RESULTS OF DEEP DOD LIFE CYCLE TESTS AT HIGH RATES ON 12Ah NiCd CELLS

Paul E. Panneton and John R. Meyer

The Johns Hopkins University
Applied Physics Laboratory
Laurel, MD 20723

N92-22756

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This presentation reviews a 12Ah NiCd LEO lifecycle test that induced 47% more deep DOD cycles by mixing them with shallow DOD cycles. This test also showed how aggressive recharging to a C/D ratio of 1.15 nearly doubled performance over cycling below a C/D of 1.11.

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JHU/APL spacecraft program - JANUS MISSION II

- ☞ 2 year Low Earth Orbit (LEO) mission
- ☞ Size and weight critical

Electrical Power System (EPS)

- ☞ Solar array
- ☞ Nickel cadmium (NiCd) battery
- ☞ Battery charge regulator
  - Voltage-temperature (V-T) limiting
  - Shunt excess array current

NiCd Battery

- ☞ High discharge rates (1.8C)
- ☞ Deep Depth-of-discharge (DOD)
  - 1500 cycles @ 70% DOD
  - 10000 cycles @ 20% DOD
- ☹ Little applicable performance data

⇒ **Lifecycle test**

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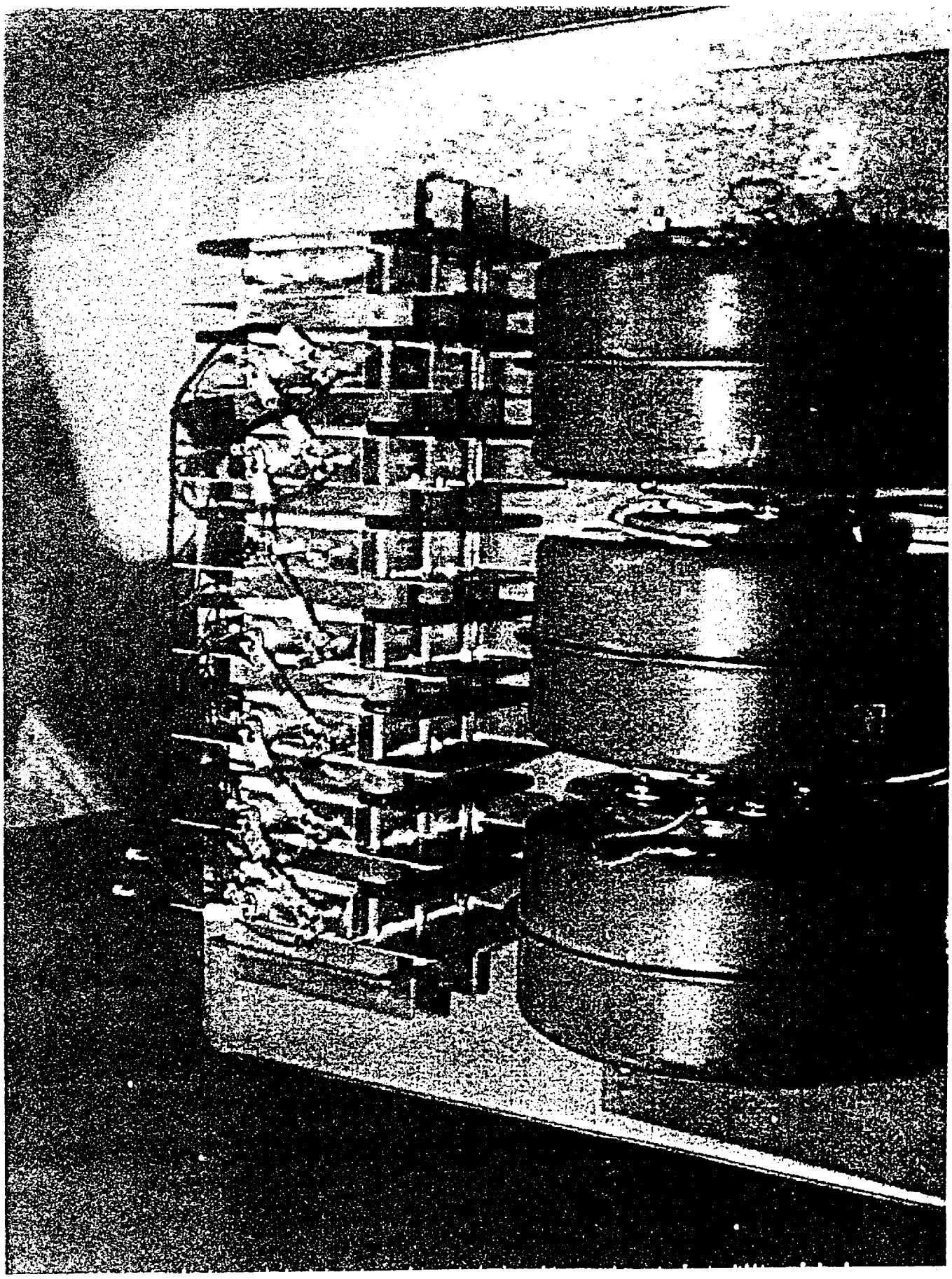
Gates Aerospace Batteries

- 12 Ampere-hour (Hr) nameplate capacity
- Pellon #2536 nylon separator

  - Hermetically sealed
  - Standard space qualified design
  - Negative plates not teflonated
  - Positive plates not passivated
  - Negative terminal attached to the case

  - All cells were from the same lot
  - Filled in April 1988
  - Short circuited
  - Put in sealed plastic bags
  - Refrigerated at 5° Centigrade



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The test parameters were chosen to produce the:

- Worst case eclipse, and
- Lowest battery cell voltages

95 minute cycles at ambient temperature (20° to 30° C.)

- Discharge to 70% DOD (35 minutes - actual 69.44%)
  - -- C/3 rate for 15 minutes (unswitched loads)
  - -- 1.8C rate for 20 minutes (switched loads)
- Charge for 60 minutes
  - -- 1C rate until reach V-T limit
  - -- V-T controlled taper

Relatively high end-of-charge (EOC) rates were required to fully recharge the battery in the short amount of time allowed.

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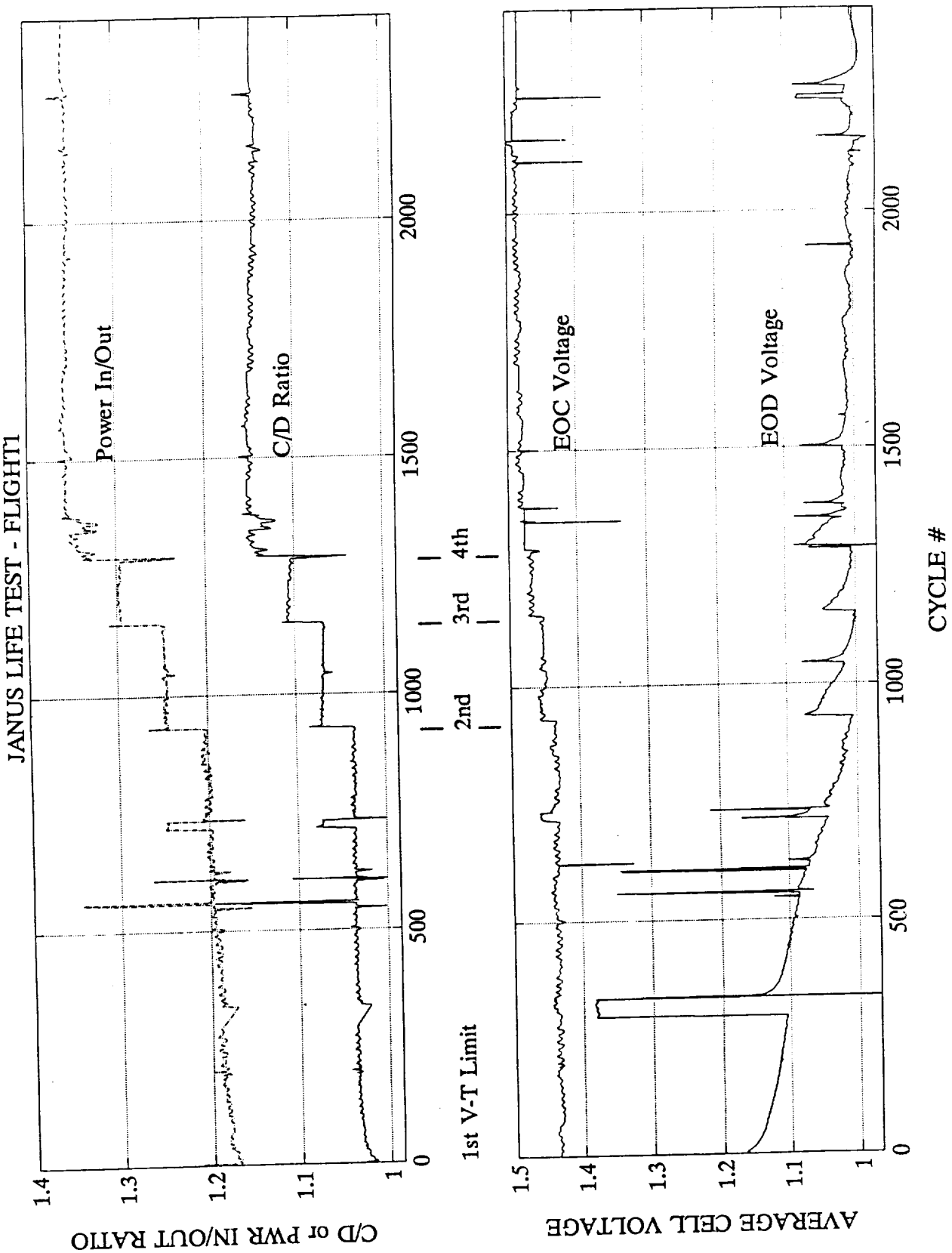
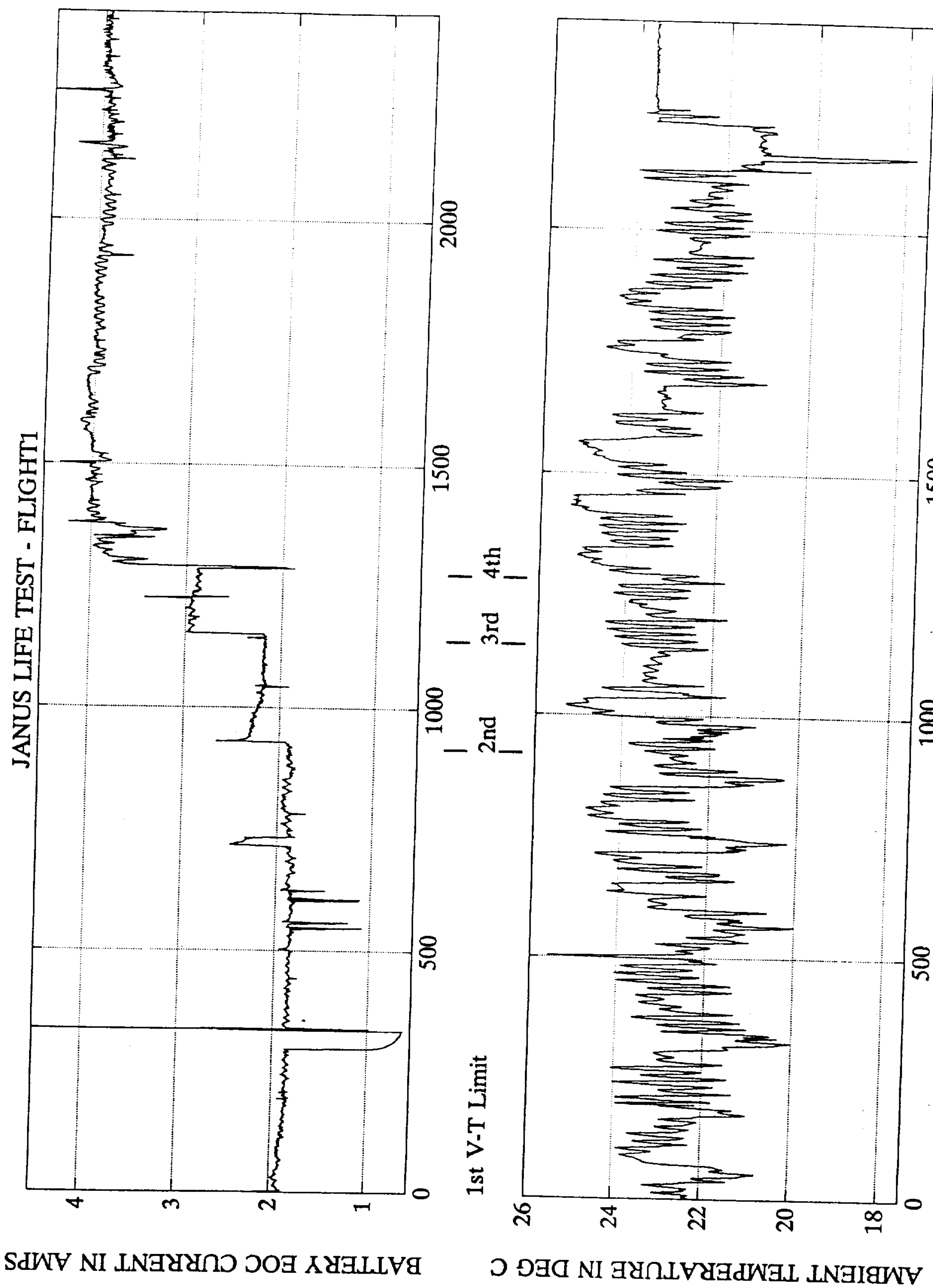
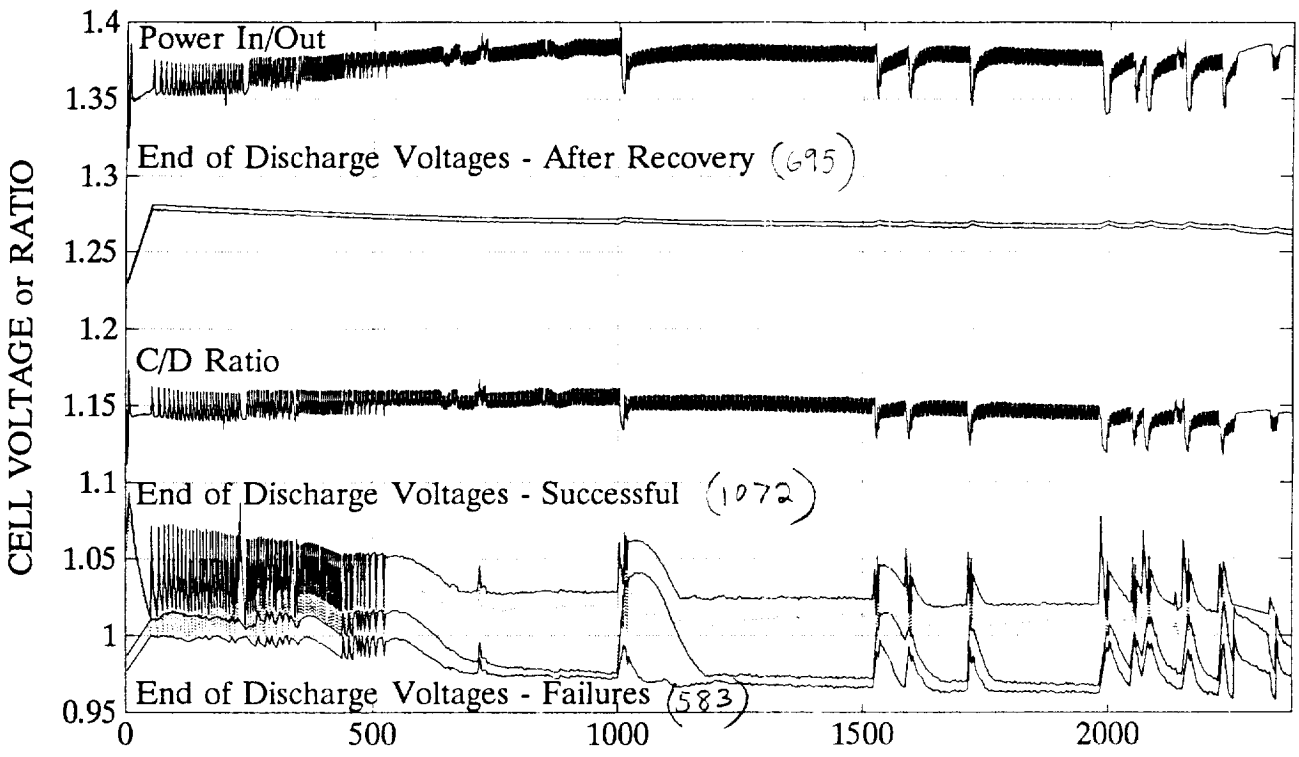
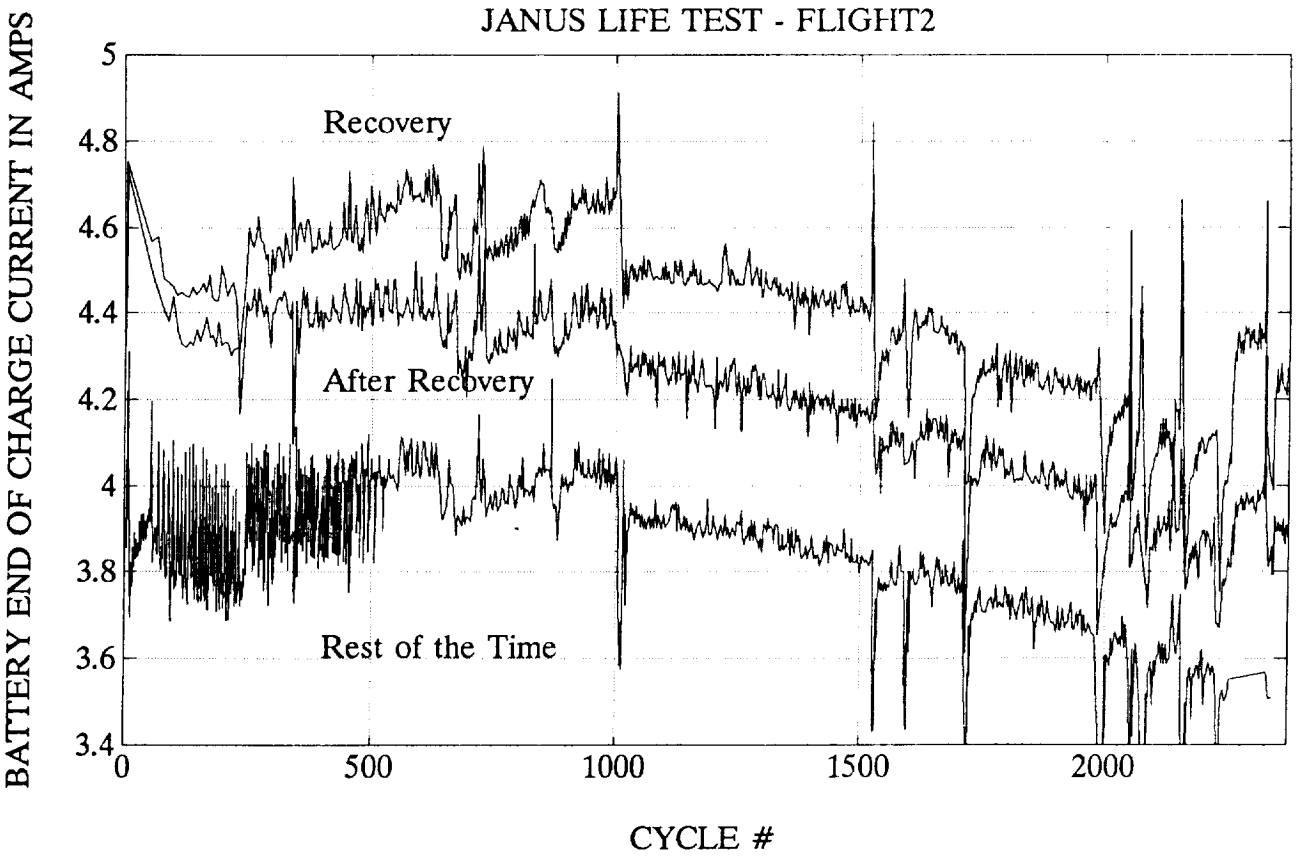
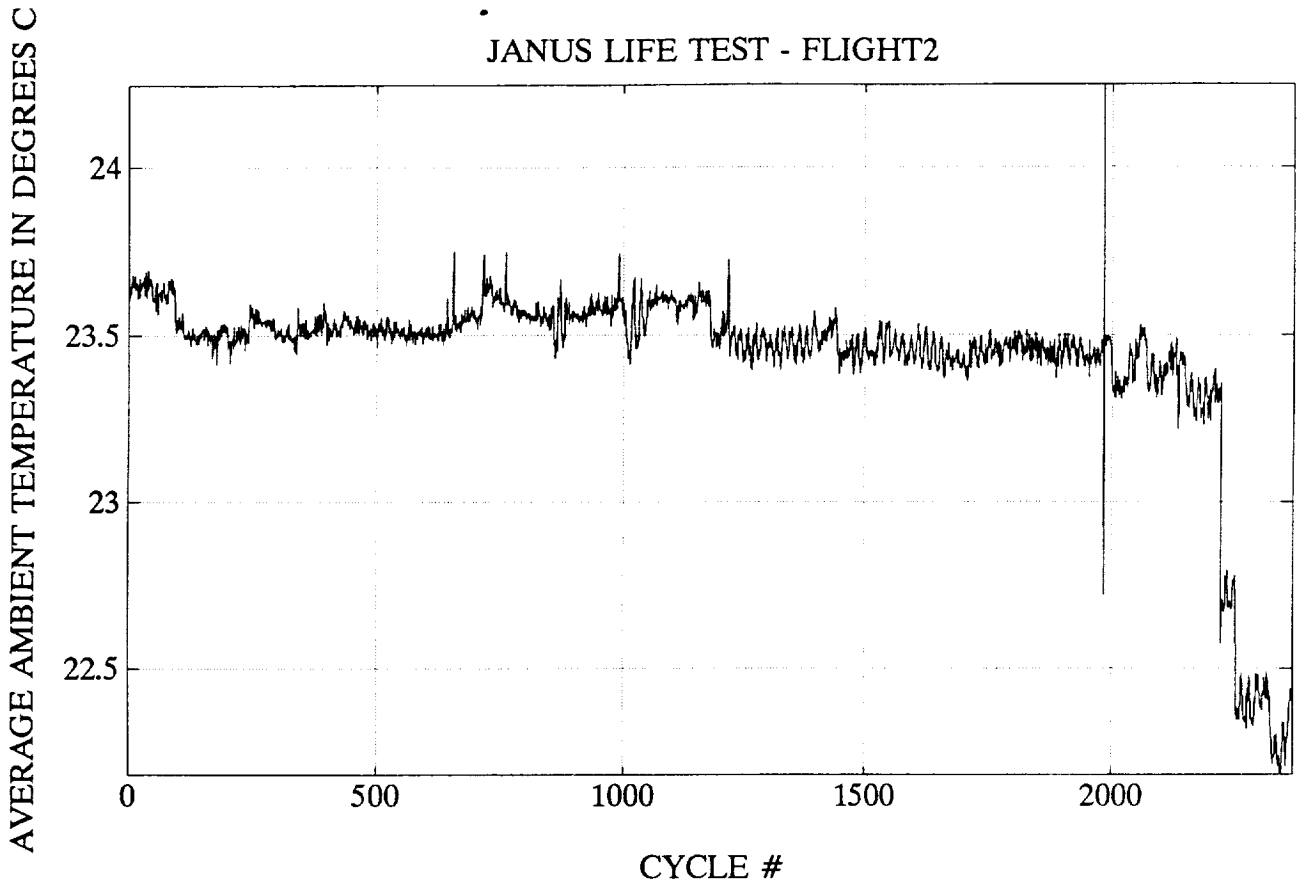
METHOD	REMARKS	# OF CYCLES	TOTAL 70% DOD	TOTAL 20% DOD
Contiguous 70% DOD Cycles. Raise VT Limit to Control C/D Ratio. 1V Cutoff.	C/D=1.036 NOAA	913	913	
	C/D=1.069 NASA	219	1132	
	C/D=1.107 SLOSAT	122	1254	
	C/D=1.146 APL LIMIT	1021	2275	
70% DOD Cycles Interspersed with 20% DOD Cycles. 1V Cutoff.	Above Cutoff	1072	3347	
	Below Cutoff	583	3930	
	20% DOD Cycles	695		695
20% DOD Cycles	C/D=1.178	6104		6799
70% DOD Cycles	.95V Cutoff	100++	4030++	

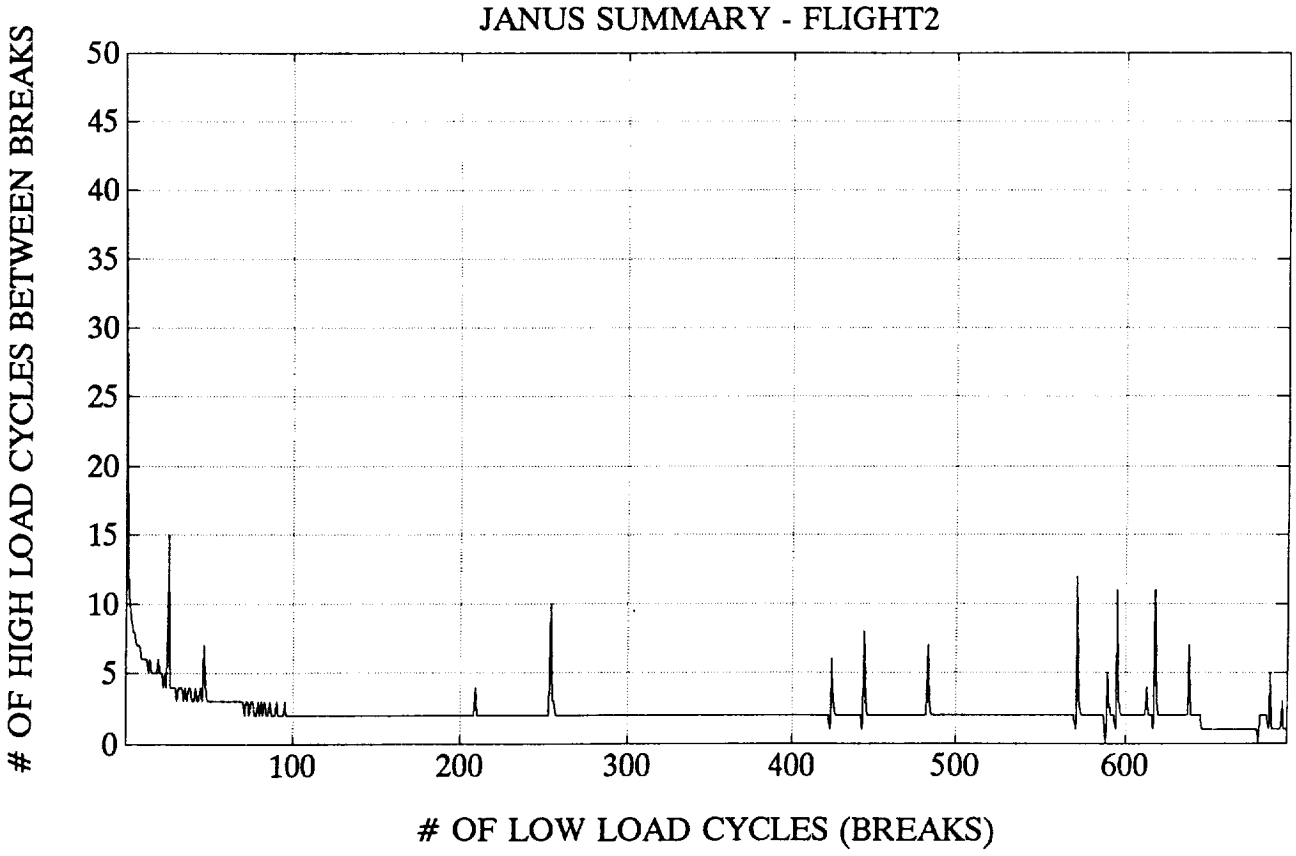

JANUS LIFE TEST - FLIGHT1
Power In/Out
C/D Ratio
C/D or PWR IN/OUT RATIO
1.4
1.3
1.2
1.1
1
0
500
1000
1500
2000
1st V-T Limit
2nd
3rd
4th
EOC Voltage
EOD Voltage
AVERAGE CELL VOLTAGE
1.5
1.4
1.3
1.2
1.1
1
0
500
1000
1500
2000
CYCLE #

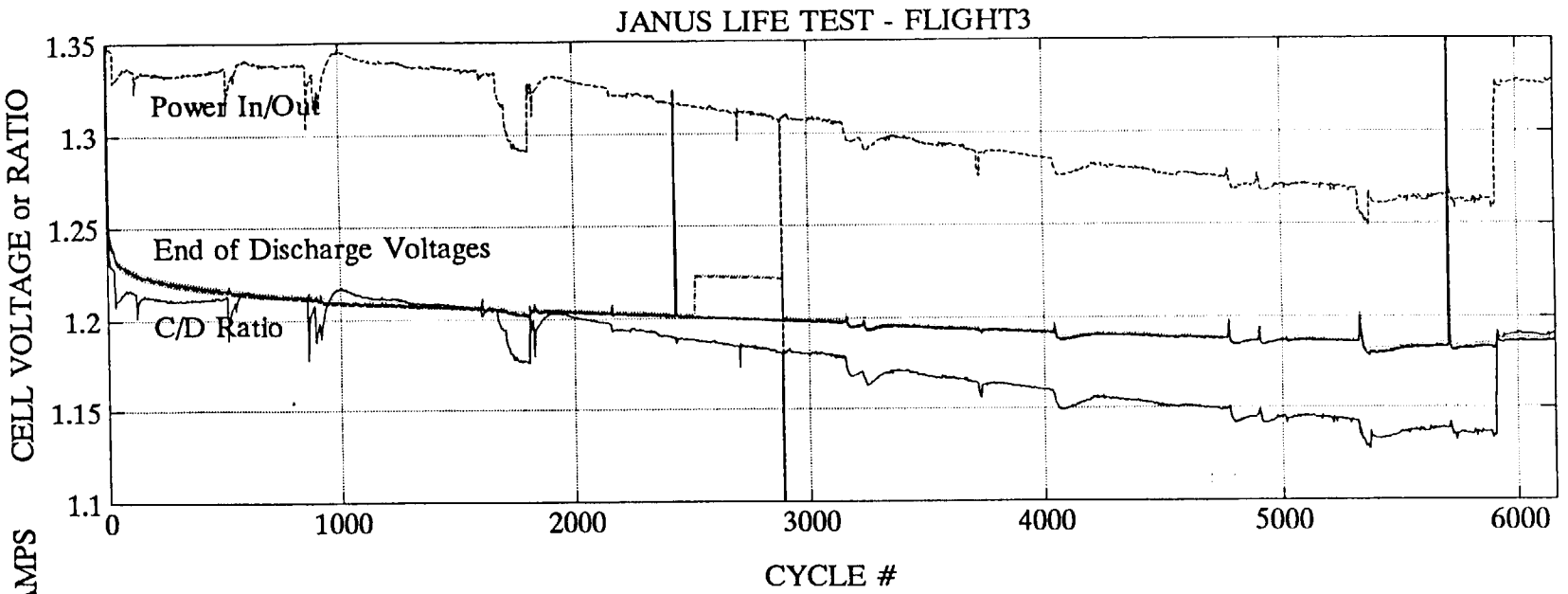

JANUS LIFE TEST - FLIGHT1
BATTERY EOC CURRENT IN AMPS
4
3
2
1
AMBIENT TEMPERATURE IN DEG C
26
24
22
20
18
0
500
1000
1500
2000
CYCLE #
1st V-T Limit
2nd
3rd
4th

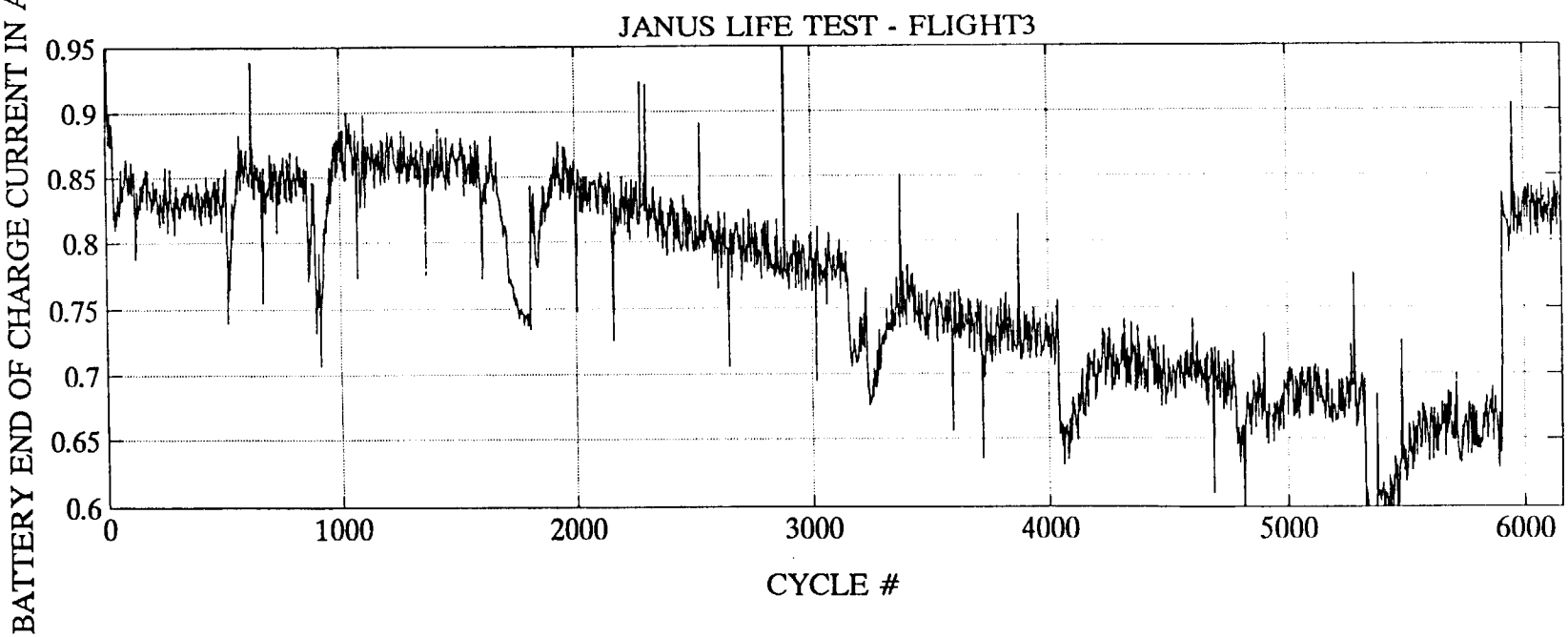

JANUS LIFE TEST - FLIGHT2
CELL VOLTAGE or RATIO
Power In/Out
End of Discharge Voltages - After Recovery (695)
C/D Ratio
End of Discharge Voltages - Successful (1072)
End of Discharge Voltages - Failures (583)
1.4
1.35
1.3
1.25
1.2
1.15
1.1
1.05
1
0.95
0
500
1000
1500
2000
CYCLE #

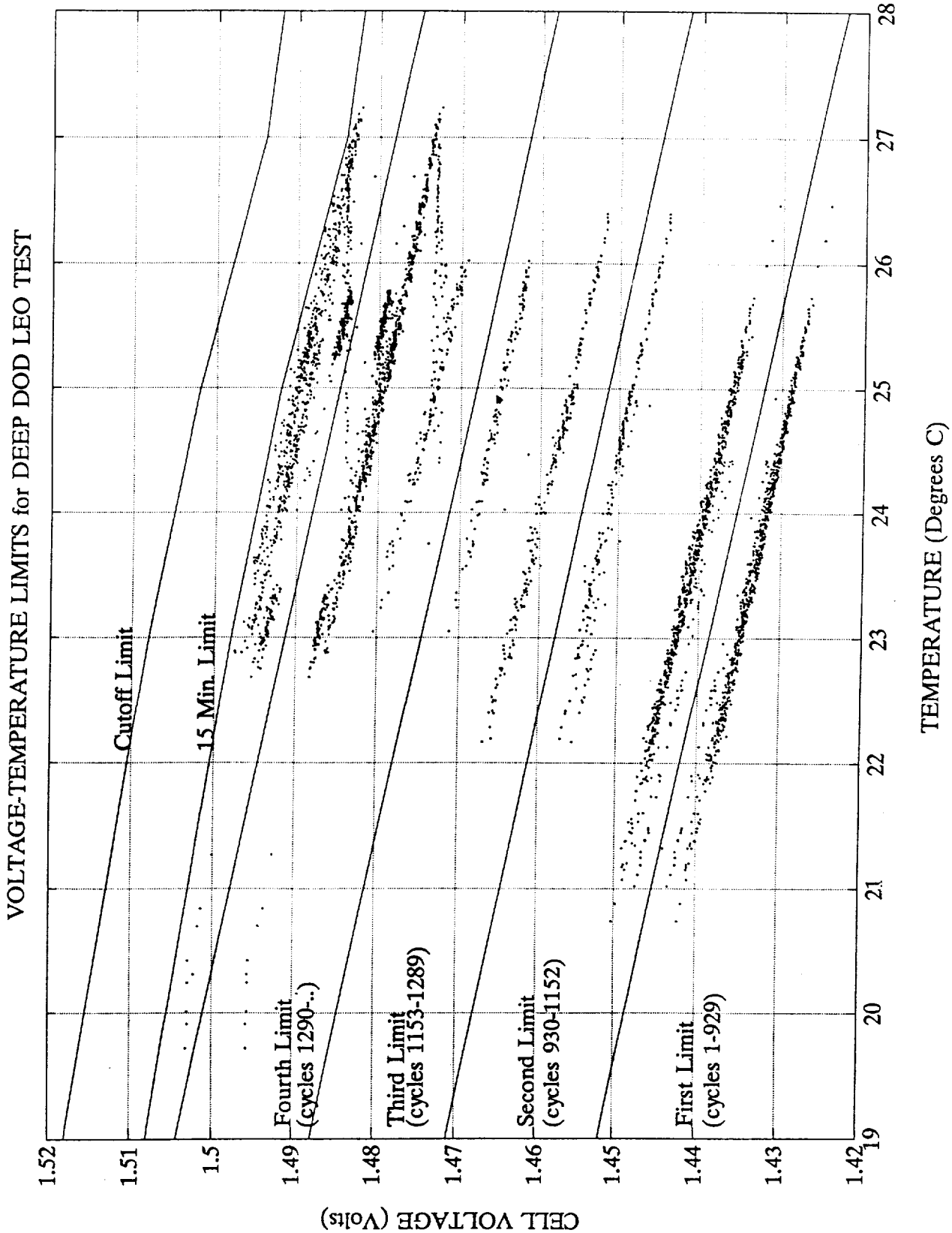

JANUS LIFE TEST - FLIGHT2
BATTERY END OF CHARGE CURRENT IN AMPS
Recovery
After Recovery
Rest of the Time
5
4.8
4.6
4.4
4.2
4
3.8
3.6
3.4
0
500
1000
1500
2000
CYCLE #

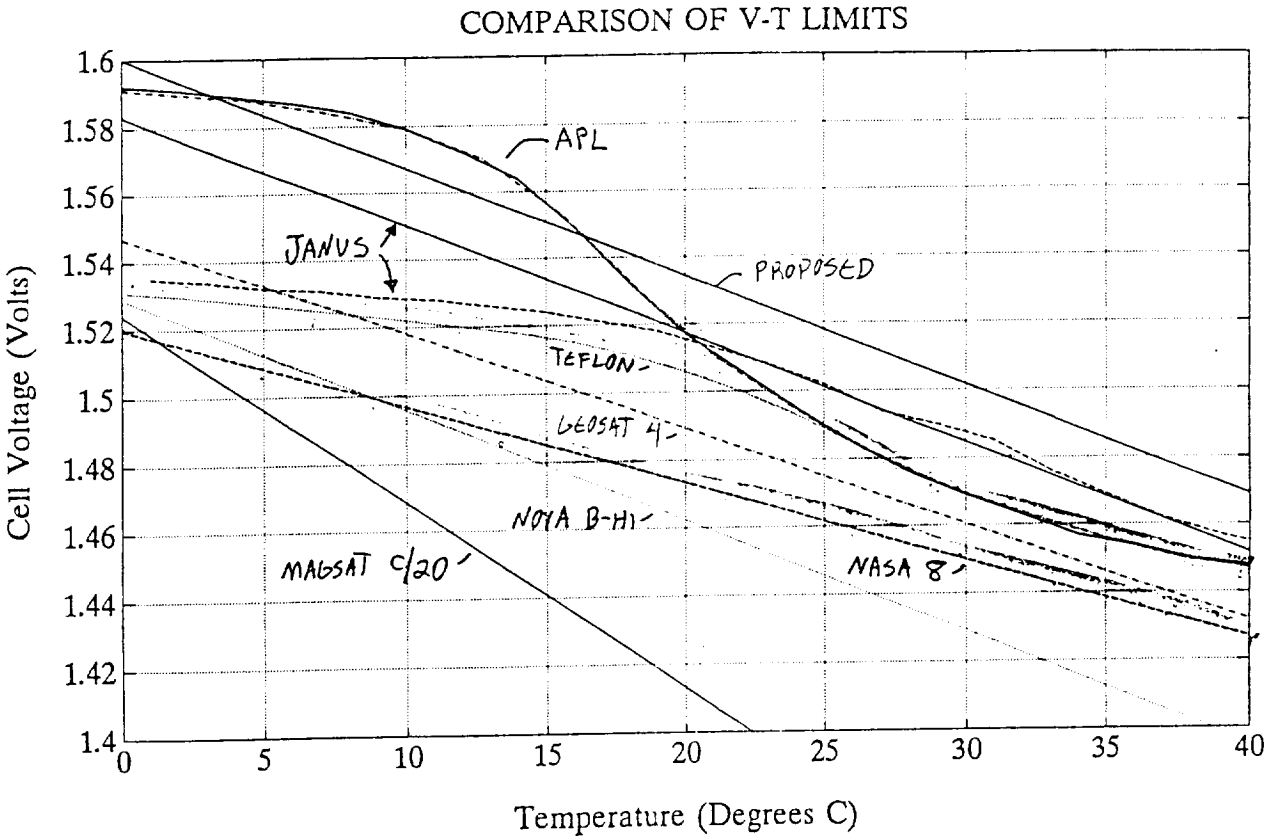

JANUS LIFE TEST - FLIGHT2
AVERAGE AMBIENT TEMPERATURE IN DEGREES C
24
23.5
23
22.5
0
500
1000
1500
2000
CYCLE #

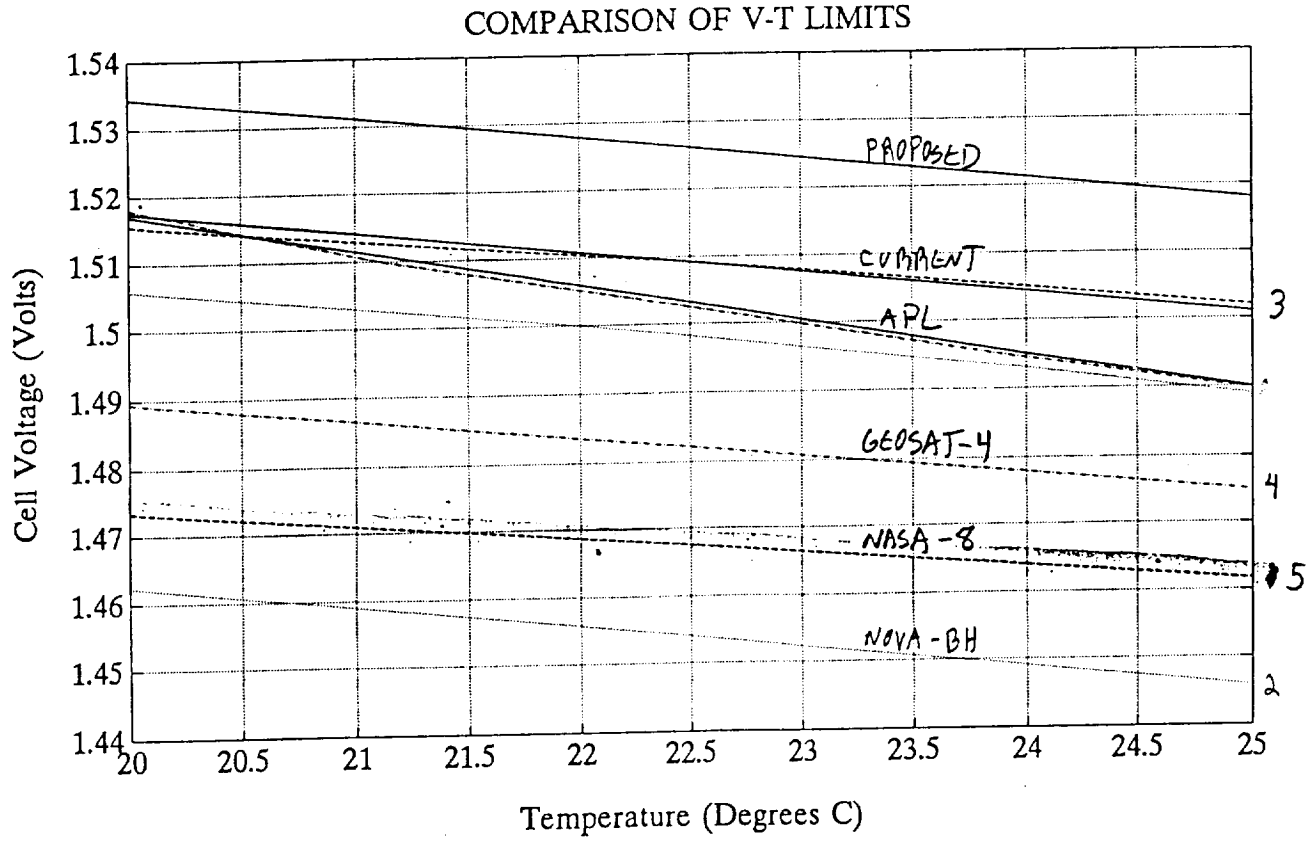

JANUS SUMMARY - FLIGHT2
OF HIGH LOAD CYCLES BETWEEN BREAKS
50
45
40
35
30
25
20
15
10
5
0
100
200
300
400
500
600
OF LOW LOAD CYCLES (BREAKS)

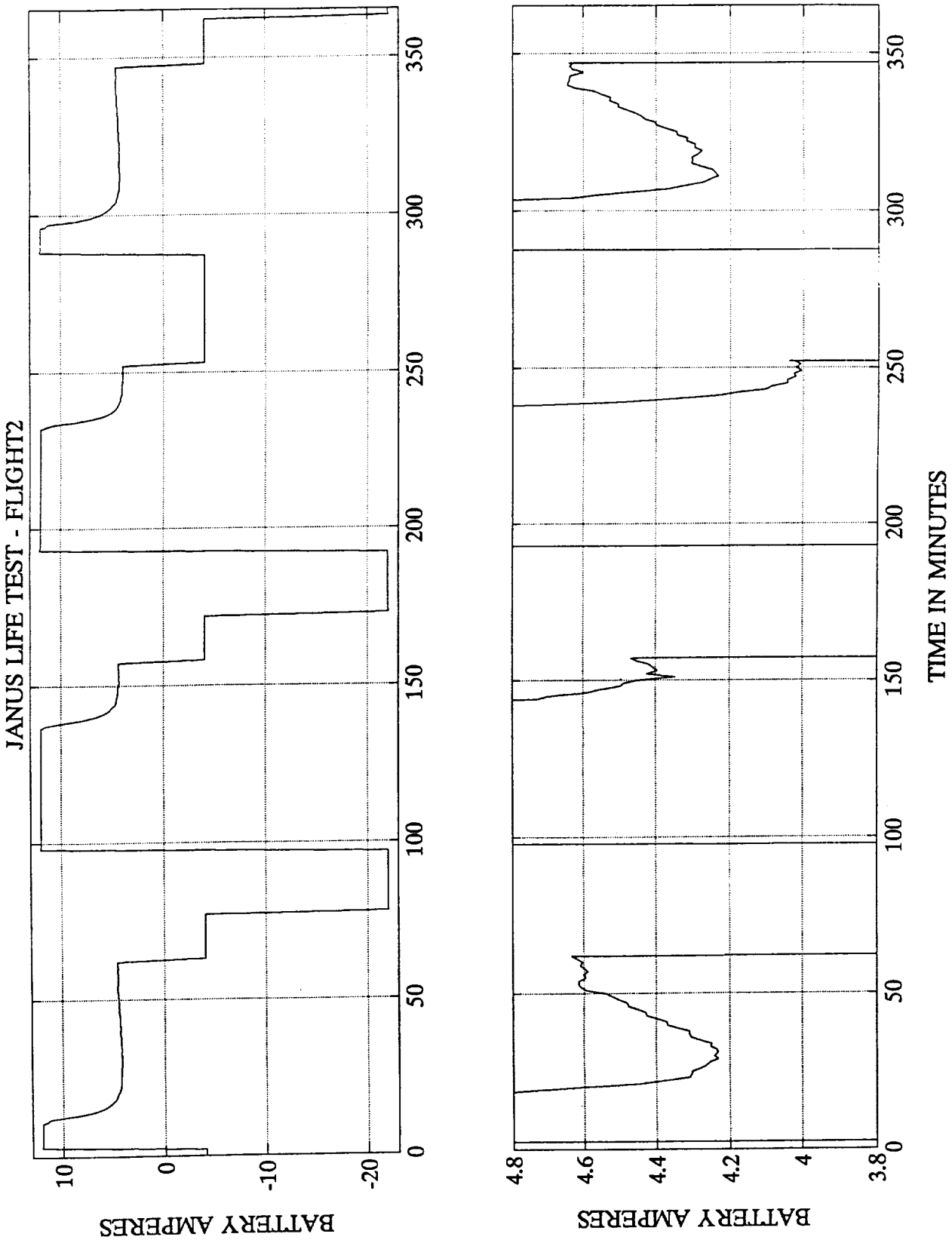

JANUS LIFE TEST - FLIGHT3
CELL VOLTAGE or RATIO
1.35
1.3
1.25
1.2
1.15
1.1
Power In/Out
End of Discharge Voltages
C/D Ratio
0
1000
2000
3000
4000
5000
6000
CYCLE #

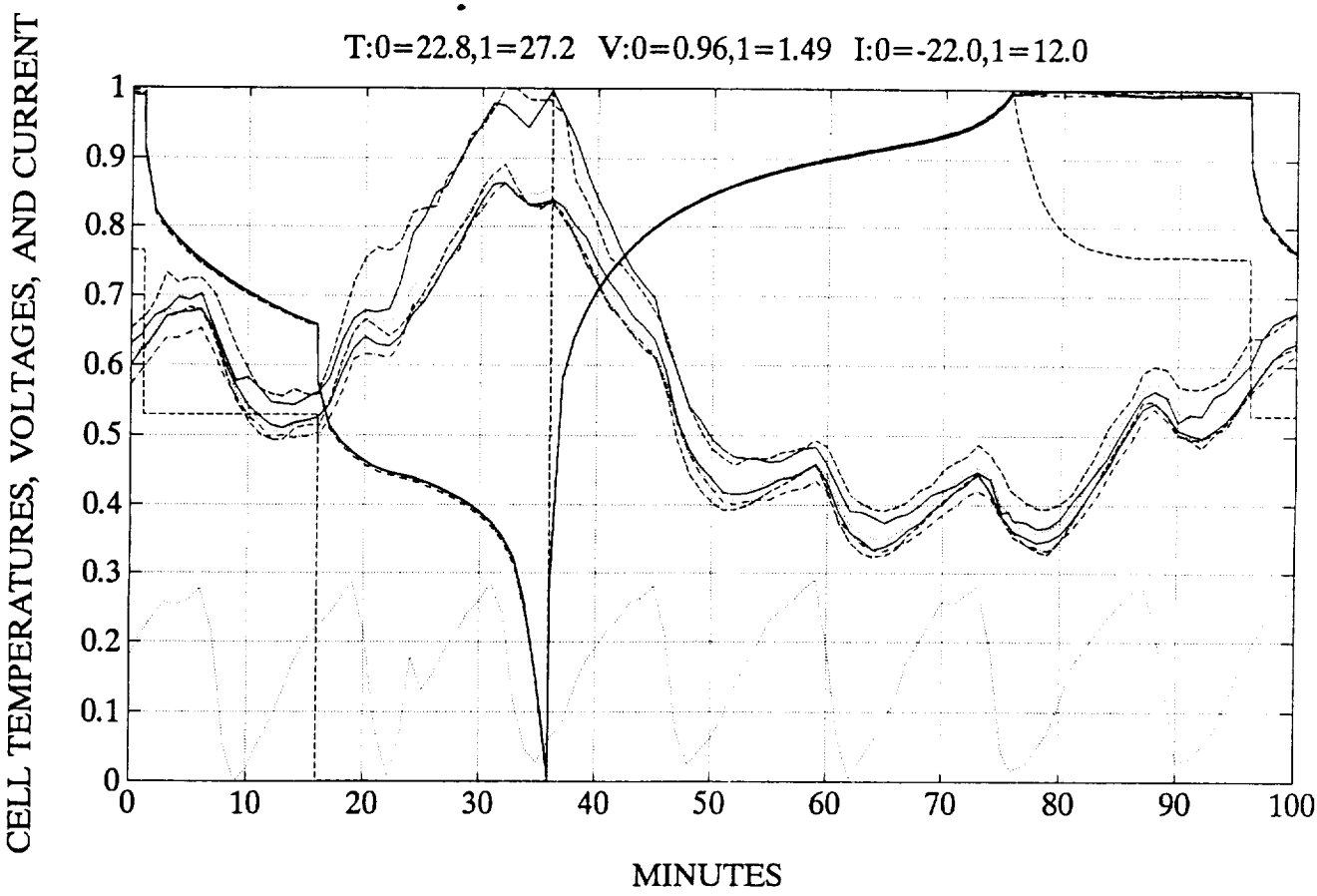

JANUS LIFE TEST - FLIGHT3
BATTERY END OF CHARGE CURRENT IN AMPS
0.95
0.9
0.85
0.8
0.75
0.7
0.65
0.6
0
1000
2000
3000
4000
5000
6000
CYCLE #


VOLTAGE-TEMPERATURE LIMITS for DEEP DOD LEO TEST
Cutoff Limit
15 Min. Limit
Fourth Limit
(cycles 1290-..)
Third Limit
(cycles 1153-1289)
Second Limit
(cycles 930-1152)
First Limit
(cycles 1-929)
CELL VOLTAGE (Volts)
TEMPERATURE (Degrees C)
1.52
1.51
1.5
1.49
1.48
1.47
1.46
1.45
1.44
1.43
1.42
19
20
21
22
23
24
25
26
27
28


COMPARISON OF V-T LIMITS
Cell Voltage (Volts)
Temperature (Degrees C)
APL
JANUS
PROPOSED
TEFLON
GEOSAT 4
NOVA B-H1
MAGSAT C/20
NASA 8
1.6
1.58
1.56
1.54
1.52
1.5
1.48
1.46
1.44
1.42
1.4
0
5
10
15
20
25
30
35
40


COMPARISON OF V-T LIMITS
Cell Voltage (Volts)
Temperature (Degrees C)
PROPOSED
CURRENT
APL
GEOSAT-4
NASA-8
NOVA-BH
3
4
5
2
1.54
1.53
1.52
1.51
1.5
1.49
1.48
1.47
1.46
1.45
1.44
20
20.5
21
21.5
22
22.5
23
23.5
24
24.5
25


JANUS LIFE TEST - FLIGHT2
BATTERY AMPERES
10
0
-10
-20
0
50
100
150
200
250
300
350
BATTERY AMPERES
4.8
4.6
4.4
4.2
4
3.8
0
50
100
150
200
250
300
350
TIME IN MINUTES


T:0=22.8,1=27.2 V:0=0.96,1=1.49 I:0=-22.0,1=12.0
CELL TEMPERATURES, VOLTAGES, AND CURRENT
MINUTES
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
0
10
20
30
40
50
60
70
80
90
100

RESULTS OF DEEP DOD LIFE CYCLE TESTS AT HIGH RATES ON 12Ah NiCd CELLS

Deep DOD LEO missions don't usually require contiguous deep cycling, so batteries can perform better than what most life cycle tests indicate. Significantly more deep DOD cycles are obtainable if the thermal design can dissipate the heat generated by an aging NiCd overcharged to high voltages to obtain a C/D of 1.15.

This test is continuing in order to determine how many more cycles can be achieved as a function of lowering the criteria for end-of-discharge voltage. It will also investigate how high the V-T limit can be pushed before the benefit of higher EOD voltages is negated by the shortened lifetime.