15	16.50	0.0000	0	27.00	0.0000	0.349
2	44	20.012	34	16.50	0.0001	0	27.00	0.0000	0.359
2	44	20.022	32	16.50	0.0001	0	27.00	0.0000	0.369
2	44	20.033	15	16.50	0.0000	0	27.00	0.0000	0.380
2	44	20.044	29	16.50	0.0001	0	27.00	0.0000	0.391
2	44	20.053	42	16.40	0.0001	0	27.00	0.0000	0.400
2	44	20.063	44	16.40	0.0001	0	27.00	0.0000	0.410
2	44	20.075	54	16.40	0.0002	0	27.00	0.0000	0.422
2	44	20.084	90	16.20	0.0002	0	27.10	0.0000	0.431
2	44	20.094	134	16.10	0.0004	0	27.10	0.0000	0.441
2	44	20.105	61	16.30	0.0002	0	27.00	0.0000	0.452
2	44	20.115	32	16.40	0.0001	0	27.00	0.0000	0.462
2	44	20.125	10	16.50	0.0000	0	27.00	0.0000	0.472
2	44	20.136	12	16.40	0.0000	0	27.00	0.0000	0.483
2	44	20.145	44	16.30	0.0001	0	27.00	0.0000	0.492
2	44	20.156	39	16.30	0.0001	0	27.00	0.0000	0.503
2	44	20.167	39	16.30	0.0001	0	27.00	0.0000	0.514
2	44	20.176	32	16.30	0.0001	0	27.00	0.0000	0.523

I EXPECTED ALL DATA TO LOOK LIKE THIS,

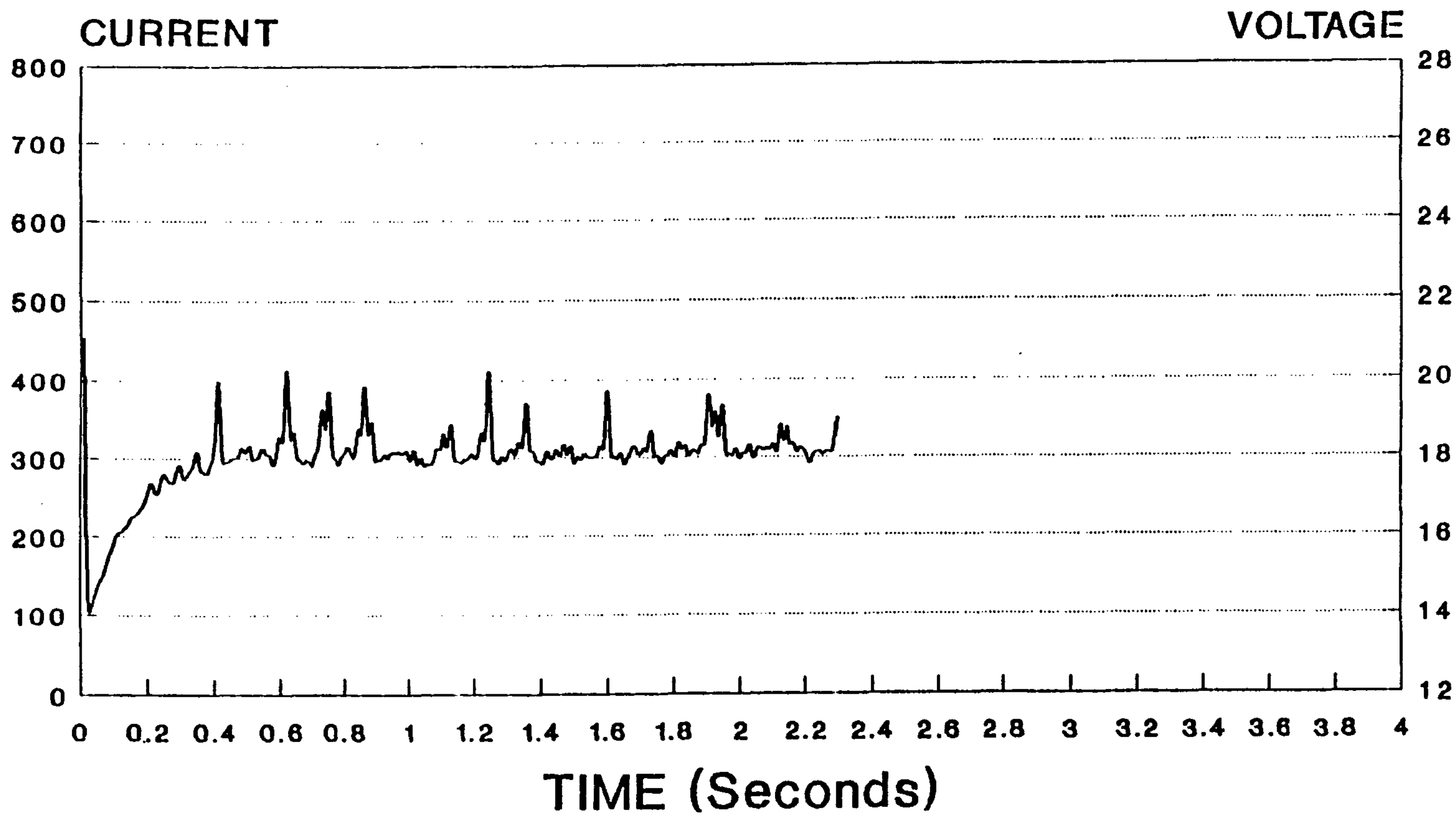
ATTACHMENT D

AC-130 GUN TEST
5 MAY 1992 (GMT)

BATTERY 1 = 40 AH
BATTERY 2 = 24 AH

TIME HR	TIME MIN	TIME SEC	GUN 1: BATT 1 CURRENT	GUN 1: BATT 1 VOLTS	AMP HOURS	GUN 1: BATT 1 CURRENT	GUN 1: BATT 1 VOLTS	AMP HOURS	TIME PER BURST
2	13	13.366	0	27.20	0.0000	0	26.90		0.000
2	13	13.377	679	15.80	0.0021	0	27.60		0.011
2	13	13.387	696	15.50	0.0019	0	27.70		0.021
2	13	13.397	684	15.80	0.0019	0	27.60		0.031
2	13	13.398	662	16.10	0.0002	0	27.60		0.032
2	13	13.410	659	16.20	0.0022	0	27.60		0.044
2	13	13.419	627	16.60	0.0016	0	27.60		0.053
2	13	13.439	605	16.90	0.0034	0	27.50		0.073
2	13	13.450	530	17.40	0.0016	0	27.50		0.084
2	13	13.460	588	17.30	0.0016	0	27.50		0.094
2	13	13.471	522	17.80	0.0016	0	27.50		0.105
2	13	13.480	491	18.00	0.0012	0	27.40		0.114
2	13	13.491	500	18.20	0.0015	0	27.40		0.125
2	13	13.501	479	18.20	0.0013	0	27.40		0.135
2	13	13.511	483	18.30	0.0013	0	27.40		0.145
2	13	13.521	481	18.60	0.0013	0	27.40		0.155
2	13	13.532	476	18.50	0.0015	0	27.40		0.166
2	13	13.542	439	19.10	0.0012	0	27.40		0.176
2	13	13.562	408	18.80	0.0023	0	27.30		0.196
2	13	13.573	420	19.10	0.0013	0	27.40		0.207
2	13	13.583	381	19.30	0.0011	0	27.30		0.217
2	13	13.614	374	19.50	0.0032	0	27.30		0.248
2	13	13.624	339	19.70	0.0009	0	27.30		0.258
2	13	13.634	422	19.30	0.0012	0	27.40		0.268
2	13	13.644	332	19.80	0.0009	0	27.30		0.278
2	13	13.645	332	19.80	0.0001	0	27.30		0.279
2	13	13.654	315	20.10	0.0008	0	27.00		0.288
2	13	13.665	364	19.90	0.0011	0	27.30		0.299
2	13	13.676	315	20.50	0.0010	0	27.30		0.310
2	13	13.685	391	19.50	0.0010	0	27.40		0.319
2	13	13.695	334	20.50	0.0009	0	27.30		0.329
2	13	13.706	354	19.80	0.0011	0	27.30		0.340
2	13	13.726	369	20.00	0.0021	0	27.30		0.360
2	13	13.737	303	20.30	0.0009	0	27.20		0.371
2	13	13.747	327	20.30	0.0009	0	27.30		0.381
2	13	13.757	278	20.30	0.0008	0	27.20		0.391
2	13	13.768	354	20.00	0.0011	0	27.30		0.402
2	13	13.777	310	20.30	0.0008	0	27.30		0.411
2	13	13.788	330	20.30	0.0010	0	27.30		0.422
2	13	13.798	283	20.40	0.0008	0	27.30		0.432
2	13	13.808	349	20.00	0.0010	0	27.30		0.442
2	13	13.818	332	20.40	0.0009	0	27.30		0.452
2	13	13.829	293	20.30	0.0009	0	27.30		0.463
2	13	13.839	334	20.40	0.0009	0	27.30		0.473

AC-130 BATTERY PROGRAM
20mm GUN FIRE TEST
BURST 4 - 6 MAY 92



40 AH/24 VOLT SEALED LEAD ACID BATTERY
BATTERY 2/GUN 2

C9206062

EAGLE PICHER