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Summary of LDEF Battery Analyses

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ABSTRACT

Tests and analyses of NiCd, $LiSO_2$ and LiCF batteries flown on the Long Duration Experiment Flight (LDEF) includes results from NASA, Aerospace and commercial labs. The $LiSO_2$ cells illustrate six-year degradation of internal components acceptable for space applications, with up to 85% battery capacity remaining on discharge of some returned cells. LiCF batteries completed their missions, but lost any remaining capacity due to internal degradation. Returned NiCd batteries tested at NASA-Goddard, showed slight case distortion due to pressure build up, but were functioning as designed.

INTRODUCTION AND BACKGROUND

Boeing in conjunction with LDEF Systems SIG has assisted in organizing the LDEF battery investigations on lithium sulfur dioxide (Li/SO_2), lithium carbon monofluoride (Li/CF) and nickel cadmium (NiCd) batteries. A summary of the batteries used on specific LDEF experiments are listed in Table 1. The quantity, type of battery and state of charge remaining for each experiment are tabulated to indicate the range of battery status upon return of LDEF. Sections following describe tests and analyses being performed on each battery type, thus the division of sections by type of battery.

ANALYSES ON LITHIUM SULFUR DIOXIDE BATTERIES

Four organizations are involved in studying the lithium sulfur dioxide batteries used on the majority of LDEF experiments: Aerospace Corporation, Jet Propulsion Laboratory, Naval Test Laboratories, and SAFT America (Manufacturer of the batteries). The primary objective of the study is to identify degradation modes of the batteries, and to provide information useful to future missions. This study is still underway, with only preliminary results thus far reported. All LDEF lithium sulfur dioxide batteries performed satisfactorily for the experiments they were designed. Interest in the ability of these batteries to maintain charge retention has prompted testing to understand the benefits and limitations of maintaining charge in lithium sulfur dioxide batteries for space applications.

Table 1. Summary of Battery Type, Quantity and State of Charge.

Exp #	Experiment Name	Battery	Voltage	# of Batteries	SOC
A 0038	Pyro Cable Cutter	Li/SO2	12	7	0%
A 0054	Space Plasma - High Voltage	Li/SO2	28	4	39%
A 0076	Variable Conduction Heat Pipes	Li/SO2	7.5	1	0%
A 0076	Variable Conduction Heat Pipes	Li/SO2	28	1	84%
A 0133	Space Based Radar	Li/SO2	7.5	3	25%
A 0133	Phased Array Antenna	Li/SO2	12	2	60%
A 0138-8	Epoxy Composite Materials	Li/SO2	7.5	3	75%
A 0138-8	Frecopa	Li/SO2	28	3	74%
A 0139-A	Crystal Growth Dewers	Li/SO2	7.5	13	49%
A 0180	Recorders fo Space Exposure	Li/SO2	12	2	64%
A 0187-1	Clam Shell Elect-Micromeorites	Li/SO2	7.5	1	59%
A 0187-1	Clam Shell Elect-Micromeorites	Li/SO2	12	2	73%
A 0201	Sun Sensor-Dust Experiment	Li/SO2	7.5	2	20%
A 0201	Sun Sensor-Dust Experiment	Li/SO2	12	2	85%
A 0201	Sun Sensor-Dust Experiment	Li/SO2	28	6	88%
M 0003	Space Env. Effects on S/C Mater.	Li/SO2	7.5	2	0%
M 0003	Space Env. Effects on S/C Mater.	Li/SO2	7.5	2	76%
M 0003	Space Env. Effects on S/C Mater.	Li/SO2	12	2	0%
M 0003	Space Env. Effects on S/C Mater.	Li/SO2	12	1	46%
M 0003	Space Env. Effects on S/C Mater.	Li/SO2	12	2	76%
M 0003	Space Env. Effects on S/C Mater.	Li/SO2	12	1	88%
M 0004	Space Effects on Fiber Optics	Li/SO2	7.5	1	0%
M 0004	Space Effects on Fiber Optics	Li/SO2	12	1	71%
M 0004	Space Effects on Fiber Optics	Li/SO2	12	2	85%
M 0004	Space Effects on Fiber Optics	Li/SO2	28	6	85%
M 0006	Space Effects - Optical Surfaces	Li/SO2	7.5	1	76%
M 0006	Space Effects - Optical Surfaces	Li/SO2	28	1	77%
P 0003	LDEF Thermal Measurements	Li/SO2	7.5	1	73%
S 0010	Exposure of S/C Coatings	Li/SO2	7.5	1	76%
S 0010	Exposure of S/C Coatings	Li/SO2	28	1	77%
S 0014	Photovoltaic Cells - Sun Sensor	Li/SO2	7.5	1	0%
S 0014	Photovoltaic Cells - Sun Sensor	Li/SO2	12	1	85%
S 0014	Photovoltaic Cells - Sun Sensor	Li/SO2	28	2	0%
S 0069	Carousel, Opt system	Li/SO2	7.5	1	0%
S 1001	Low Temperature Heat Pipes	Li/SO2	7.5	1	0%
S 1001	Low Temperature Heat Pipes	Li/SO2	12	1	85%
S 1002	Solar cells, QCM	Li/SO2	7.5	1	0%
S 1002	Solar cells, QCM	Li/SO2	28	2	80%
S 1005	Flat Plate Heat Pipe Experiment	Li/SO2	7.5	1	0%
S 1005	Flat Plate Heat Pipe Experiment	Li/SO2	12	1	85%
INIT	LDEF Initiation System	Li/SO2	28	2	89%
S 0069	Carousel-Thermal Counductive. Surfaces	Li/CF	28	4	0%
S 1005	Flat Plate Heat Pipe Experiment	Li/CF	28	6	0%
S 1001	Low Temperature Heat Pipes	NiCd	18	1	Recharge

Discharge data of selected experiment batteries was performed by L. Thaller of The Aerospace Corporation (3). The discharges were performed by placing resistive loads across the cells and monitoring the voltage to determine capacity remaining. Data from these experiments are included in Table 1, which summarizes the state of charge remaining in the lithium sulfur dioxide batteries for specific experiments.

Lithium sulfur dioxide batteries generally exhibit good charge retention, with loss in capacity of less than 3-5 percent per year. LDEF lithium.sulfur dioxide batteries showed charge retention properties commensurate with that expected based on the temperature profile experienced by these batteries. The state of charge remaining versus the quantity of batteries is shown in Figure 1. Some batteries retained greater than 80 percent of their original capacity. Ground stored batteries retained charge better than the flight batteries, which saw minimal use. This is an expected result, since the average storage temperature of the ground batteries was lower than that of the flight batteries. Ground stored batteries remained in refrigeration at NASA Langley with an average temperature of 0 $\pm$ 5 °C. The average temperature of LDEF flight batteries was 15 $\pm$ 10 °C, which would produce a greater degradation of the lithium electrode. Ground stored batteries experienced an average capacity loss of 11 percent over the 6-year LDEF flight time, while some flight batteries on LDEF showed up to 30 percent capacity loss (2). The favorable performance of LDEF lithium sulfur dioxide batteries adds credence to the selection of lithium sulfur dioxide batteries of similar design for the Galileo mission.

ANALYSES ON LITHIUM CARBON MONOFLUORIDE BATTERIES

Investigation of lithium carbon monofluoride batteries was accomplished with a subcontract from The Boeing Company to AZ Technology. Ten Li/CF batteries were flown on LDEF as listed on Table 1. The batteries were depleted on return of LDEF. Figure 2 shows the gradual degradation of battery voltage with time for the battery used on the Thermal Control Surfaces Experiment (4). The required experiment life was twelve months, with an expected life of 18 months, which the batteries exceeded.

The LiCF batteries experienced slight leakage of one cell in one of the LDEF batteries. An "Odor" was detected in the battery case of experiment S0069, upon opening. H. L Lewis and V. L. Hammersley at the Naval Weapons Center, Crane, Indiana, are investigating the phenomena and will be presenting their findings in January 1992 (5). The electrolyte used in the Eagle-Picher Industries LiCF batteries is dimethyl sulfide, which contains small amounts of other sulfur compounds that can be quite odorous. AZ Technology investigated the effect of the leaked electrolyte vapors on the O-ring seal of the battery containment case (6). The seal experienced a softening and deformation due to the attack, however indications are that any leakage was contained in the case and created no performance problem for the battery or associated experiment.

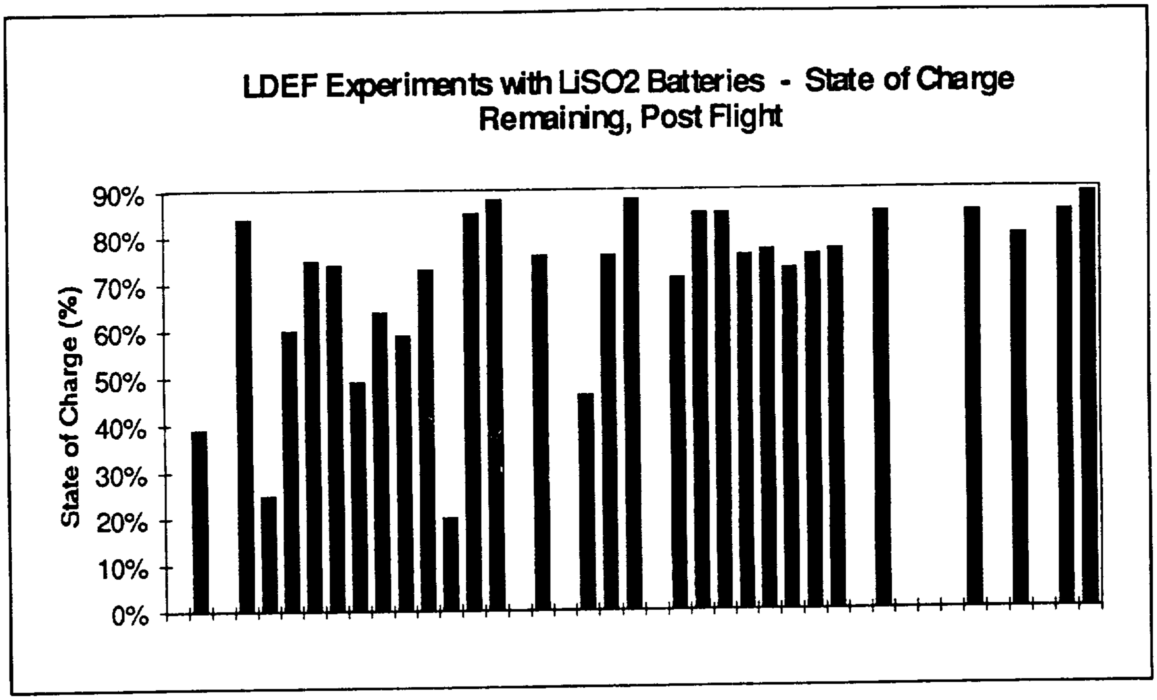

Figure 1. State of Charge Remaining in Li/SO_2 Batteries Returned from LDEF Flight.

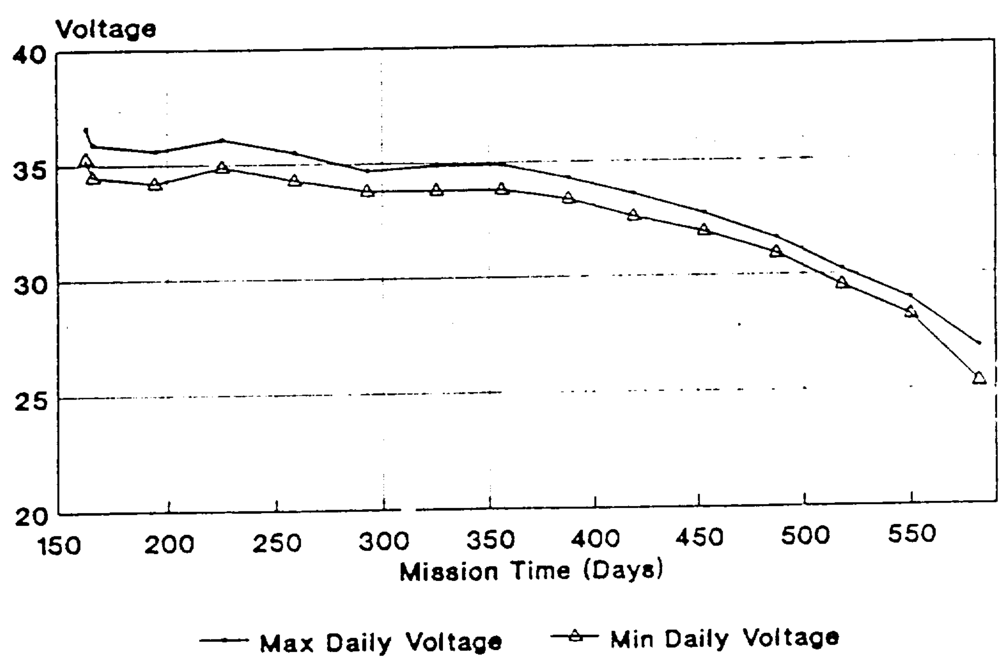

Figure 2. Gradual Degradation of Voltage with Flight Duration for Li/CF Batteries

TESTS AND ANALYSES ON THE NICKEL CADMIUM BATTERY

One nickel cadmium battery was flown on the Low Temperature Heat Pipe Experiment Package (Experiment #S1001). Analysis and test of the battery has been conducted by S. Tiller and D. Sullivan of NASA Goddard Space Flight Center (7). The battery consisted of two 9-cell packs, which were mounted onto a 0.75 inch thick aluminum baseplate. Prior to flight, power analysis for the 12-Ah NiCd battery indicated a need for 2 to3 ampere discharge; however, reduction in the experiment during flight resulted in a much lower power demand. The resulting over charge of the battery became a duration test for the NiCd battery. These batteries are not known for their ability to withstand excessive overcharging for long times. The battery survived the entire 6-year usage and was still functioning upon retrieval. The overcharge was reported to have developed internal pressure, resulting in bulging of the cell cases, especially those cells on the end of the cell pack.

The loss of overcharge protection is obvious from the difference in voltage performance shown for pre-flight and post-flight cells on constant charge, see Figure 3. Preflight charge profile showed all cells were matched and reached full state of charge in 18 hours, while maintaining voltage below 1.46V. Post-flight data experienced considerable differences between cells with cell # 10 reaching a high voltage of 1.52 volts, which tripped the charge for the battery off at 14 hours of charge. Discharge performance produced similar results with pre-flight reaching 6.4 hours discharge at a C/4.8 rate, while post-flight cells attained only 6 hours for the same conditions, see Figure 4.

CONCLUSIONS

LDEF batteries experienced mild temperature extremes during flight providing a favorable environment for life considerations. All batteries performed to expectations meeting and exceeding original design requirements. Minor leakage was experienced on one cell of a LiCF battery, which resulted in minor attack of the o-ring on the battery case, with no damage to experiment hardware. The NiCd battery endured considerable over charge and returned with case bulging, but still functioned with decreased capacity capability.

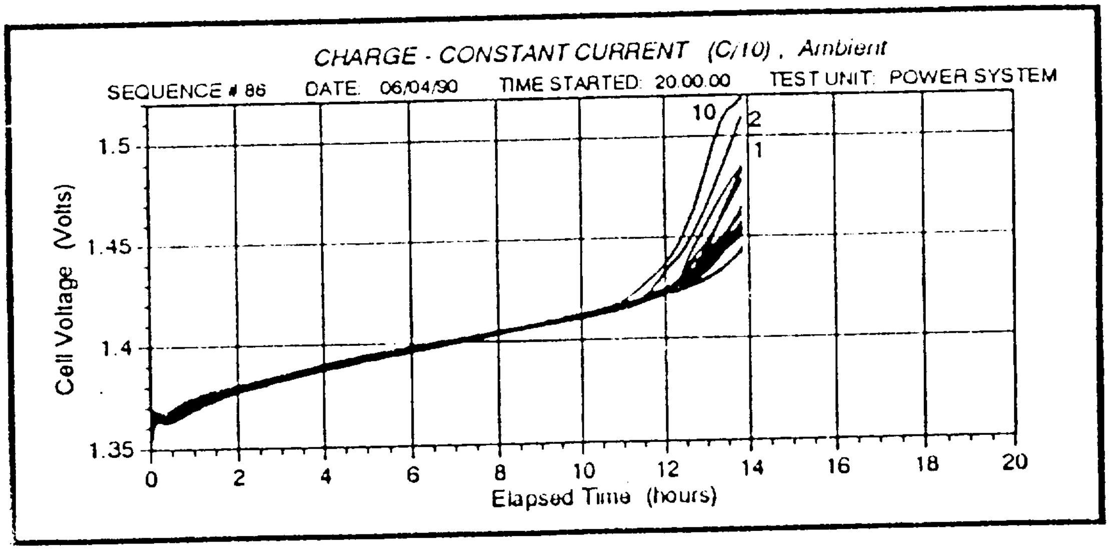

Figure 3. Constant Current Charge Indicates Loss of Overcharge Protection

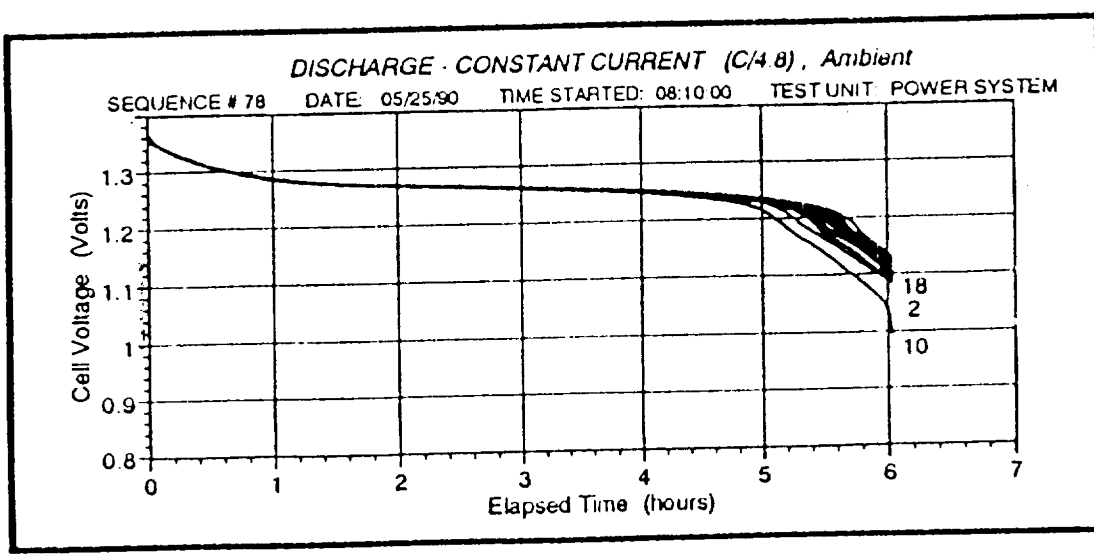

Figure 4. Constant Current Discharge Produces Low Capacity, Post Flight

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