PARALLEL 50 AMPERE HOUR NICKEL CADMIUM BATTERY PERFORMANCE IN THE MODULAR POWER SUBSYSTEMS (MPS)

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Modular power subsystems is one of the major subsystems of the NASA multimission modular spacecraft. Module 2 was subjected to a temperature vacuum test at McDonnell Douglas Astronautics Company in St. Louis in June 1979. Parallel data to follow was generated during that testing.

Before we address that data I would like to discuss a few things briefly: the test objectives and the approach. Secondly, I would like to talk a little bit about the module with respect to the power circuit, the charger operation, and the data system. And third, a few comments on the batteries.

The test objectives were twofold. It was a thermal test, mainly. The first objective was to establish the system thermal performance under controlled conditions. The second objective was to demonstrate the ability of the components and structural parts to tolerate extremes in temperature.

To accomplish the first objective, the module was subjected to worst-case space environment, either a hot or a cold condition, while the components were generating waste heat at design rates, either high rates or low rates, depending on the environmental conditions. After stabilization of the components, the temperatures recorded were compared to the thermal model predictions and were used as acceptance criteria for the model.

The second objective was accomplished by artifically raising or lowering the stable temperatures that were determined in the first part of the test, and then demonstrating adequate and acceptable system performance in near-Earth orbit simulation. These simulations were 36 minutes of discharge and 56 minutes of charge.

The module is a passively cooled system, and as I said, the components were artifically—the temperatures were artificially raised or lowered by means of thermal control panels, which were facing the module radiator systems or surfaces.

(Figure 3-68 and Figure 3-69)

The module has capability of installing up to three standard 20-ampere hour nickel-cadmium batteries, or three 50 NASA batteries. The configuration that was tested, as you see here, contained three 50s. This is a prototype test to demonstrate full-up capability.

On the center screen you see the brief schematic of the power system. The batteries are as you see here, and the power contractor unit, PCU, that contains the contactors and all of the diodes are as you see here. Also, the current sinters are indicated by the blocks.

As you can see here, there are three batteries in parallel off a common bus fed by a single regulator. The regulator is a standard NASA part and is located near the top of the module.

(Figure 3-70)

The regulator has eight selectable voltage levels, and the batteries are charged until their charged voltage reaches a selected voltage level and that voltage level is maintained until the end of the daylight period.

Normally, the charge goes through two modes of operation in a sunlight phase. The first is where the battery voltage is below the voltage limit mode, or voltage limit established by the selected curve.

The charger will cause the power drawn by the system to track the available peak power drawn by the system to track the available peak power of the array that is feeding the system. It does his by a 70-hertz perturbation signal on the array. I am not quite sure of the change in the power conditions to adjust this output voltage to do this.

Once the batteries have reached the voltage limit, as I say, it is maintained until the end of the daylight period. If the bus demand is greater than the available array power, then the batteries can be in a noncontributing mode, or they can be supplementing the array power by contributing to bus demands. So it is a bus-demand system.

(Figure 3-71)

I wanted to show you this because it has an effect on the data that you will see later on the cycles that we were conducting during the hot and cold testing.

When the regulator is in a cold phase, around 5°C, there is an AC component that is on the bus which is due to the 70-hertz perturbation signal that the charger is injecting into the array. The same type of thing occurs in the hot phase, but you will see that the magnitude of the disturbance is greater. When you take instantaneous readings on bus voltages, you can induce more error.

We know that this is amplified because the screw is looking into a solar array simulator which is hot through the solar array. And there is a compatibility problem between the screw and the power regulating unit and the solar array simulator which goes away.

We have run quite an array test where we have used three batteries in series with a series resistor, and the disturbance is diminished. Also, after you pass from the peak power tracking mode into the voltage limit mode, we find about a 4½-kilohertz AC signal on the bus, which is very much affected by the operating temperature of the regulator. That is shown in the lower figure on the vugraph. I mention this again because you will see these effects on the data.

(Figure 3-72)

The data system that we used to accumulate the data on the battery performance was an analog to digital system, and the parameters of interest with respect to the battery performance are shown here. They are normal engineering ranges, and here is the analog range. These signals are conditioned to this type of a range by a signal conditioning unit which you see here on the modules.

Those voltages at those levels are fed to redundant remote interface units which are the devices that digitize the data. We break into the data bus—this normally goes to a central unit which transmits that information to ground and flight. We break into that data bus with a simulation of that central unit.

We recently worked a computer into the setup so that we can freeze the digital data in various slots and change them back to engineering units and give us the amounts during the testing.

Here again I show you the equivalent of a single count change on the digital system. We will also see some of this effect in the data.

With respect to the batteries, they are twenty-two 50-ampere hour nickel-cadmium cells. The manufacturer is GE. These cells are not a NASA standard. However, a manufacturing control document is used to control their manufacturing and has all the detail that was worked into the NASA standards. The only difference is that it has not been formalized as a NASA standard.

Cells are selected for battery assembly based on the charge voltage and the capacity during zero-degree and 24-degree capacity cycles at the vendor. The plates are chemically impregnated.

(Figure 3-73)

I have only included battery one voltage here. It is typical, instantaneous reading. I show all three battery currents to amplify their uniformity. These are five reading averages. Because of the data problem that we were having, we worked into the program an averaging of five readings to try and smooth the perturbations that we have.

There is only one point on the graph that is not an average, and it will be these points here. Normally, the data is on 4-minute intervals. During the first 120 seconds of charge, we took 10-second data. This is an instantaneous reading here during that 120 seconds. It is a maximum reading.

Once again, this was conducted at voltage level 4. It was a light bus load, 250 watts. The batteries were running about minus 5 degrees. Batteries 1 and 2 were equal as far as temperature is concerned in this test, and battery 3 was running slightly higher by 2 or 3 degrees.

On that instantaneous data taken on the charge, the maximum difference between the batteries on charge was 1.2 amperes. That covered the spread of all three batteries during initial shots. And toward the end, there is 0.72 to 0.76 at the end of the paper.

(Figure 3-74)

I didn't point out on the other one, but you could see the bit change in the bus voltage there. Here you can see a much wider spread in the instantaneous voltages and for the reasons I stated earlier. These are three consecutive cycles in both cases that I am showing.

Seventy-two hours of this type of operation went on at each condition, when the conditions were cold and the batteries were on minimal load, and when the conditions were hot and the batteries were running at 25 degrees and 1200 watts.

Even with the averaging–this is all average–and some of this data going on, the current does follow the instantaneous voltage and we don't get a very smooth curve. In this case batteries 1 and 3 were running equal temperature, and battery 2 was cooler by 2 or 3 degrees. Charge level 5 was used here. I picked level 4 for the cold and level 5 for a reason that will decome apparent shortly.

(Figure 3-75)

This shows a variation in top of cell temperature for the three batteries during the cycles that I presented during the hot phase.

You see that we get a heating during discharge and a cooling and indication of a slight heating there at the end of charge on the cycles. It looks as if I picked a couple of cycles here where they may have been fooling around with the TCP's and then dropping off.

Here you see the difference between the batteries in the period that ran cooler. Battery 2 ran cooler, as it says, and battery 1 and 3 were running at very similar temperatures.

(Figure 3-76)

This is a summation of percent factors that we obtained at various levels. As you can see, level 5 and 6 were evaluated during the initial test. The 17 percent that you see here and the 3.6 were data taken from June. Since that time, we have changed some of the components in the module to free them up for use on module number 1, put in new equipment, and we have gone through a current data retest.

The normal configuration of the model when delivered is with two batteries. So what you see is the absence of the third battery. We went through the same levels, same bus wattage levels, in this test that we went through in the first test. Subsequently, the percent depth is greater on the two batteries.

As you saw, the charge current both during the hot test there and during the cold test was somewhere between 14 and 16 amperes maximum. During the second test, the batteries were running somewhere between 21 and 23 amperes maximum during the peak power tracking mode.

Level 7 was analyzed here on one cycle. There were only two cycles with level 6. These are not the total number of cycles around, but the total number of cycles I have down on this.

The conclusion that we draw here is that the parallel battery operation off the single bus with the single regulator feeding it, the performance was certainly consistent and showed no tendency to deviate from that acceptable performance. And we are pleased at the way things went.

DISCUSSION

THIERFELDER: Is there a current limit on melting point?

WEBB: No, there is no limit. It is the available current.

THIERFELDER: If one battery would short or it went out or was turned off, all the current would not vent to the other two batteries?

WEBB: Yes. I believe there is a paper to follow here shortly on parallel power testing that Goddard is doing under various conditions of shorted cells, or what have you. Jerry, is that limited to imminent current, available current?

HALPERT: 98 amperes, I think.

WEBB: I understand what you are saying. The regulator had six modules in it, or 18-ampere limit on each of those modules. So the maximum current that it can put out is 108 amperes. So what is taken by the bus load, the remainder is for the battery, and it will divide as conditions exist.

YOUNG: Can you tell, were these old or new batteries? How many cycles did you actually do during the test?

WEBB: These were new batteries that were built specifically for testing the module. They had gone through probably 200 to 300 hours of performance testing on the module before we got to this stage. Then we went through a retest here again. So I would say 200 or 300 hours of operation, and probably in the module—we don't keep any track of cycles, so it's probably a good 15 fairly deep depth-of-discharge cycles.

Normally, it is operation of other equipment while the battery is off feeding. So it isn't a purposeful attempt to break them down.

OTZINGER: The body of the battery gets charged directly during the solar array, not directly from the modules? They get charged from the modules?

WEBB: Yes. The batteries directly across the bus, downstream of the screw.

Here you see the unregulated bus. The batteries are directly off that. We have a load bus. Off this comes the module loads, and then there is a contractor that goes to an instrument bus, which feeds the instrument packet.

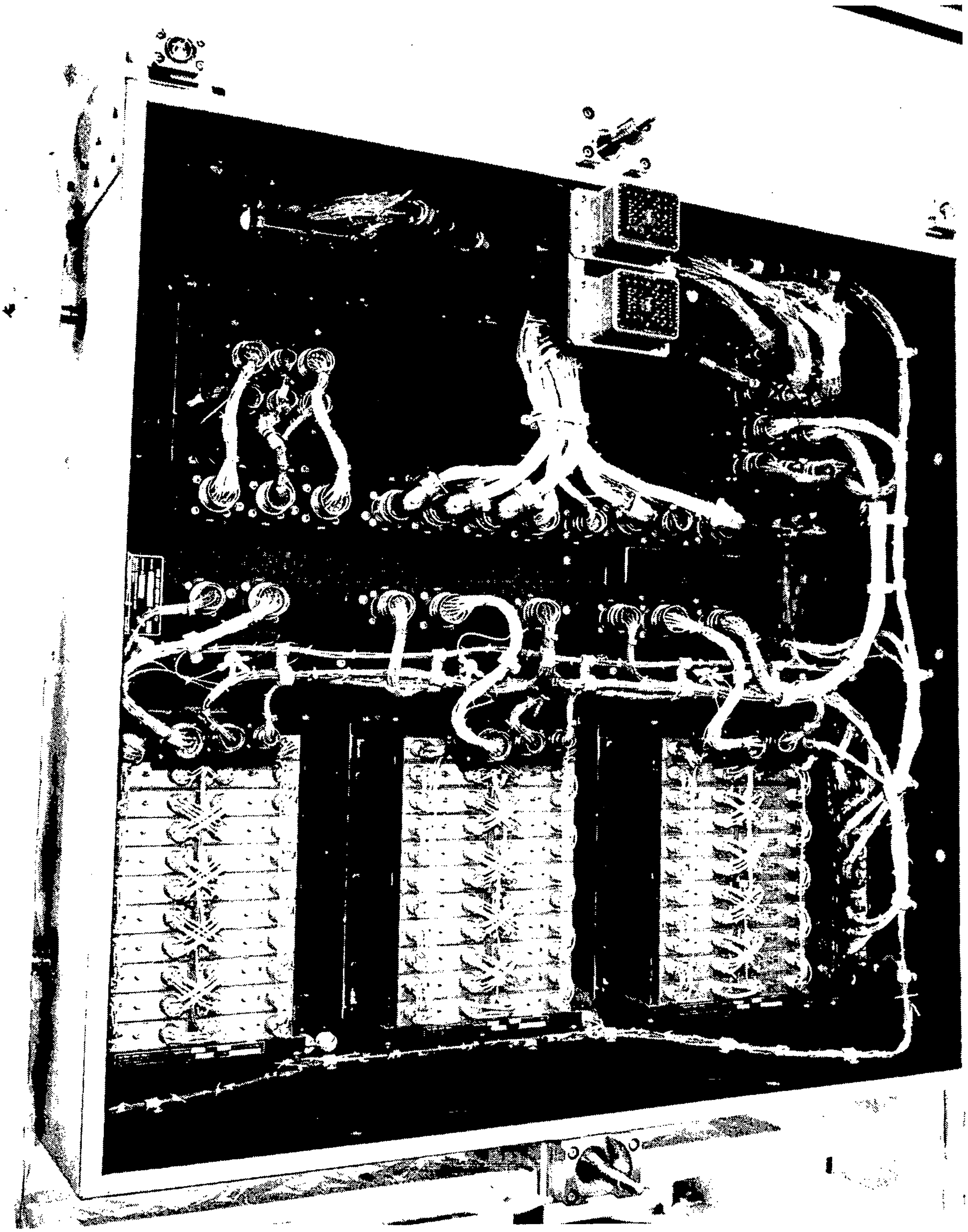

Figure 3-68

POWER CIRCUIT
MODULAR POWER SUBSYSTEM

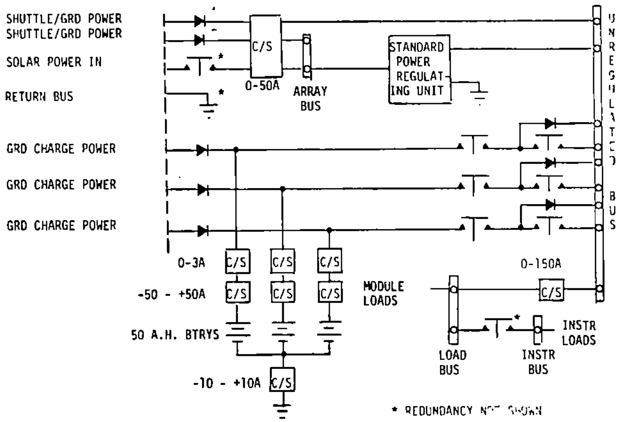

Figure 3-69

SELECTABLE BATTERY CHARGE VOLTAGE LEVELS

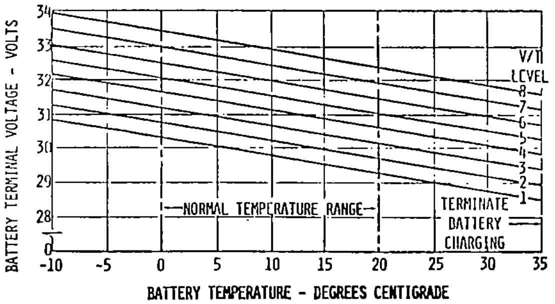

Figure 3-70

BUS EFFECTS VS. REGULATOR OPERATING MODES

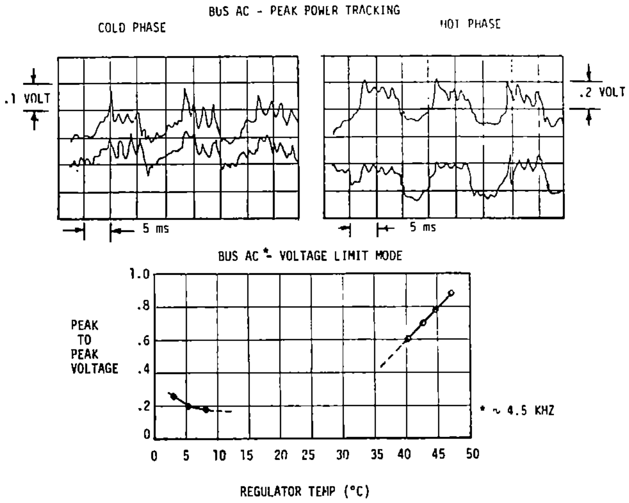

Figure 3-71

MODULE BATTERY DATA SYSTEM - SUMMARY

PARAMETER	FLIGHT MONITOR	RANGE ENGR UNITS	ANALOG OUTPUT RANGE	ACCURACY	TM * RANGE	SINGLE COUNT ENGR EQUIVALENT
BTRY LO I	CURRENT SENSOR	0-3A	0-5V	1% FS**	0-250	.012 AMPS
BTRY HI I	CURRENT SENSOR	-50 TO +50A	0-5V	1% FS	0-250	.400 AMPS
BTRY VOLTAGE	VOLTAGE DIVIDER CIRCUIT	0-40V	0-5V	1/2% FS	0-250	.160 VOLTS
BTRY TEMP	PASSIVE THERMISTOR	+65° - -25°C	.429 - 4.345V	NEGLIGIBLE	21-217	.3°C IN LINEAR RANGE***
HALF BTRY VOLT COMPARISON	VOLTAGE COMPARATOR	-.7 TO +.7V	0-5V	1% FS	0-250	5 MV

* RIU F/S = 5.12V = 256 COUNT
** IN TOP 90% OF RANGE
*** LINEAR RANGE +40° TO -10°C

Figure 3-72

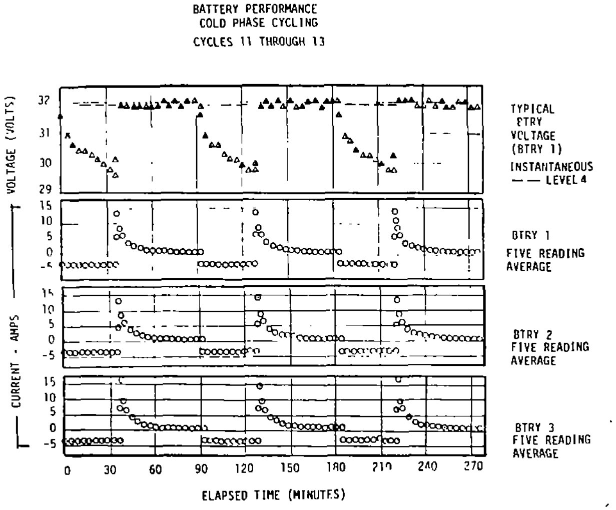

Figure 3-73

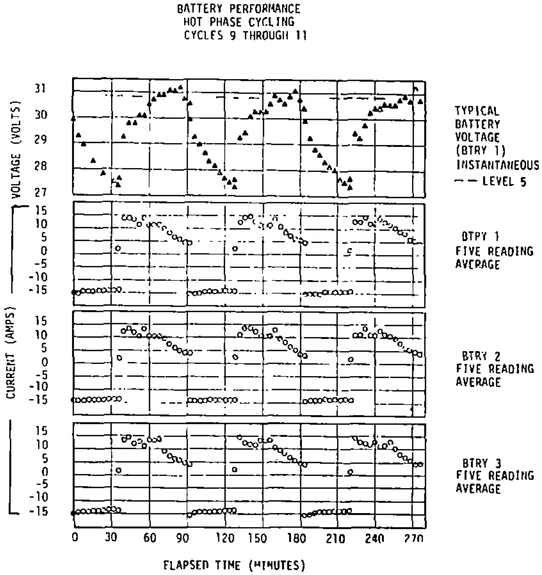

Figure 3-74

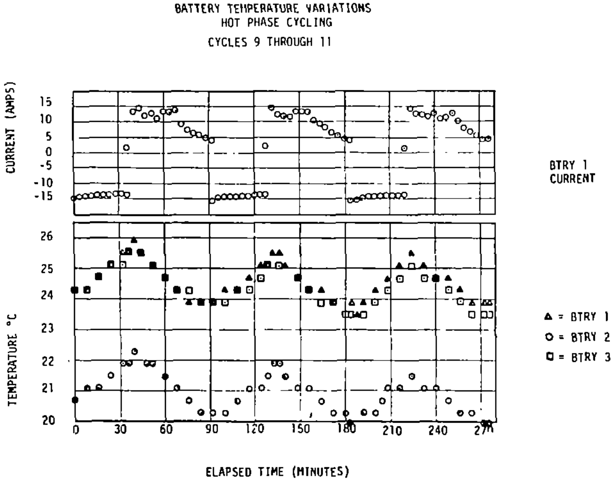

Figure 3-75

CHARGE TO DISCHARGE RATIO RESULTS

PHASE	CYCLE DEPTH		BATTERY TEMPS END OF CHG LO	HI	VOLTAGE LEVEL	C/D RATIOS* BTRY 1	BTRY 2	BTRY 3	
HOT	17%	(8.5 AH)	20°C	24°C	5	1.096	1.071	1.128	(10)
	17%	(8.5 AH)	23°C	27°C	6	1.258	1.243	1.276	②
	27%	(13.5 AH)	19.5°C	22.7°C	5	1.026	1.015	—	⑦
COLD	3.6%	(1.8 AH)	-5.2°C	-2.5°C	5	1.210	1.203	1.313	⑦
	3.6%	(1.8 AH)	-5.9°C	-4.9°C	4	1.052	1.047	1.116	⑨
	3.6%	(1.8 AH)	-7.9°C	-6.9°C	3	.946	.938	.986	④
	5.6%	(2.8 AH)	-2.9°C	-1.5°C	5	1.162	1.170	—	(10)

* AVERAGE VALUES OVER THE NUMBER OF CYCLES SHOWN ENCIRCLED.

Figure 3-76