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LOCKHEED MARTIN

EOS–AM1 Nickel Hydrogen Cell Interim Life Test Report

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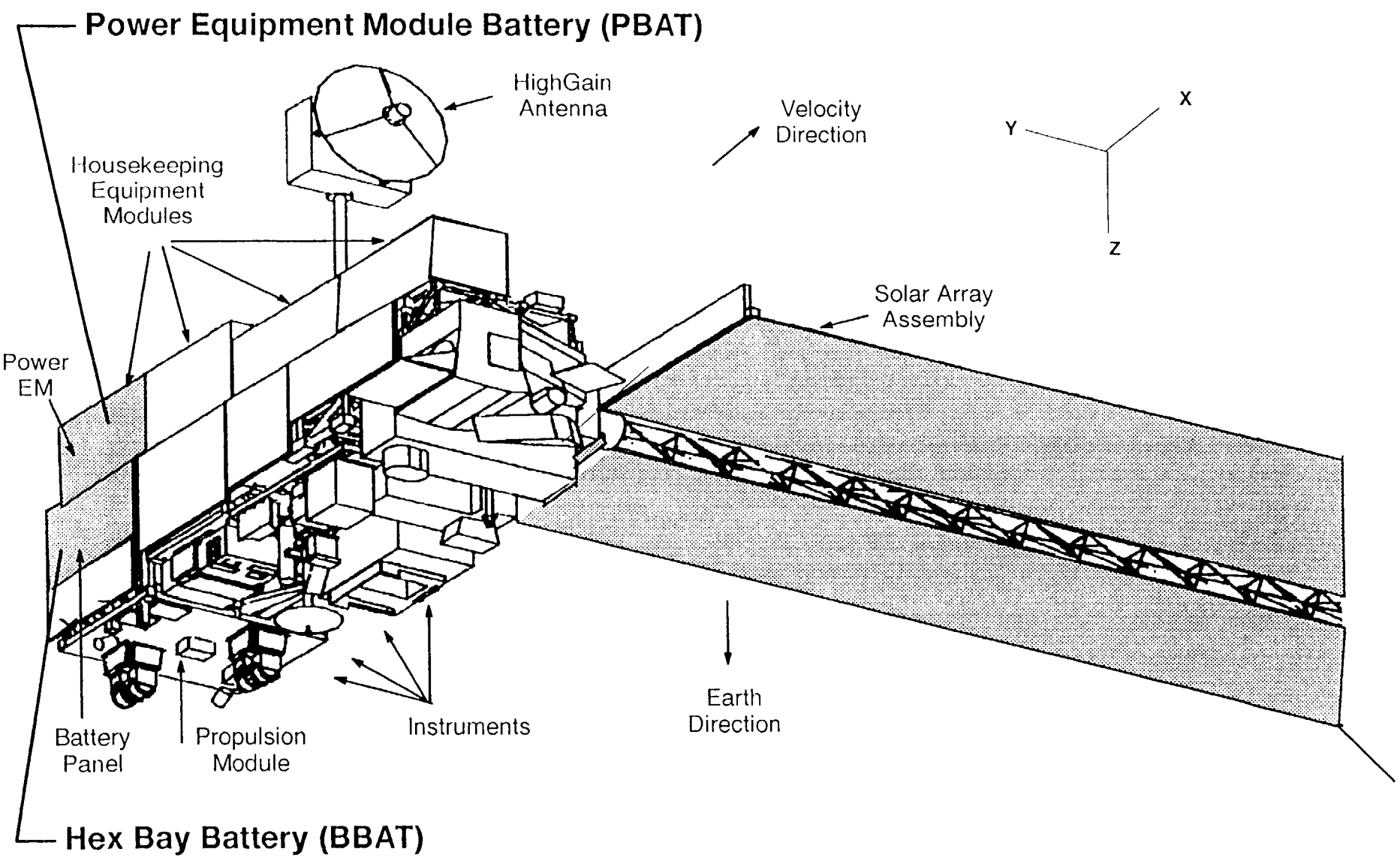
Abstract

This paper reports the interim results of the Earth Observing Systen AM–1 project (EOS–AM–1) nickel hydrogen cell life test being conducted under contract to National Aeronautics and Space Administration (NASA) Goddard Space Flight Center (GSFC) at the Lockheed Martin Missles and Space (LMMS) facility in East Windsor, NJ; and at COMSAT Labs., Glarksburg, MD. The purpose of the tests is to verify that the EOS–AM–1 cell design can meet five years of real–time Low Earth Orbit (LEO) cycling. The tests include both real–time LEO and accelerated stress tests. At LMMS, the first real–time LEO simulated 99 minute orbital cycle started on February 7, 1994 and the test has been running continuously since that time, with 13000 LEO cycles completed as of September 2, 1996. Each cycle consists of a 64 minute charge (VT at 1.507 volts per cell, 1.06 C/D ratio, followed by 0.6 ampere trickle charge) and a 35 minute constant power discharge at 177 watts (22.5% DOD). At COMSAT, the accelerated stress test consists of 90 minute orbital cycles at 60% DOD with a 30 minute discharge at 60 amperes and a 60 minute charge at 40 amperes (VT at 1.54 volts per cell to 1.09 C/D ratio, followed by 0.6 ampere trickle charge).

The real–time LEO life test battery consists of seven, 50AH (nameplate rating) Eagle–Picher, Inc. (EPI) Mantech cells manufactured into three, 3–cell pack assemblies (there are two place holder cells that are not part of the life test electrical circuit). The test pack is configured to simulate the conductive thermal design of the spacecraft battery, including: conductive aluminum sleeves, 3–cell pack aluminum baseplate, and honeycomb panel all mounted to a liquid (–5°C) cold plate. The entire assembly is located in a thermal chamber operating at +3°C. The accelerated stress test unit consists of five cells mounted in machined aluminum test sleeves and is operating at +10°C.

The real–time LEO life test battery has met all performance requirements through the first 13,000 cycles, including: end of charge and discharge cell voltages and voltage gradients; end of charge and discharge cell pressures; within cell and between cell temperature gradients; discharge capacity; current and power levels; and all charge parameters. The accelerated stress test battery has completed over 5900 cycles as of 9/11/96. This paper reports both battery performances as a function of cycle life, with individual cell performance comparisons reported for selected cycles in both tests.

Battery Assembly/Spacecraft Interface



Outline

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- EOS–AM cell parameters
- Real–time LEO test conditions
- Real–time LEO test results
  - Figures 1–13
- Accelerated LEO stress test conditions
- Accelerated LEO stress test results
  - Figures 14–20
- Summary and conclusions

EOS–AM Cell Parameters

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- Single stack, IPV, Mantech design
- Rabbit ear terminals
- 40, 30 mil slurry electrodes
- Back to back with double layer Zircar, catalyzed wall wick
- 31% KOH, nickel precharge
- Average cell weight = 1490 grams
- Average delivered capacity (C/2 discharge)
  - –10°C: 75 AH
  - 0°C: 71 AH
  - +10°C: 63 AH
  - +20°C: 56 AH
  - +30°C: 51 AH

Real–time LEO Test Conditions

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- Performed at LMMS, East Windsor, NJ
- Number of cells: 7
- Cell configuration:
  - Conductive thermal design with same configuration as spacecraft
  - Machined aluminum sleeves and baseplate
  - Chotherm and RTV 566 isolation
  - Mounted to spacecraft honeycomb panel with Al face sheets
  - Liquid cooled (–5°C) cold plate
- Discharge regime: 177 watts (total) constant power discharge for 35 minutes
- Depth of discharge: 22.5% nominal
- Charge regime:
  - 12.3 ampere to 1.507 V/T (per cell), taper to 1.06 C/D, 0.6 A trickle
  - 64 minute total charge time

LMMS Test Anomalies

Table I
Schedule of Test Interruptions and Changes

Event[1]	Date	Cycle	Description
A	2/21/94	200	Charge time reached prior to VT limit. Several test aborts
B	4/26/94	1110	STE malfunction caused cells to be discharged ~ 45 AH without recharge. Charge time limit reached prior to VT limit
C	10/21/94	3500	VT changed from 10.550 to 10.626
D	10/28/94	3750	Discharge load changed from 177 watts to 88 watts
E	11/5/94	3850	Discharge load changed from 88 watts to 177 watts
F	11/7/94	3900	VT changed from 10.626 to 10.550
G	2/7/95 - 3/26/95	5200 - 5900	Data printouts not found
H	5/15/95	6600	Several short duration test aborts
I	6/30/95– 7/3/95	7200	Test cells on open circuit due to STE problems
J	9/1/95– 9/28/95	8100	Test cells on open circuit due to STE problems
K	11/10/95– 11/1195	8700	Test cells on open circuit due to STE problems

Notes:
1. Event letters are used as markers in Figures 1–13

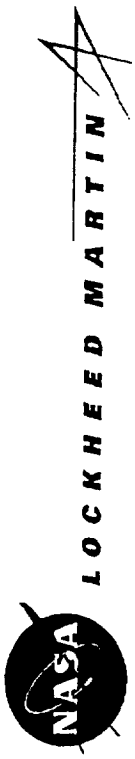
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Fig 1

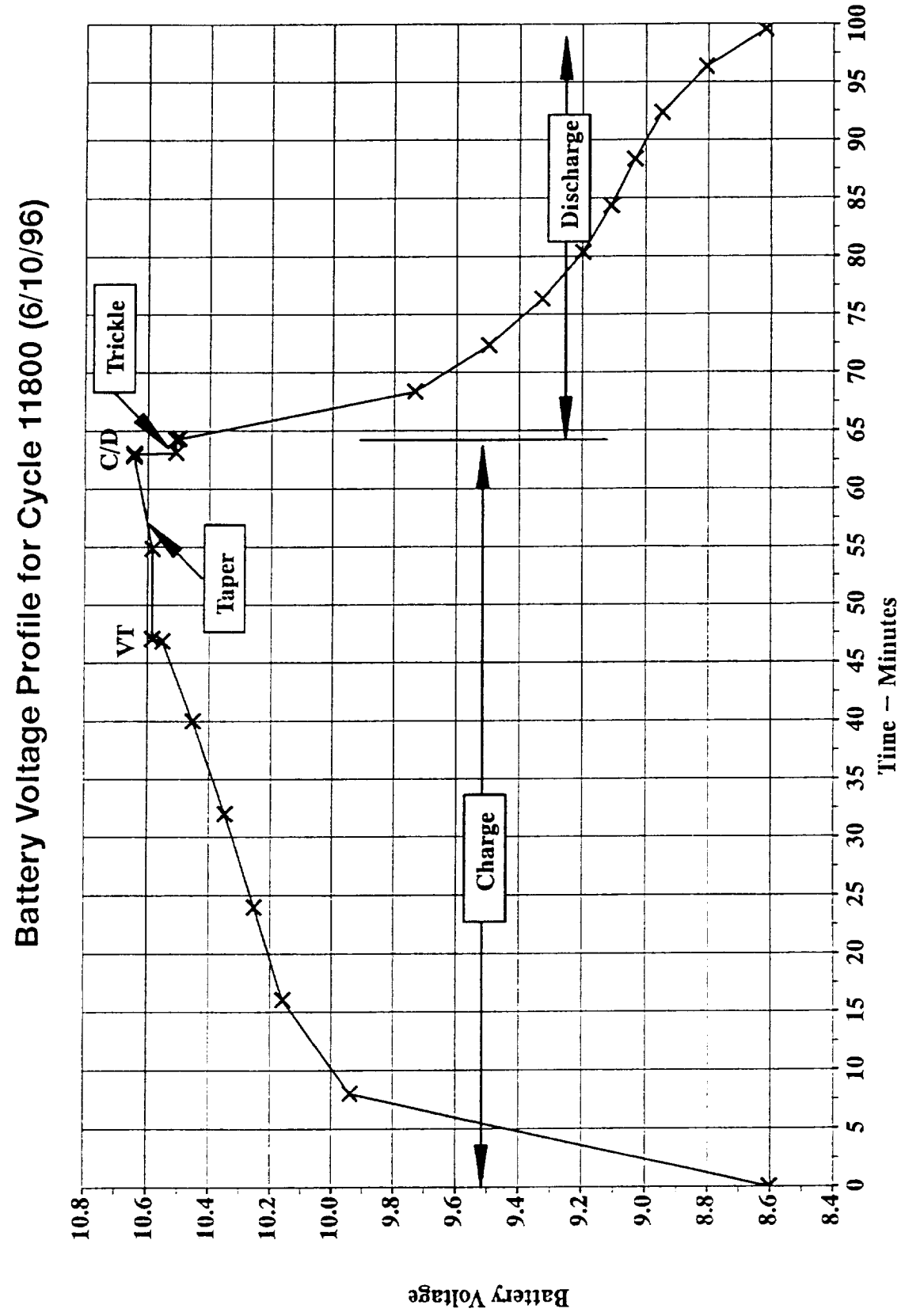
Battery Voltage Profile for Cycle 11800 (6/10/96)
Trickle
C/D
Taper
VT
Charge
Discharge
Battery Voltage
Time – Minutes
10.8
10.6
10.4
10.2
10.0
9.8
9.6
9.4
9.2
9.0
8.8
8.6
8.4
0
5
10
15
20
25
30
35
40
45
50
55
60
65
70
75
80
85
90
95
100

Fig 2

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Battery Current Profile for Cycle 11800 (6/10/96)

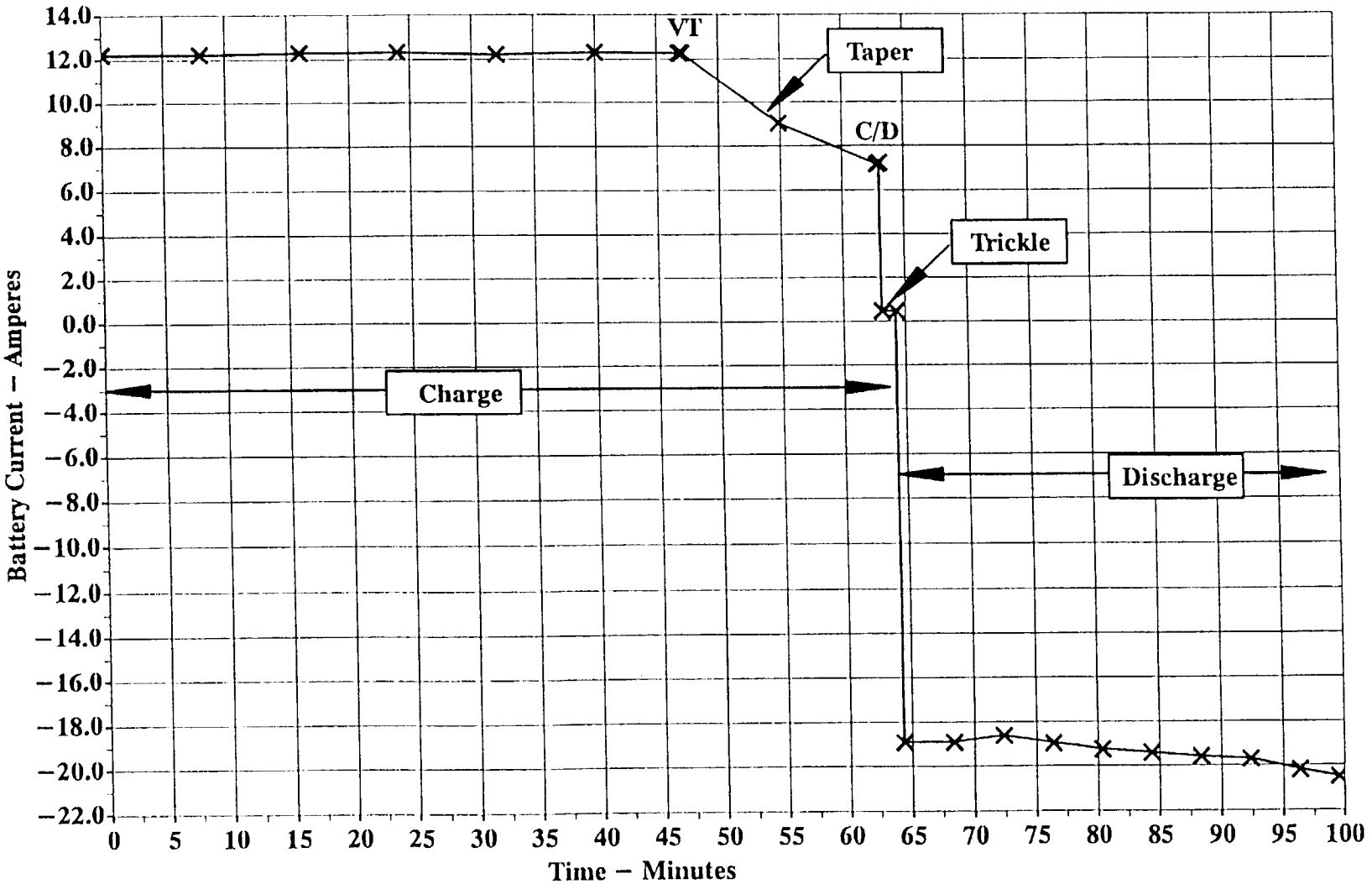

Fig 3

End of Charge and Discharge Battery Voltage vs LEO Cycle

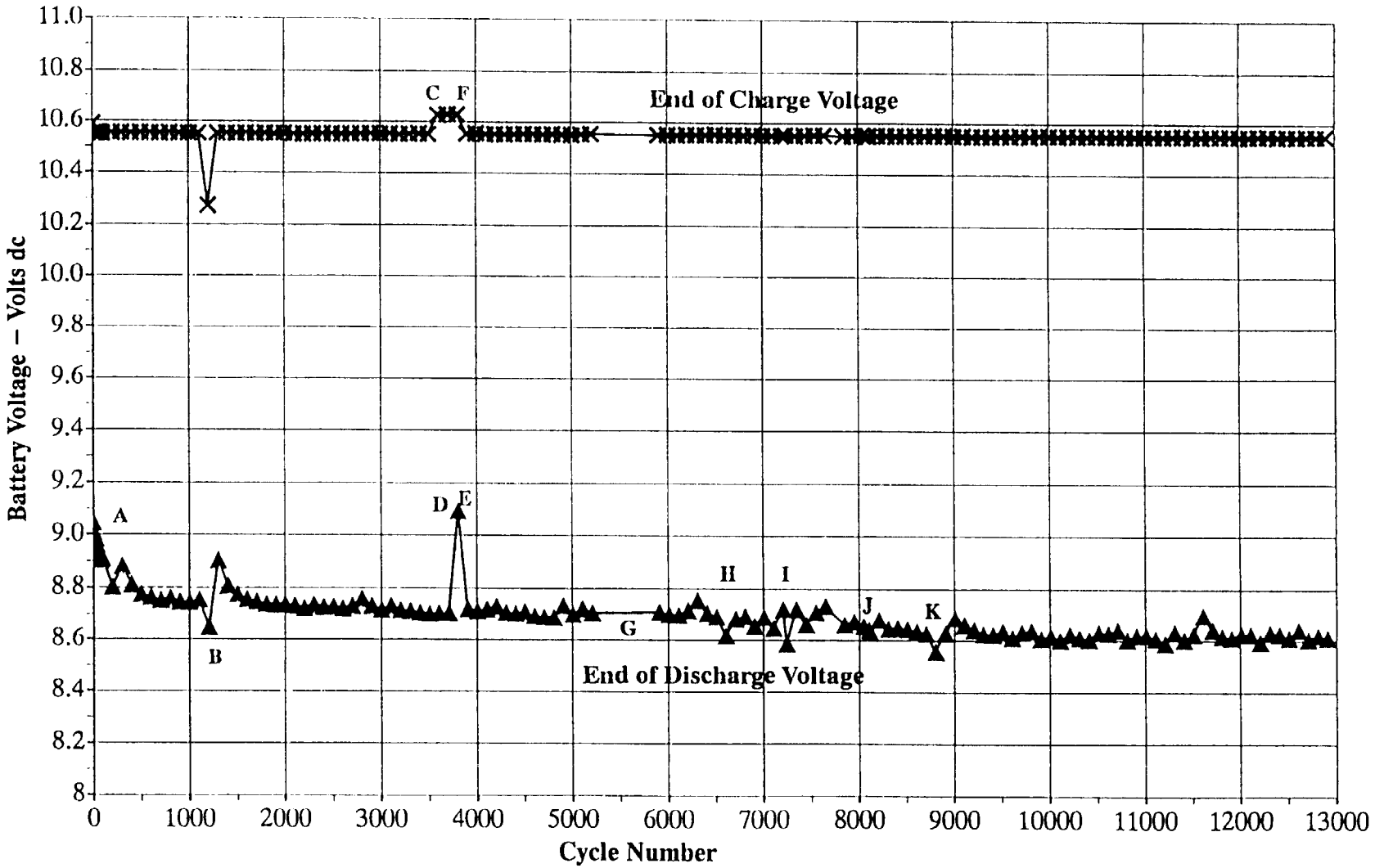

Fig 4

Minimum and Maximum Cell End of Charge and Discharge Voltage vs LEO Cycle

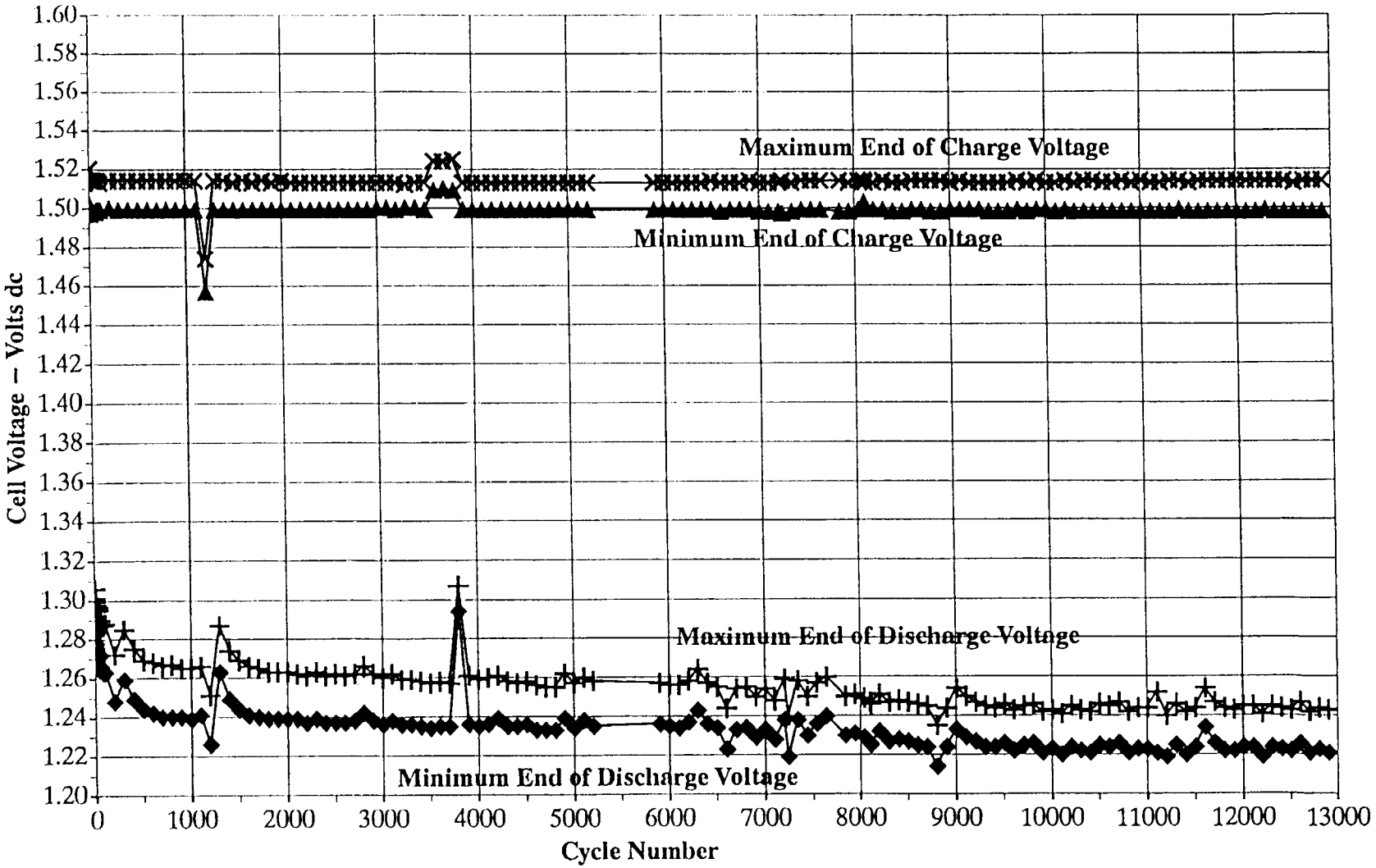

Fig 5

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Minimum and Maximum Cell End of Discharge Voltage (Expanded Scale) vs LEO Cycle

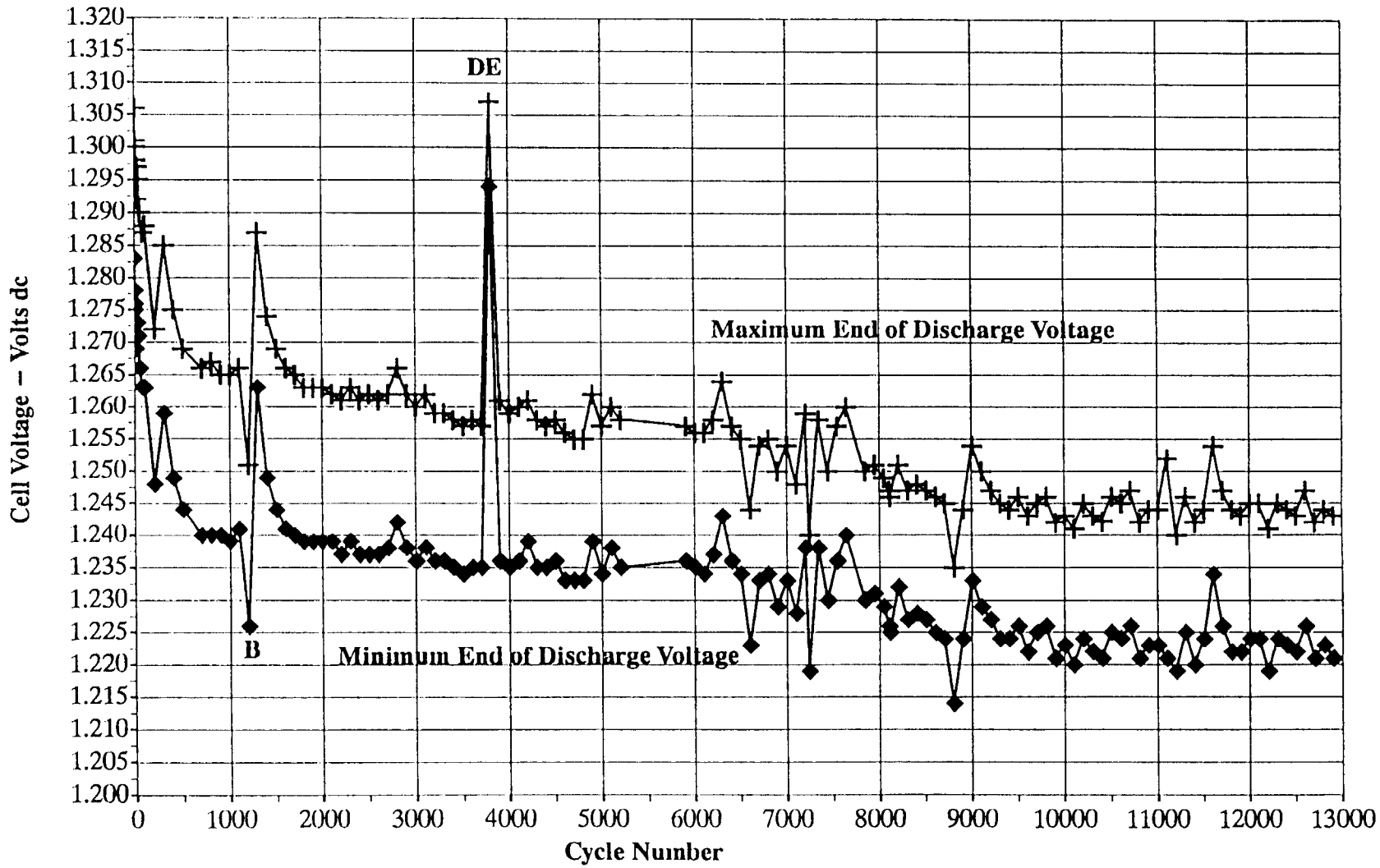

Fig 6

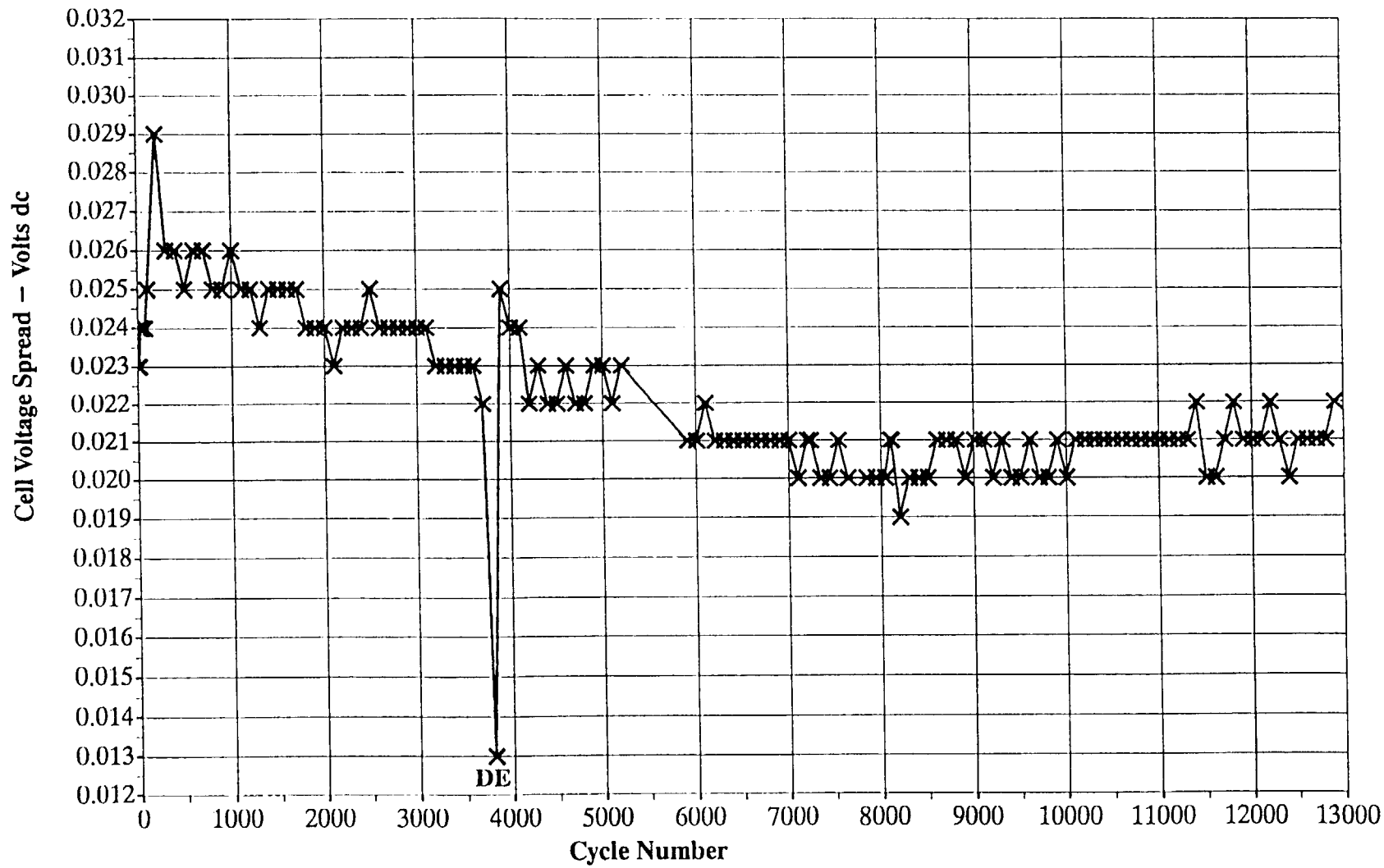
End of Discharge Cell Voltage Gradient vs LEO Cycle
Cell Voltage Spread – Volts dc
0.032
0.031
0.030
0.029
0.028
0.027
0.026
0.025
0.024
0.023
0.022
0.021
0.020
0.019
0.018
0.017
0.016
0.015
0.014
0.013
0.012
DE
0
1000
2000
3000
4000
5000
6000
7000
8000
9000
10000
11000
12000
13000
Cycle Number

Fig 7

C/D Ratio (Total Charge Capacity/Total Discharge Capacity) vs LEO Cycle

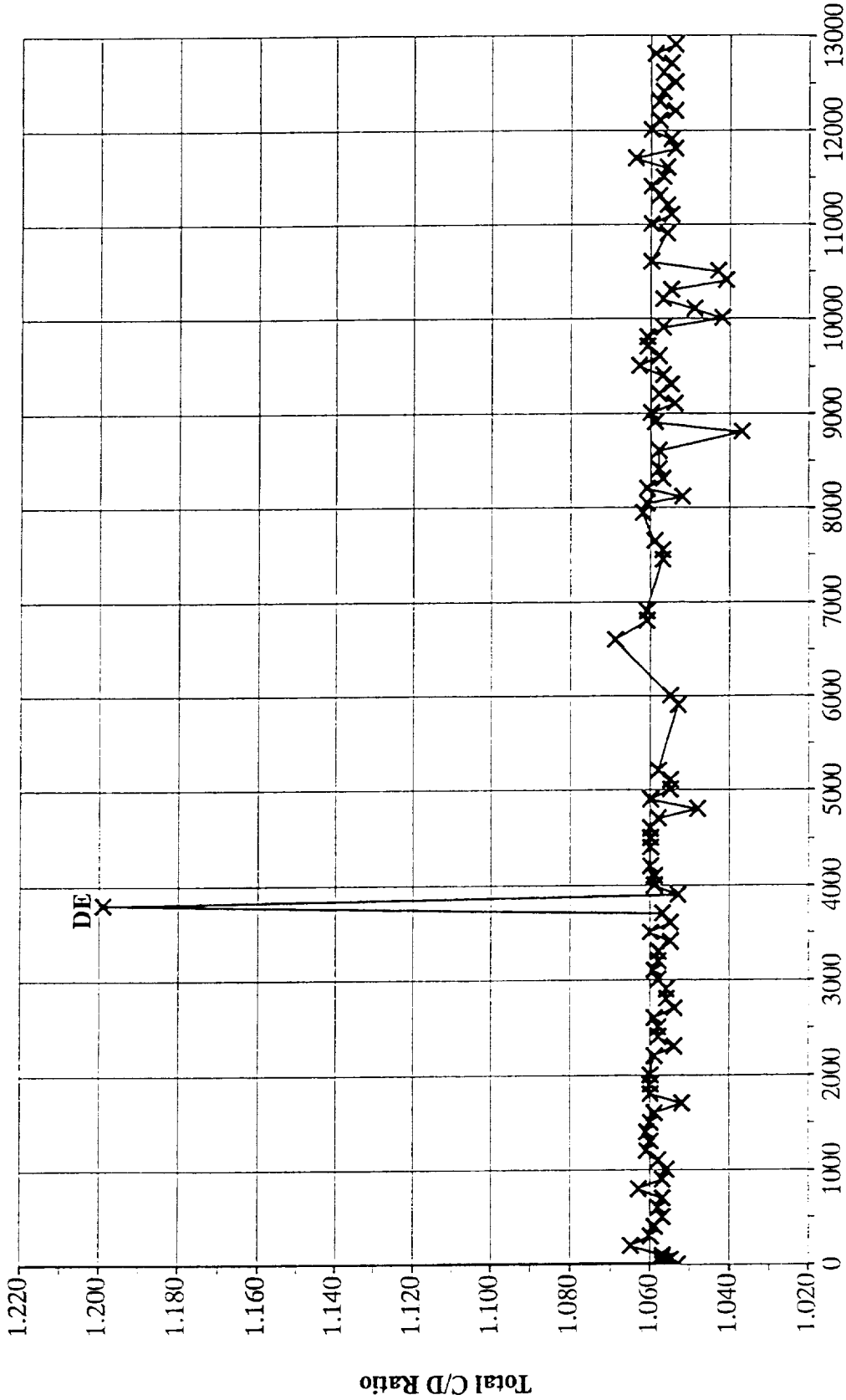

Fig 8

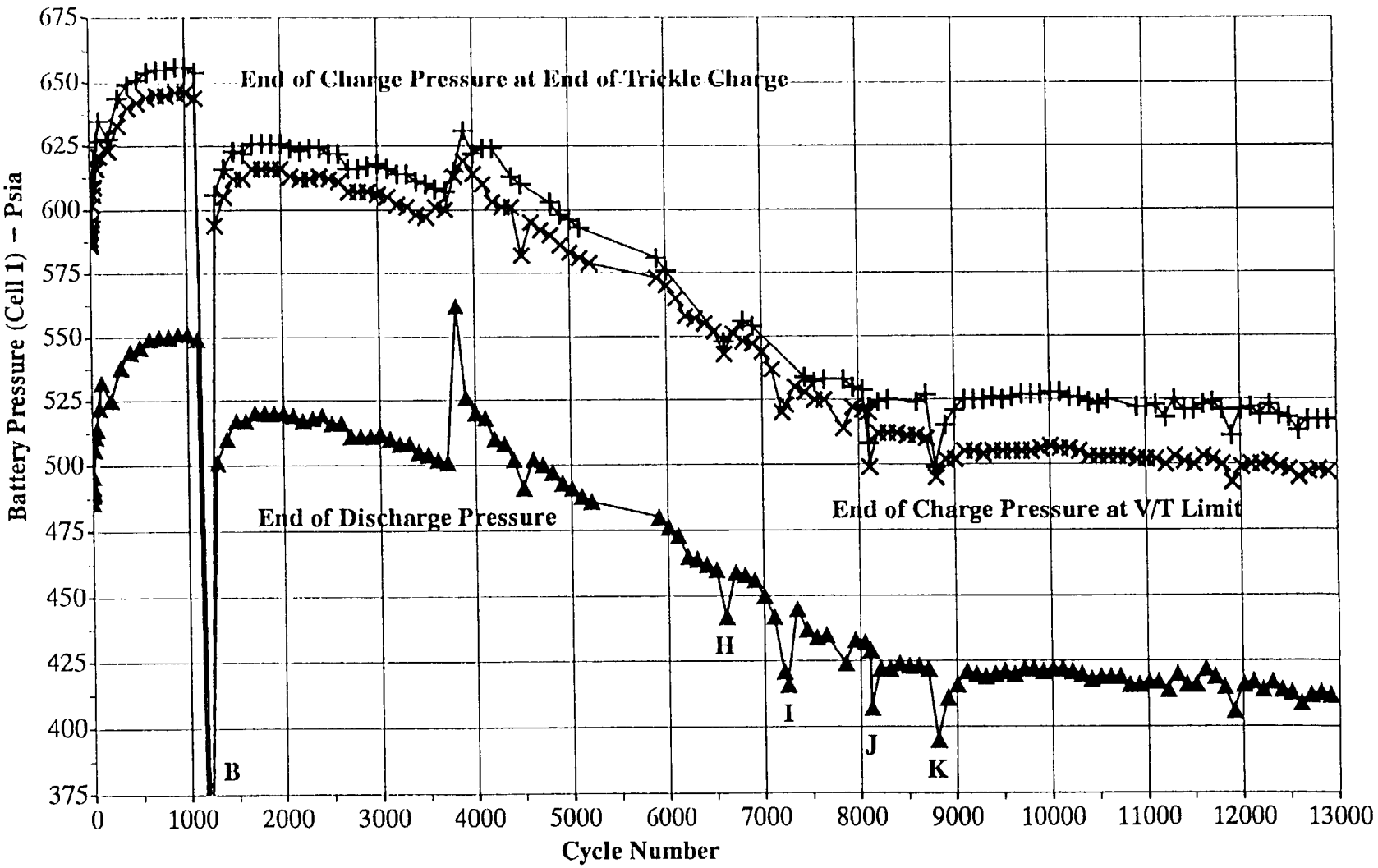
Cell 1 Pressure vs LEO Cycle
End of Charge Pressure at End of Trickle Charge
End of Discharge Pressure
End of Charge Pressure at V/T Limit
B
H
I
J
K
Battery Pressure (Cell 1) – Psia
Cycle Number
675
650
625
600
575
550
525
500
475
450
425
400
375
0
1000
2000
3000
4000
5000
6000
7000
8000
9000
10000
11000
12000
13000

Fig 9

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Individual Cell Voltage Profile for Cycle 11800

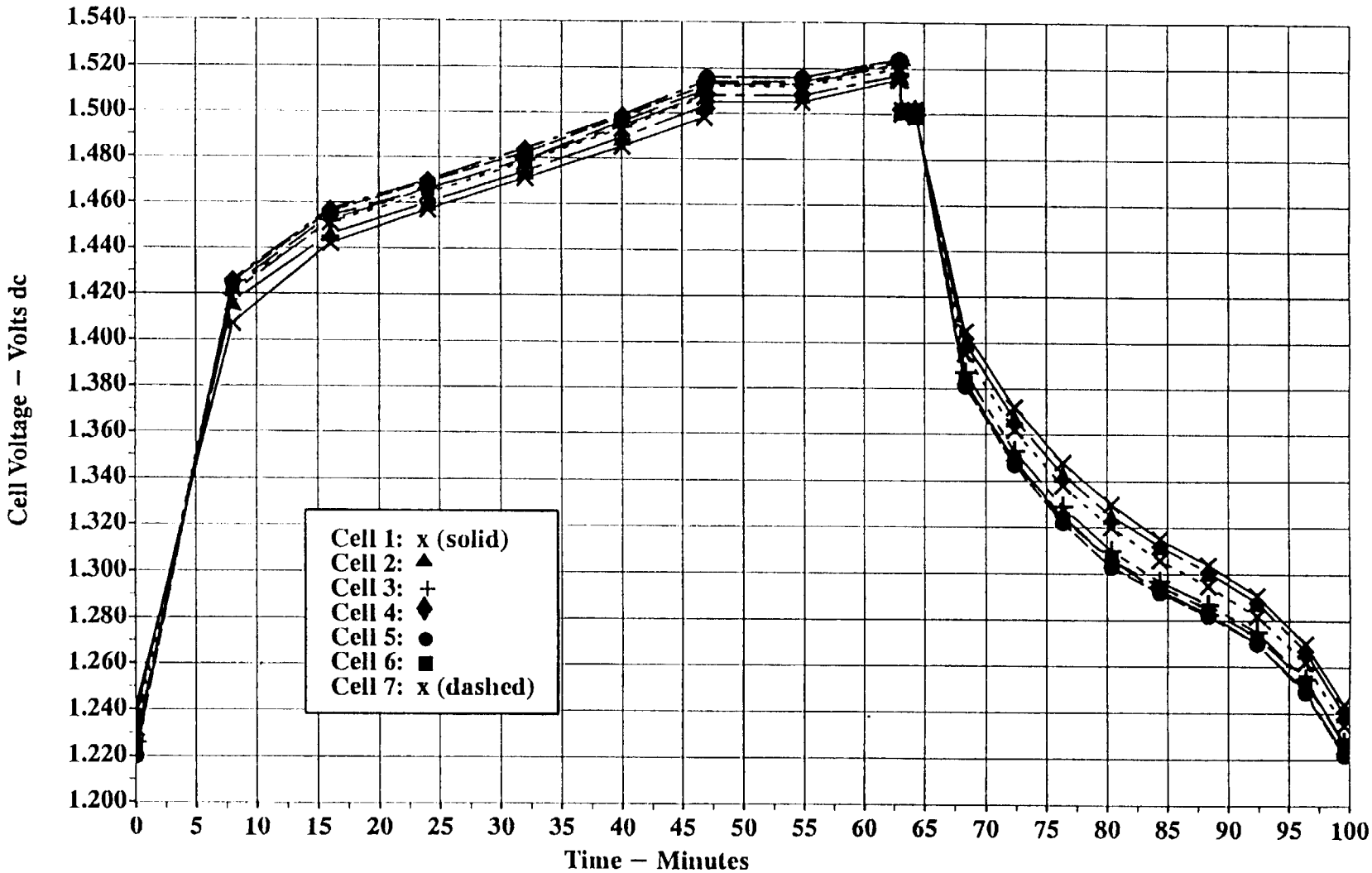

Fig 10

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Individual Cell Voltage Profile (Charge Regime) for Cycle 11800

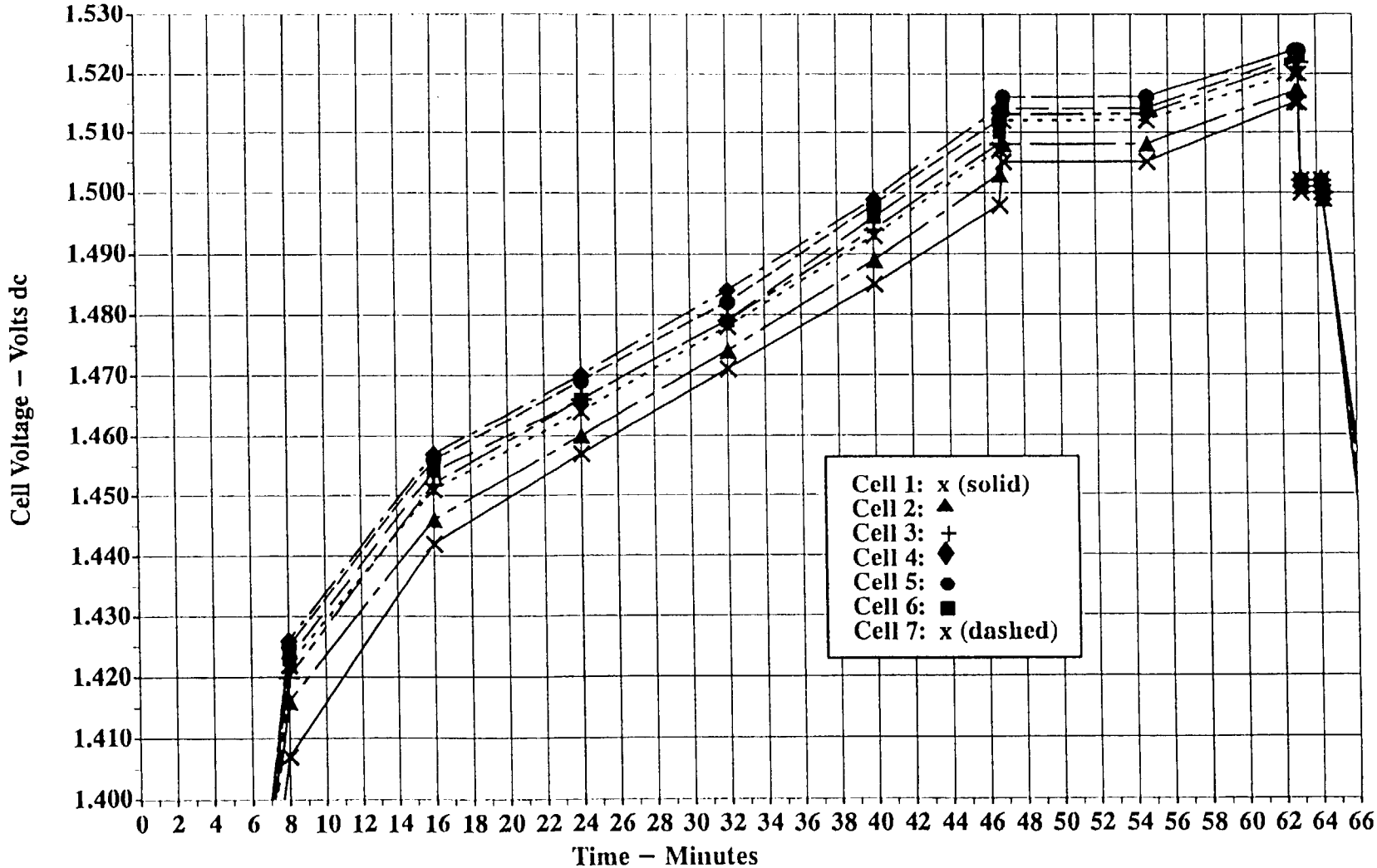


Fig 11

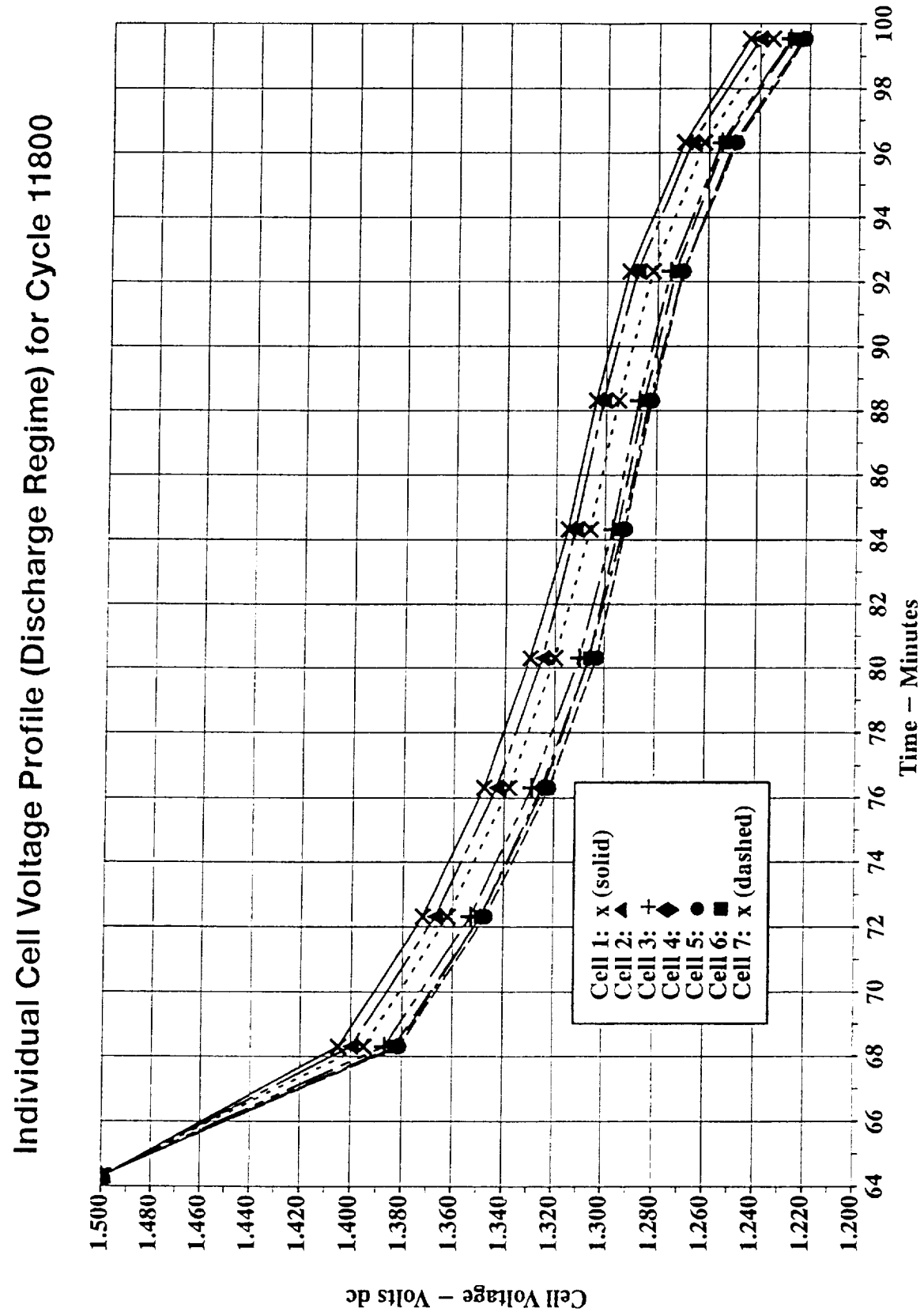

Individual Cell Voltage Profile (Discharge Regime) for Cycle 11800
Cell Voltage – Volts dc
Time – Minutes
1.500
1.480
1.460
1.440
1.420
1.400
1.380
1.360
1.340
1.320
1.300
1.280
1.260
1.240
1.220
1.200
64
66
68
70
72
74
76
78
80
82
84
86
88
90
92
94
96
98
100
Cell 1: x (solid)
Cell 2: ▲
Cell 3: +
Cell 4: ◆
Cell 5: ●
Cell 6: ■
Cell 7: x (dashed)

Fig 12

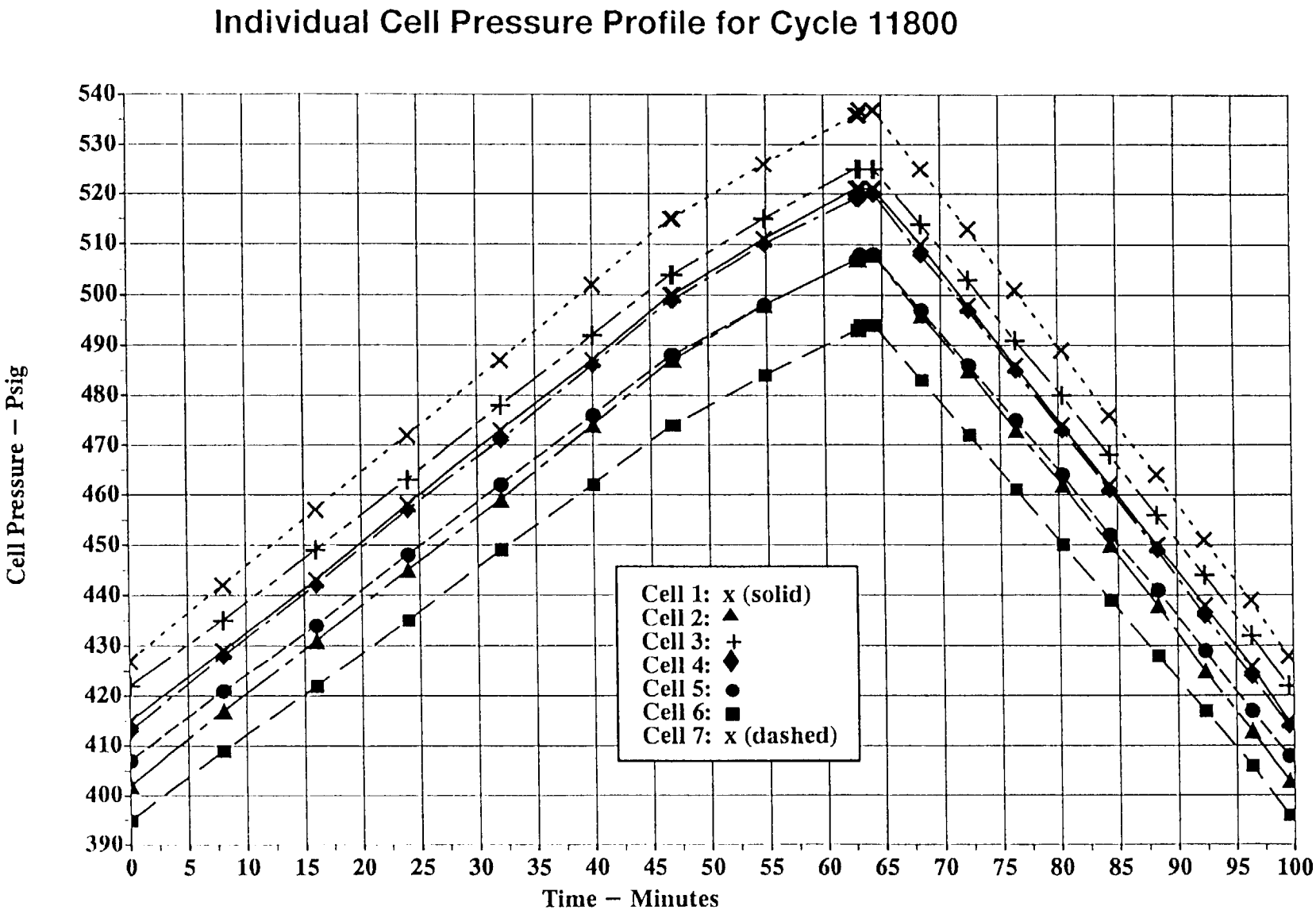
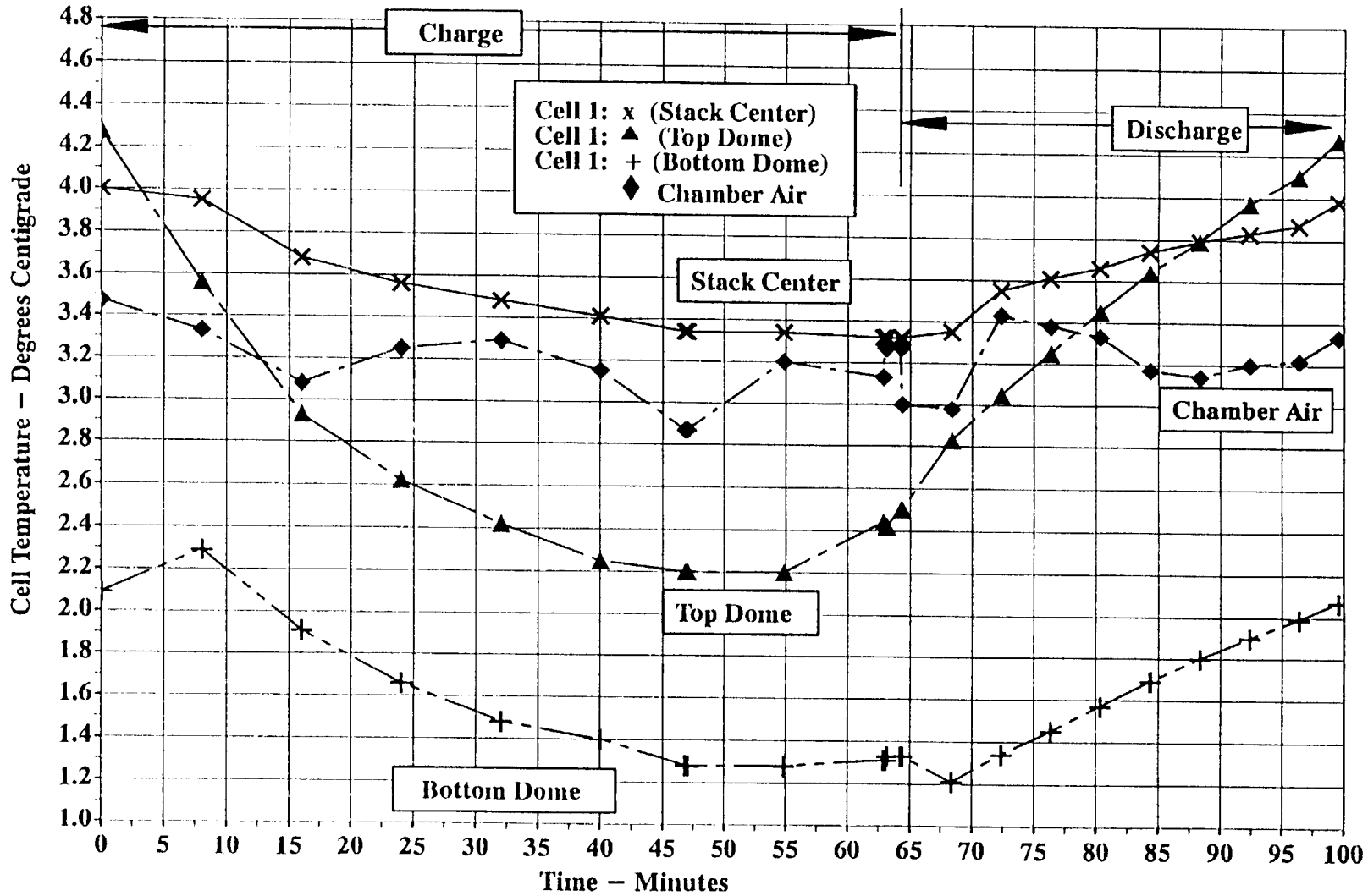

Individual Cell Pressure Profile for Cycle 11800
Cell Pressure – Psig
Time – Minutes
Cell 1: x (solid)
Cell 2: ▲
Cell 3: +
Cell 4: ♦
Cell 5: ●
Cell 6: ■
Cell 7: x (dashed)
540
530
520
510
500
490
480
470
460
450
440
430
420
410
400
390
0
5
10
15
20
25
30
35
40
45
50
55
60
65
70
75
80
85
90
95
100

Fig 13

NASA LOCKHEED MARTIN

Cell 1 Temperature Profile for Cycle 11800



Accelerated Stress Test Conditions

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- Performed at COMSAT Laboratories
- Number of cells: 5
- Cell configuration:
  - Machined aluminum sleeves
  - Mounted on a cold plate
  - Chotherm and RTV 566 isolation
- Test temperature: 10°C
- Discharge regime: 60 amperes for 30 minutes
- Depth of discharge: 60%
- Charge regime:
  - 40 ampere to 1.54 V/T (per cell), taper to 1.09 C/D, 0.6 A trickle
  - 60 minute total charge time

Fig 14

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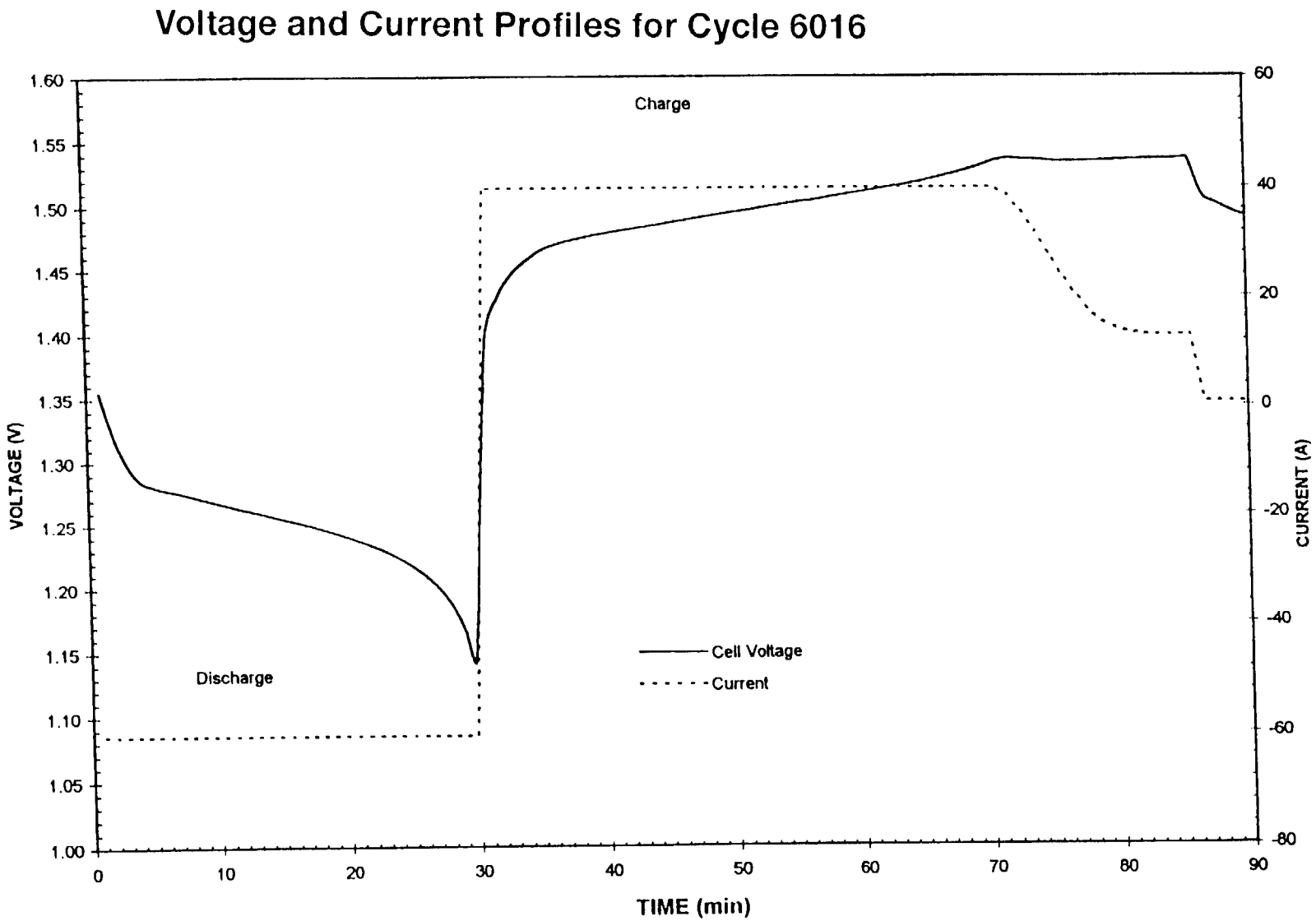

Fig 15

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Variation of C/D Ratio with Cycling

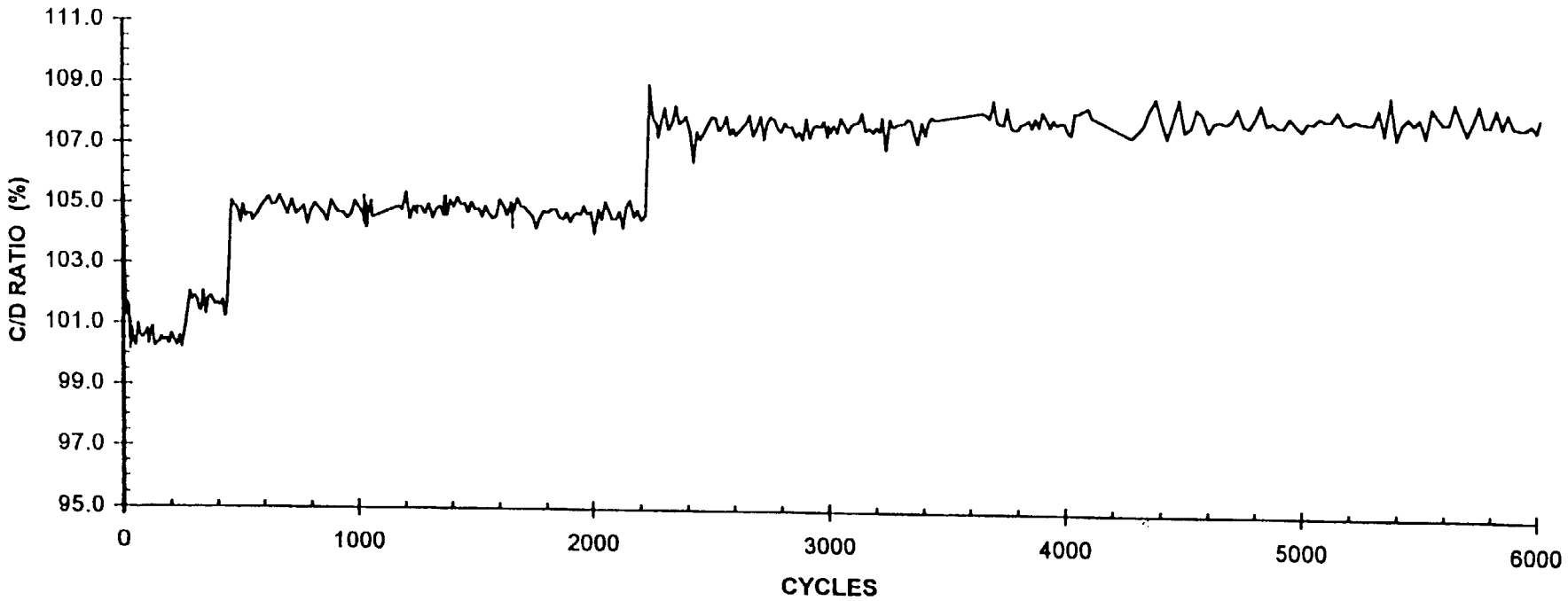

Fig 16

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Variation of Temperature with Cycling

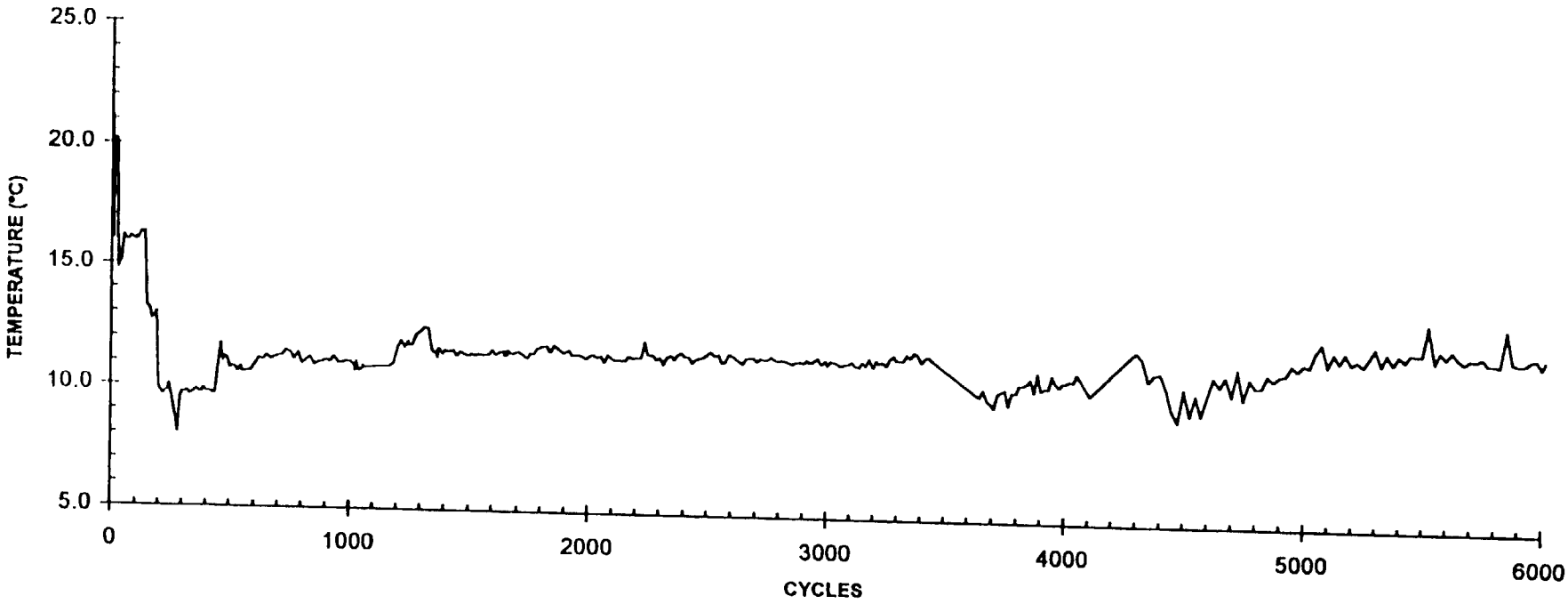

Fig 17

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Variation of End of Discharge Voltage with Cycling

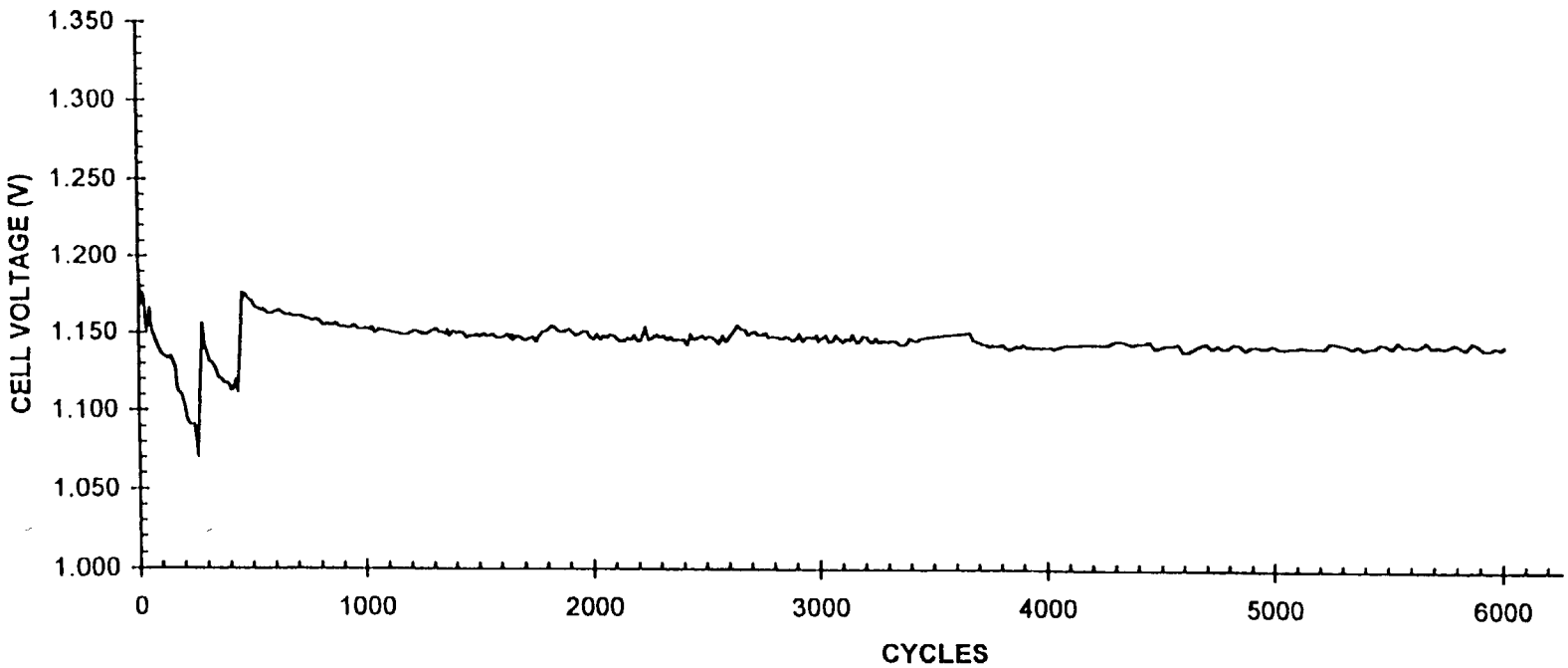

Fig 18

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Variability in the End of Discharge Voltage Among Cells

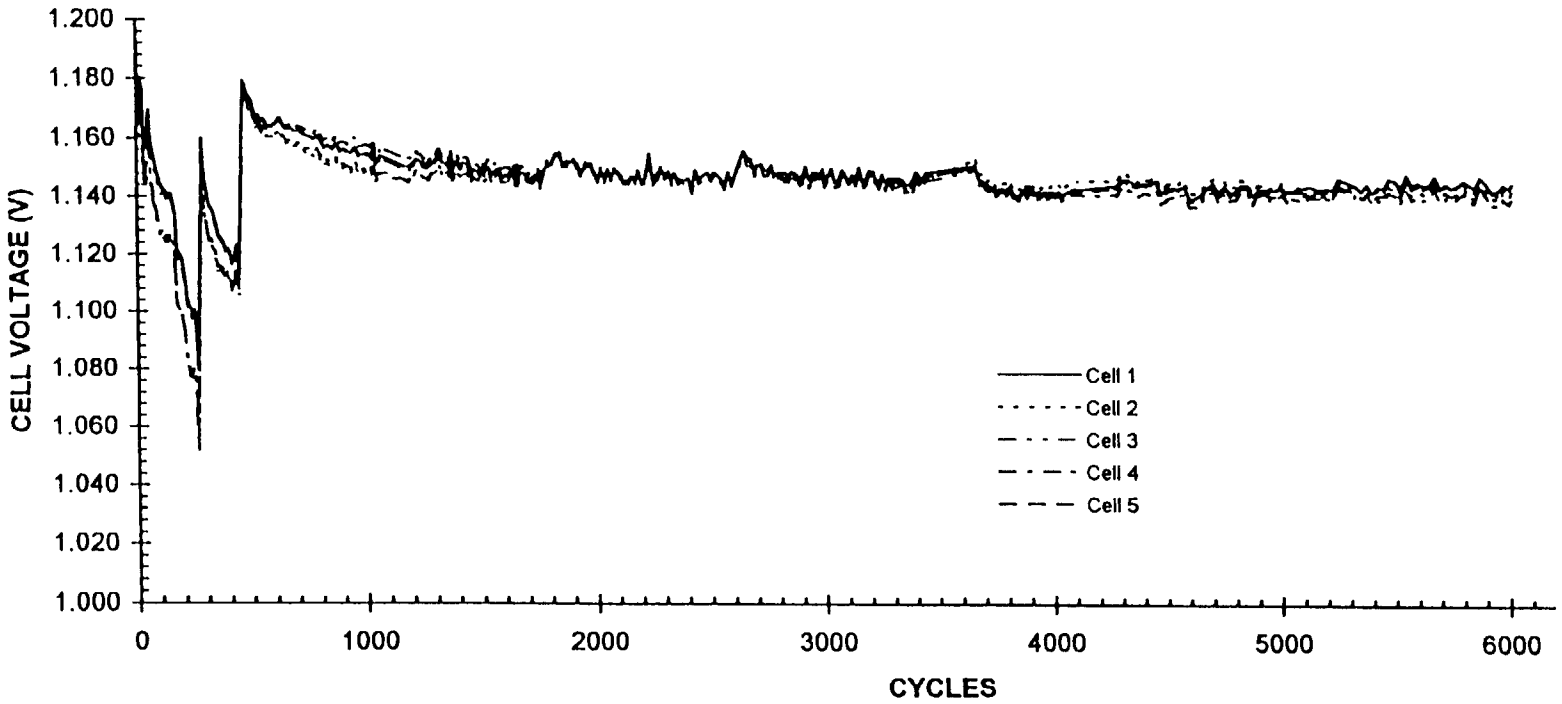

Fig 19

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Variation of End of Charge Pressure with Cycling

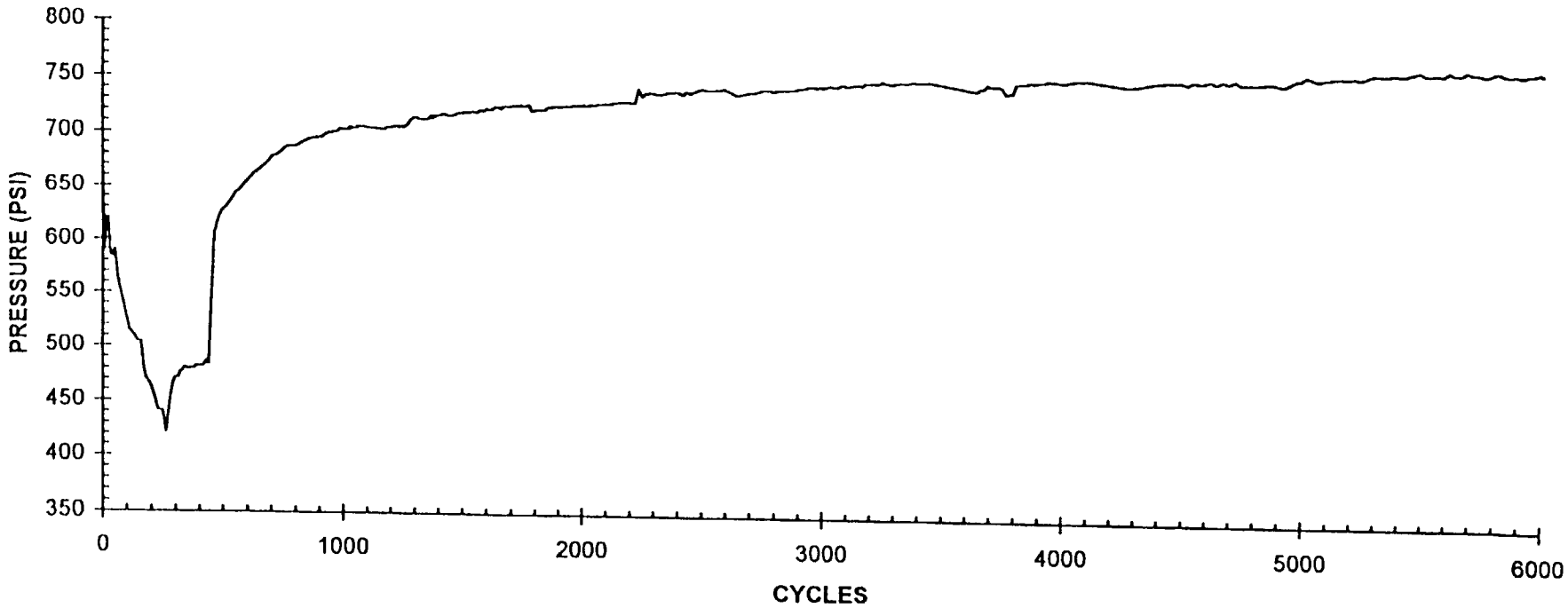

Fig 20

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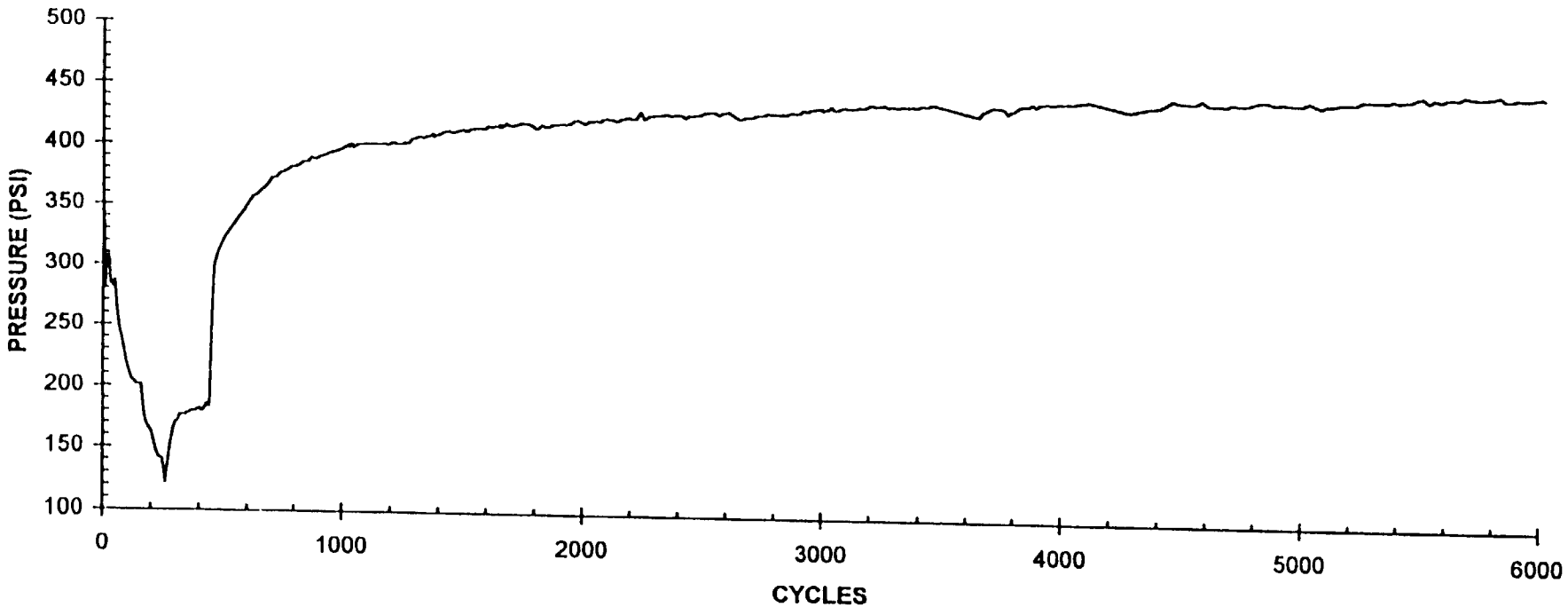
Variation of End of Discharge Pressure with Cycling



Summary and Conclusions

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- Real–time LEO life test at Lockheed Martin Missles and Space
  - Cells have completed 14300 cycles as of 12/2/96
  - End of discharge voltage decreased initially and has stabilized
  - Variation in end of discharge cell voltage has converged with cycling
  - Cell EODP and EOCP stabilized after 8000 cycles
    - 1.51 V/T limit and 1.06 C/D insufficient to makeup for early test problems (cells on open circuit during all test outages)
  - A reconditioning cycle (first cell to 1.000 volt) is scheduled to be performed
    - Sequence will replicate spacecraft operations
- Accelerated LEO stress test at COMSAT Labs.
  - Cells have completed 6015 cycles
  - End of discharge voltage decreased initially and has stabilized
  - Charge termination at 1.54 V and 1.09 C/D is appropriate for 60% DOD cycling
  - Pressure increased with cycling and has stabilized in 6000 cycles