PRELIMINARY RESULTS: ROOT CAUSE INVESTIGATION OF ORBITAL ANOMALIES AND FAILURES IN NASA STANDARD 50 AMPERE-HOUR NICKEL-CADMIUM BATTERIES

PRESENTED: 1992 NASA AEROSPACE BATTERY WORKSHOP
17 - 19 NOVEMBER 1992

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PROBLEM STATEMENT

TWO LOTS OF NASA STANDARD 50 A.H. NICD BATTERY CELLS, MANUFACTURED BY GATES AEROSPACE BATTERIES AND BUILT INTO BATTERIES BY McDONNELL DOUGLAS, HAVE EXPERIENCED SIGNIFICANT PERFORMANCE PROBLEMS:

- COMPTON GAMMA RAY OBSERVATORY - MODULAR POWER SUBSYSTEM (MPS) #1: 3 BATTERIES (GRO-1)*
- UPPER ATMOSPHERE RESEARCH SATELLITE: 3 BATTERIES (UARS)

BOTH ARE LEO SATELLITES CONTAINING BATTERIES ON A PARALLEL BUS CHARGED TO NASA STANDARD V/T CURVES USING A NASA STANDARD POWER REGULATOR.

* A SECOND MPS (GRO-2), WHICH IS ELECTRICALLY INDEPENDENT OF THE FIRST MPS (GRO-1), ALSO CONTAINS 3 BATTERIES THAT HAVE EXPERIENCED NO PERFORMANCE PROBLEMS TO DATE.

NOTE: DEVELOPMENT OF BATTERIES FOR THE GRO AND UARS MISSIONS WAS PERFORMED UNDER CONTRACTS NAS5-28066 AND NAS5-30227 WITH THE GODDARD SPACE FLIGHT CENTER, GREENBELT, MARYLAND.

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ANOMALY DESCRIPTION

GRO-1 BATTERIES

- SPACECRAFT LAUNCHED 5 APRIL 1991.
- BATTERIES DEVELOPED HALF-BATTERY DIFFERENTIAL VOLTAGES EXCEEDING 100 mV APPROXIMATELY 7 MONTHS AFTER LAUNCH.

  NOTE: THE HALF-BATTERY DIFFERENTIAL MONITORS THE VOLTAGE DIFFERENCE BETWEEN THE "TOP" 11 CELLS IN THE 22-CELL SERIES STRING AND THE "BOTTOM" 11 CELLS.
- BATTERIES LATER DEVELOPED EVEN GREATER DIFFERENTIAL VOLTAGES, LOAD-SHARING IMBALANCE, AND TEMPERATURE DIVERGENCE.
- ONE BATTERY APPARENTLY DEVELOPED A HARD SHORT AFTER ONLY 15 MONTHS ON ORBIT, AND HAD TO BE REMOVED FROM THE CHARGE BUS.
- THE REMAINING TWO BATTERIES ARE BEING EXTENSIVELY "MANAGED" TO MINIMIZE OVERCHARGE

NOTE: THE GRO-2 BATTERIES, FROM A DIFFERENT CELL LOT, ON A SEPARATE CHARGE BUS, CONTINUE TO OPERATE SATISFACTORILY.

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ANOMALY DESCRIPTION (continued)

UARS BATTERIES

- LAUNCHED 12 SEPTEMBER 1991.
- BEGAN DEVELOPING HALF-BATTERY DIFFERENTIAL VOLTAGES JUST 4 MONTHS AFTER LAUNCH, EVENTUALLY EXCEEDING 400 mV IN ONE BATTERY.
- SIGNIFICANT LOAD-SHARING IMBALANCES AND TEMPERATURE ANOMALIES HAVE ALSO BEEN OBSERVED.
- THESE BATTERIES ARE ALSO BEING EXTENSIVELY "MANAGED" TO MINIMIZE OVERCHARGE.

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OTHER RELATED ANOMALIES

CELL PACKS ON LIFE-TEST AT NWSC

- PACK 6051H (GRO-1 FLIGHT LOT; LEO REGIME, 20°C, 40% DOD) BEGAN DEVELOPING VOLTAGE DIVERGENCE AT END OF CHARGE AND END OF DISCHARGE AFTER ~6600 CYCLES.

- PACK 6052A (UARS FLIGHT LOT; LEO REGIME, 20°C, 40% DOD) BEGAN DEVELOPING VOLTAGE DIVERGENCE DUE TO HIGH VOLTAGE AT END OF CHARGE AND END OF DISCHARGE AFTER ~1700 CYCLES. (NOTE: EXCEPT FOR ONE, THESE CELLS HAVE 2 - 4% LESS ELECTROLYTE THAN THE LOT AVERAGE.)

- PACK 6052B (UARS FLIGHT LOT; LEO REGIME, 15°C, 21.4% DOD) BEGAN DEVELOPING VOLTAGE DIVERGENCE DUE TO LOW VOLTAGE IN ONE CELL AT END OF CHARGE AFTER ~2000 CYCLES.

  THE TEST REGIME WAS CHANGED AFTER ~4300 CYCLES TO REFLECT THE TRUE MISSION CONDITIONS (0°C, HIGHER CHARGE RATE, LOWER V/T LEVEL, SAME DOD) . THE ORIGINAL DIVERGENT CELL WAS UNAFFECTED BY THE CHANGE, BUT A 2ND CELL DEVELOPED A SEVERELY DEGRADED CHARGE AND DISCHARGE VOLTAGE AFTER JUST 39 CYCLES

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OTHER RELATED ANOMALIES (continued)

CELL PACKS ON LIFE-TEST AT NWSC (continued)

- PACK 0351G (UARS PLATE AND 2536 NYLON SEPARATOR; LEO REGIME, 20°C, 40% DOD) BEGAN DEVELOPING VOLTAGE DIVERGENCE DUE TO LOW CHARGE VOLTAGE AND LOW DISCHARGE VOLTAGE IN ONE CELL AFTER ~3200 CYCLES. (NOTE: EXCEPT FOR TWO, THESE CELLS HAVE 2% LESS ELECTROLYTE THAN THE FLIGHT LOT AVERAGE.)

- PACK 0352G (UARS PLATE AND 2538 NYLON SEPARATOR; LEO REGIME, 20°C, 40% DOD) BEGAN DEVELOPING VOLTAGE DIVERGENCE DUE TO LOW DISCHARGE VOLTAGE IN ONE CELL AFTER ~2800 CYCLES. (NOTE: THESE CELLS HAVE APPROXIMATELY THE SAME AMOUNT OF ELECTOLYTE AS THE FLIGHT CELLS)

- PACK 0350G (UARS PLATE AND SEPARATOR; LEO REGIME, 20°C, 40% DOD) HAS NOT SHOWN ANY SIGNIFICANT DIVERGENCE IN OVER 6000 CYCLES. (NOTE: EXCEPT FOR ONE, THESE CELLS HAVE 2.5% MORE ELECTROLYTE THAN THE FLIGHT LOT AVERAGE.)

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OTHER RELATED ANOMALIES (continued)

ERBS BATTERIES

- LAUNCHED 5 OCTOBER 1984.
- BEGAN DEVELOPING HALF-BATTERY DIFFERENTIAL VOLTAGES APPROXIMATELY 4 YEARS AFTER LAUNCH, WITH SOME SUBSEQUENT LOAD-SHARING IMBALANCES AND TEMPERATURE ANOMALIES.
- APPROXIMATELY 8 YEARS AFTER LAUNCH, ONE BATTERY DEVELOPED A HARD SHORT IN ONE OF ITS CELLS. THE BATTERY WAS KEPT ON THE CHARGE BUS, HOWEVER, FOR EVALUATION AND EXPERIMENTATION.
- APPROXIMATELY 4 WEEKS AFTER THE FIRST HARD SHORT, A SECOND CELL DEVELOPED A HARD SHORT AND THE BATTERY HAD TO BE TAKEN OFF OF THE CHARGE BUS.
- PERFORMANCE OF THE ERBS BATTERIES WAS SUCCESSFUL AND ACCEPTABLE SINCE THE MISSION OBJECTIVES WERE MET LONG AGO.

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SPACECRAFT BATTERY USAGE PROFILES

(BEGINNING OF LIFE VALUES)

SPACECRAFT	LAUNCH DATE	DEPTH OF DISCHARGE	BATTERY TEMPERATURE	COMMENTS
LANDSAT 4	JULY 1982	10 - 14%	0 - 5°C	SOLAR ARRAY NOW PARTIALLY DISABLED
LANDSAT 5	MARCH 1984	10 - 14%	0 - 5°C	
ERBS	OCTOBER 1984	0 - 12%	9°C	FIXED SOLAR ARRAY (COSINE POWER CURVE)
GRO-1 / GRO-2	APRIL 1991	12%	2 - 4°C	
UARS	SEPTEMBER 1991	0 - 20%	3 - 8°C	BATTERY TEMPS ORIGINALLY 0°C TO 4°C
EUVE	MAY 1992	8 - 10 %	7 - 8°C	BATTERY TEMPS ORIGINALLY -2°C TO 0°C
TOPEX	AUGUST 1992	0 - 14%	5 - 7°C	

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DATABASE FOR INVESTIGATION

MORE THAN 20 PLATE AND CELL LOTS HAVE BEEN PRODUCED UNDER THE NASA STANDARD 50 A.H. DESIGN. FOURTEEN CELL LOTS WERE SINGLED OUT FOR DETAILED INVESTIGATION FOR VARIOUS REASONS:

- FLIGHT BATTERY EXPERIENCE
- EXPOSURE OF RESIDUAL CELLS TO LONG-TERM LEO CYCLING UNDER A NOMINAL OR ANTICIPATED MISSION ENVIRONMENT
- EXPOSURE OF RESIDUAL CELLS TO LONG-TERM LEO CYCLING UNDER AN ACCELERATED OR STRESSFUL MISSION ENVIRONMENT
- LONG-TERM SUCCESSFUL USAGE AS BATTERIES FOR SPACECRAFT INTEGRATION AND TEST
- BATTERIES WERE POTENTIAL OR IMMINENT CANDIDATES FOR LAUNCH

IT SHOULD BE NOTED THAT ALL OF THE FLIGHT BATTERIES, WITHOUT EXCEPTION, SUCCESSFULLY MET STRINGENT NASA-CONTROLLED ACCEPTANCE TEST CRITERIA.

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DATABASE FOR INVESTIGATION (continued)

SUMMARY OF BATTERY/CELL LOT USAGE AND EXPOSURE

CELL LOT	PROGRAM	FLIGHT	LONG I & T BATTERY USE	CELL LIFE TEST	CELL STRESS TEST	BATTERY ANOMALIES	BATTERY FAILURES	COMMENTS
50AB20 LOT 1	LANDSAT		X			0 of 1	0 of 1	QUAL BATTERY
LOT 2	LANDSAT		X	X	X	0 of 4	0 of 4	
LOT 3	LANDSAT	X				0 of 3	0 of 3	
LOT 4	LANDSAT	X				0 of 2	0 of 2	
LOT 5	LANDSAT	X				0 of 2	0 of 2	
LOT 7	LANDSAT	X				0 of 2	0 of 2	
LOT 12	ERBS	X	X (3rd battery)			**1** of 3	**1** of 3	
LOT 14	GRO		X		X	0 of 3	0 of 3	
LOT 16	GRO/EUVE	X		X	X	0 of 3	0 of 3	
LOT 17	GRO	X		X	X	0 of 3	0 of 3	
50AB35 LOT 1	GRO	X			X	**2** of 3	**1** of 3	
LOT 2	UARS	X		X	X	**3** of 3	0 of 3	
LOT 4	EUVE				limited	0 of 3	0 of 3	RECENT FLIGHT CANDIDATE
LOT 6	TOPEX	X		limited	limited	0 of 3	0 of 3	

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DATABASE FOR INVESTIGATION (continued)

- OVER 60 PARAMETERS OR PARAMETRIC RELATIONSHIPS WERE CALCULATED AND TABULATED IN SUPPORT OF THIS INVESTIGATION, ~ 40 WERE PLOTTED.

- 21 OF THESE PLOTS ARE REPRODUCED HERE BECAUSE OF THE OVERALL TRENDS THAT THEY IDENTIFIED (MANY OF WHICH MAY BE COUNTER-PRODUCTIVE TO LONG CYCLE-LIFE) OR BECAUSE OF THEIR APPARENT UTILITY IN DISTINGUISHING BETWEEN GOOD AND ANOMALOUS CELL LOTS.

- THESE PLOTS, WITH THEIR ACCOMPANYING ANALYSES, ARE A SUMMARY OF THE SIGNIFICANT FINDINGS TO-DATE IN MDC'S ONGOING INVESTIGATION INTO THE AFOREMENTIONED PERFORMANCE ANOMALIES IN THE NASA STANDARD 50 A.H. NICD BATTERIES.

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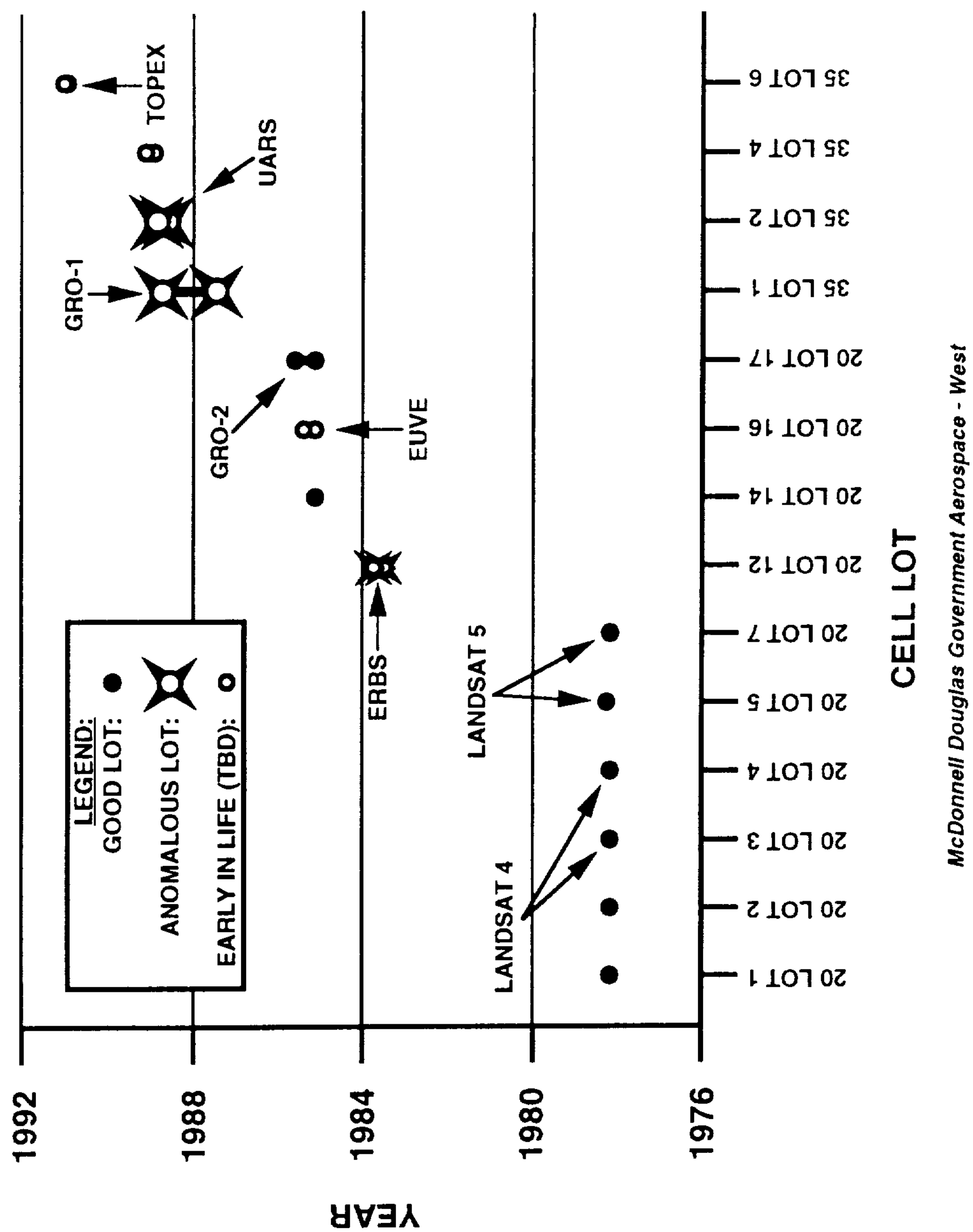
NASA STANDARD 50 A.H. BATTERY CELL

SINTERING DATE CHRONOLOGY



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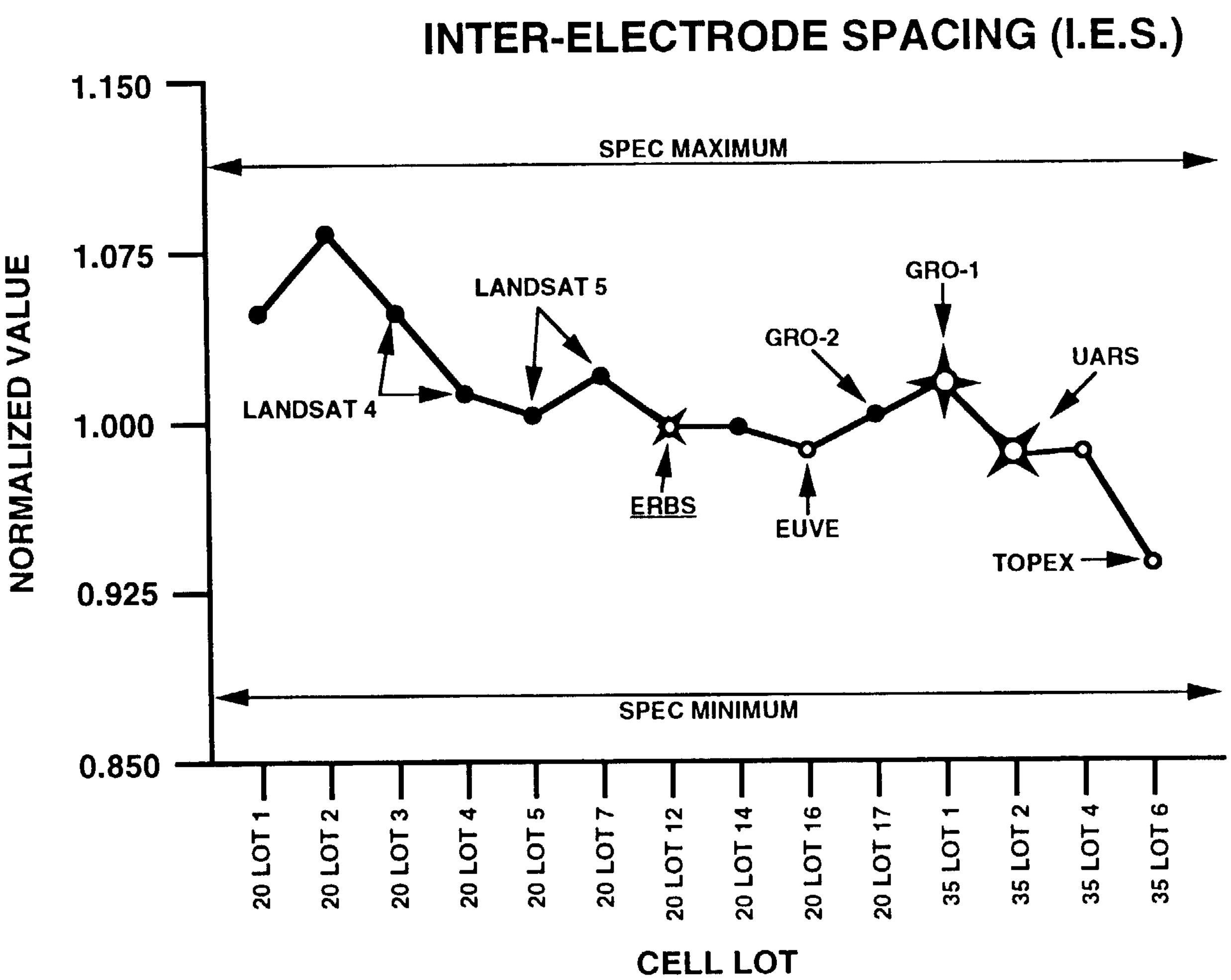
NASA STANDARD 50 A.H. BATTERY CELL HISTORICAL TREND



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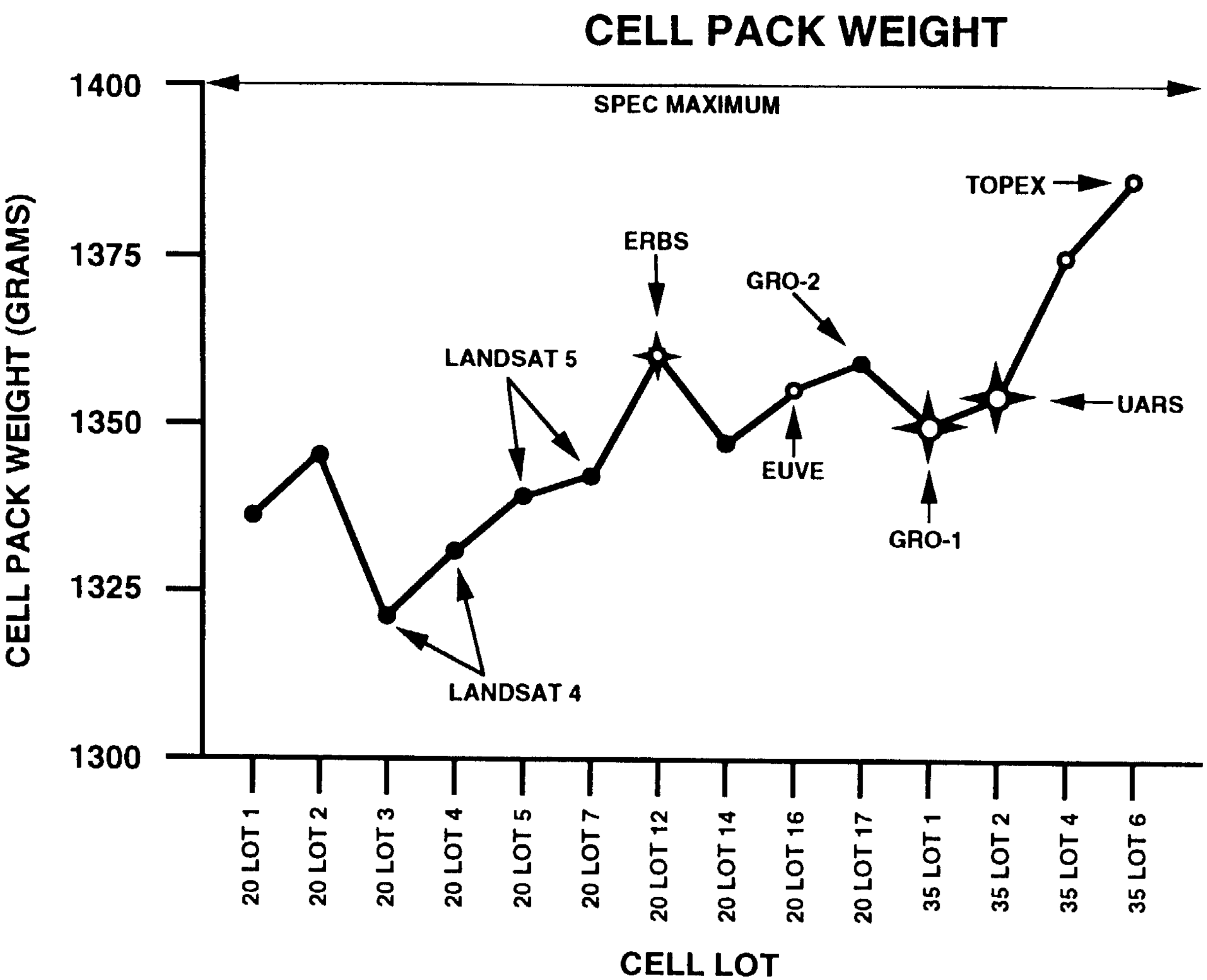
- ALL VALUES ARE LOT AVERAGES AND ARE NORMALIZED TO THE SPEC NOMINAL.
- VALUES ARE DERIVED FROM NOMINAL DIMENSIONS OF CELL CASE AND CELL PACK WRAPPER, AND ACTUAL CELL PACK THICKNESS MEASUREMENTS (UNDER COMPRESSION).
- I.E.S. HAS DECREASED ~11% FROM THE FIRST LOT.
- THERE IS NO KNOWN CORRELATION BETWEEN DIMINISHED I.E.S. AND ANY PAST OR PRESENT ANOMALOUS NASA STANDARD 50 A.H. CELL LOTS.

NASA STANDARD 50 A.H. BATTERY CELL HISTORICAL TREND



- ALL VALUES ARE LOT AVERAGES AND WERE OBTAINED FOR EACH CELL PACK IN CONCERT WITH CELL PACK THICKNESS MEASUREMENTS.
- NO SPEC MINIMUM.
- RECENT LOT-AVERAGE CELL PACK WEIGHTS ARE ALMOST 5% GREATER THAN EARLIER CELL LOTS.
- TREND IS CONSISTENT WITH DECREASED I.E.S.
- THERE IS NO KNOWN CORRELATION BETWEEN INCREASED CELL PACK WEIGHT AND ANY PAST OR PRESENT ANOMALOUS NASA STANDARD 50 A.H. CELL LOTS.

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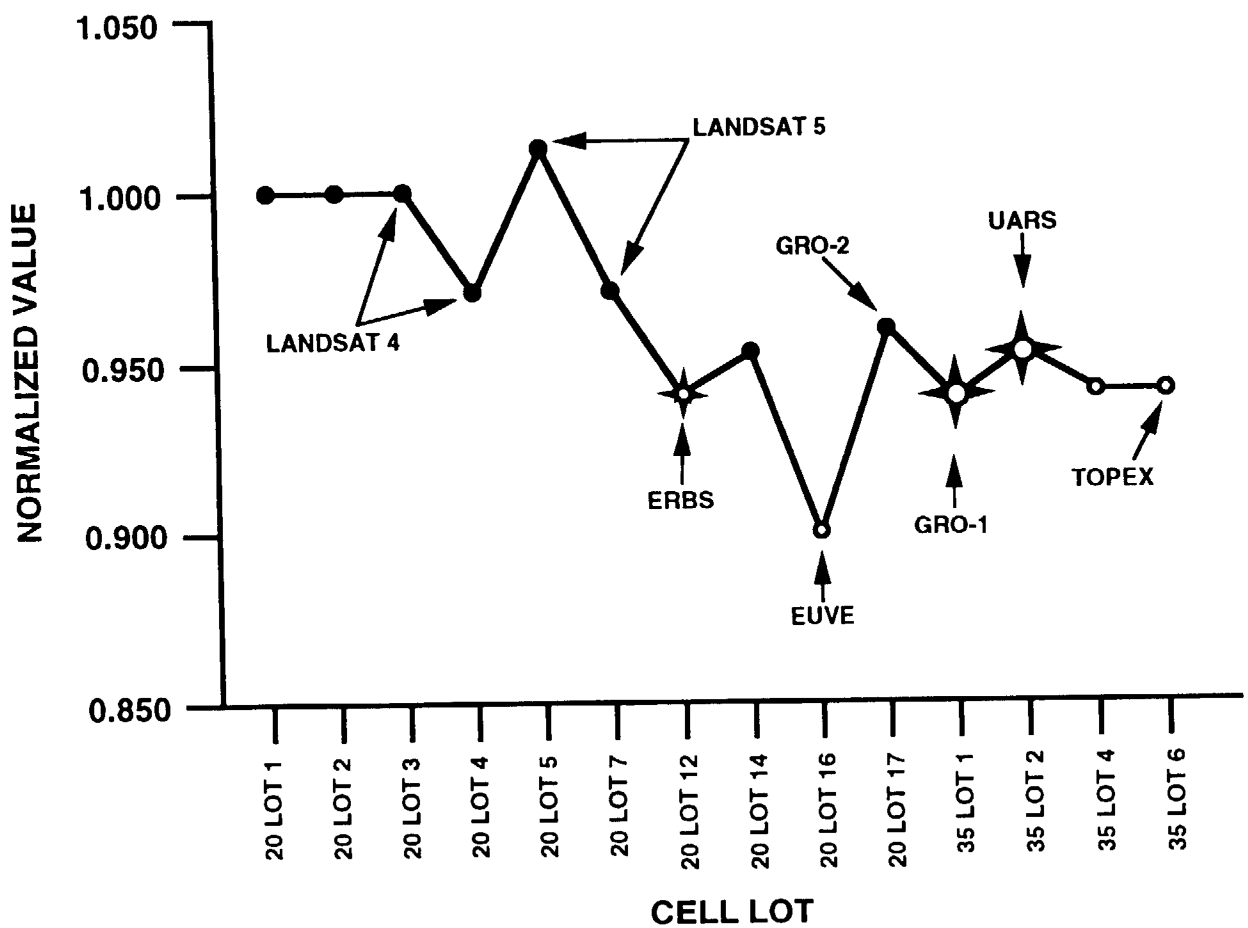
NASA STANDARD 50 A.H. BATTERY CELL HISTORICAL TREND

FINAL ELECTROLYTE AMOUNT



- ALL VALUES ARE LOT AVERAGES AND ARE NORMALIZED TO 50AB20 LOT 1.
- NO SPEC MINIMUM OR MAXIMUM.
- RECENT CELL LOTS CONTAIN ~6% LESS ELECTROLYTE THAN EARLIER LOTS.
- THIS TREND IS CONSISTENT WITH THICKER AND HEAVIER PLATE (LESS FREE VOLUME).
- THERE IS NO KNOWN CORRELATION BETWEEN DECREASED ELECTROLYTE AND ANY PAST OR PRESENT ANOMALOUS NASA STANDARD 50 A.H. CELL LOTS.

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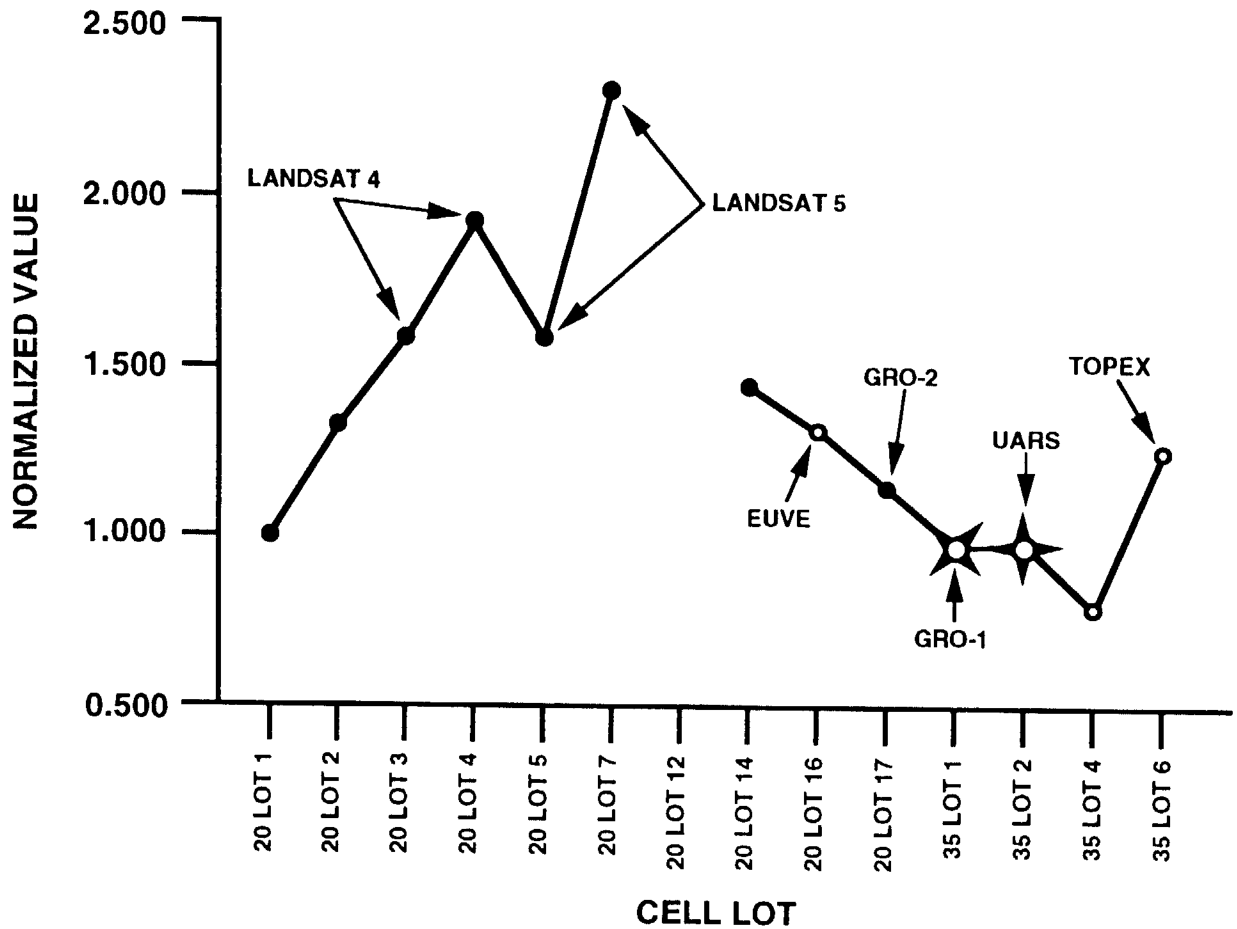
NASA STANDARD 50 A.H. BATTERY CELL HISTORICAL TREND

NEGATIVE PLATE TEFLON LOADING



- ALL VALUES ARE LOT AVERAGES AND ARE NORMALIZED TO 50AB20 LOT 1.
- NO SPEC MINIMUM OR MAXIMUM.
- NO TEFLON LOADING DATA AVAILABLE FOR ERBS (50AB20 LOT 12).
- EARLIER LOTS HAD 1.5 TO 3 TIMES THE AMOUNT OF TEFLON LOADING OF RECENT LOTS.
- NO KNOWN CHANGES OR DEVIATIONS HAVE BEEN INTRODUCED INTO THE TEFLON LOADING PROCESS.
- LIGHTER TEFLON LOADING MAY MAKE TREATMENT/ COATING LESS UNIFORM AND MAY ALSO BE PARTLY RESPONSIBLE FOR DECREASED ELECTROLYTE.
- THERE MAY BE SOME CORRELATION BETWEEN REDUCED TEFLON AND THE ANOMALOUS NASA STANDARD 50 A.H. CELL LOTS.

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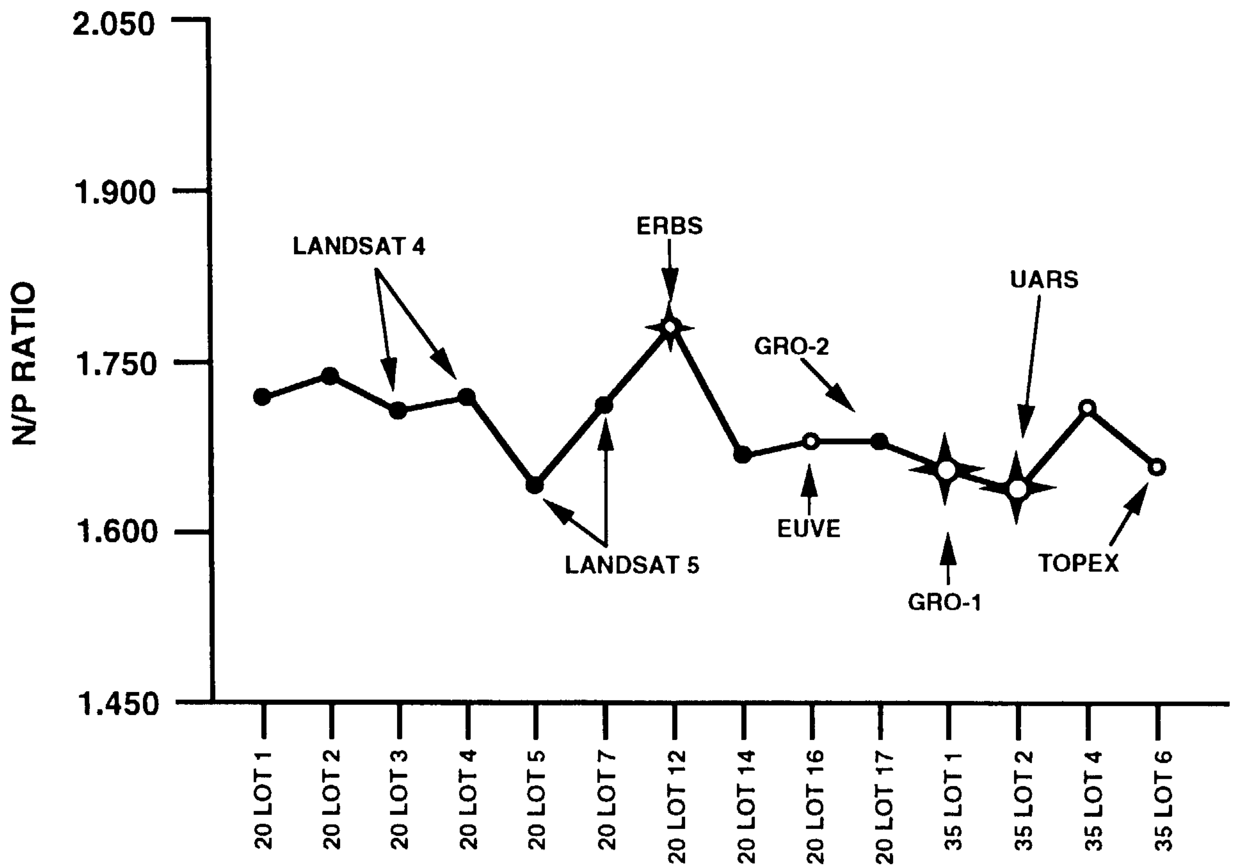
NASA STANDARD 50 A.H. BATTERY CELL HISTORICAL TREND:

THEORETICAL NEGATIVE TO POSITIVE (N/P) RATIO



- NO SPEC MINIMUM OR MAXIMUM.
- VALUES WERE DERIVED USING THE MAXIMUM THEORETICAL NEGATIVE AND MAXIMUM THEORETICAL POSITIVE CAPACITY. THESE ARE BASED ON PLATE LOADING, PLATE AREA, # OF PLATES, AND ELECTROCHEMICAL CONSTANTS.
- TREND APPEARS TO BE VERY CONSTANT AND STABLE, WITH A SLIGHT DECREASE OVER TIME..
- THERE IS NO KNOWN CORRELATION BETWEEN THEORETICAL N/P RATIO AND ANY PAST OR PRESENT ANOMALOUS NASA STANDARD 50 A.H. CELL LOTS.

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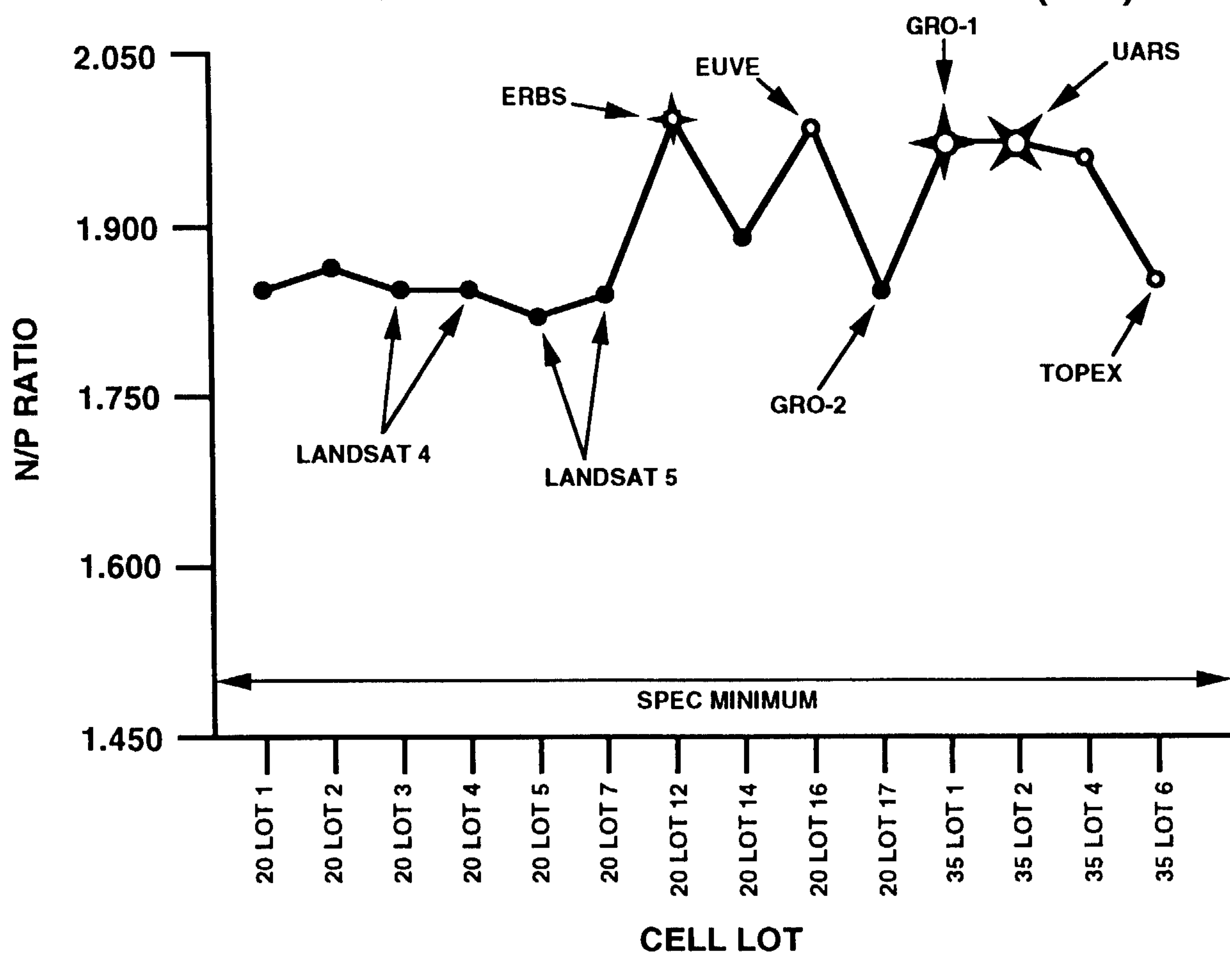
NASA STANDARD 50 A.H. BATTERY CELL HISTORICAL TREND

ACTUAL NEGATIVE TO POSITIVE (N/P) RATIO



- DATA IS FROM 100% FLOODED-CELL TESTING AND IS THE RATIO OF THE NEGATIVE PLATE CAPACITY (DISCHARGED TO SOME NEGATIVE VOLTAGE) TO THE POSITIVE PLATE CAPACITY (DISCHARGED TO SOME POSITIVE VOLTAGE < 1.0 VOLT).
- TEMPORARY FLOODED-CELLS CONTAIN THE SAME NUMBER OF PLATES AS THE SEALED CELL.
- ALL VALUES ARE LOT AVERAGES.
- NO SPEC MAXIMUM.
- THE TREND IS NOT AS STABLE AS THE THEORETICAL N/P RATIO.
- THE TREND APPEARS TO MAKE AN EXCELLENT DISTINCTION BETWEEN GOOD AND ANOMALOUS LOTS, WITH SOME LOTS STILL TBD AND PROVIDED THE FIRST REAL CLUE ABOUT WHICH WAY TO TAKE THE INVESTIGATION.
- QUESTION: WHICH IS THE DYNAMIC ELEMENT: N OR P?

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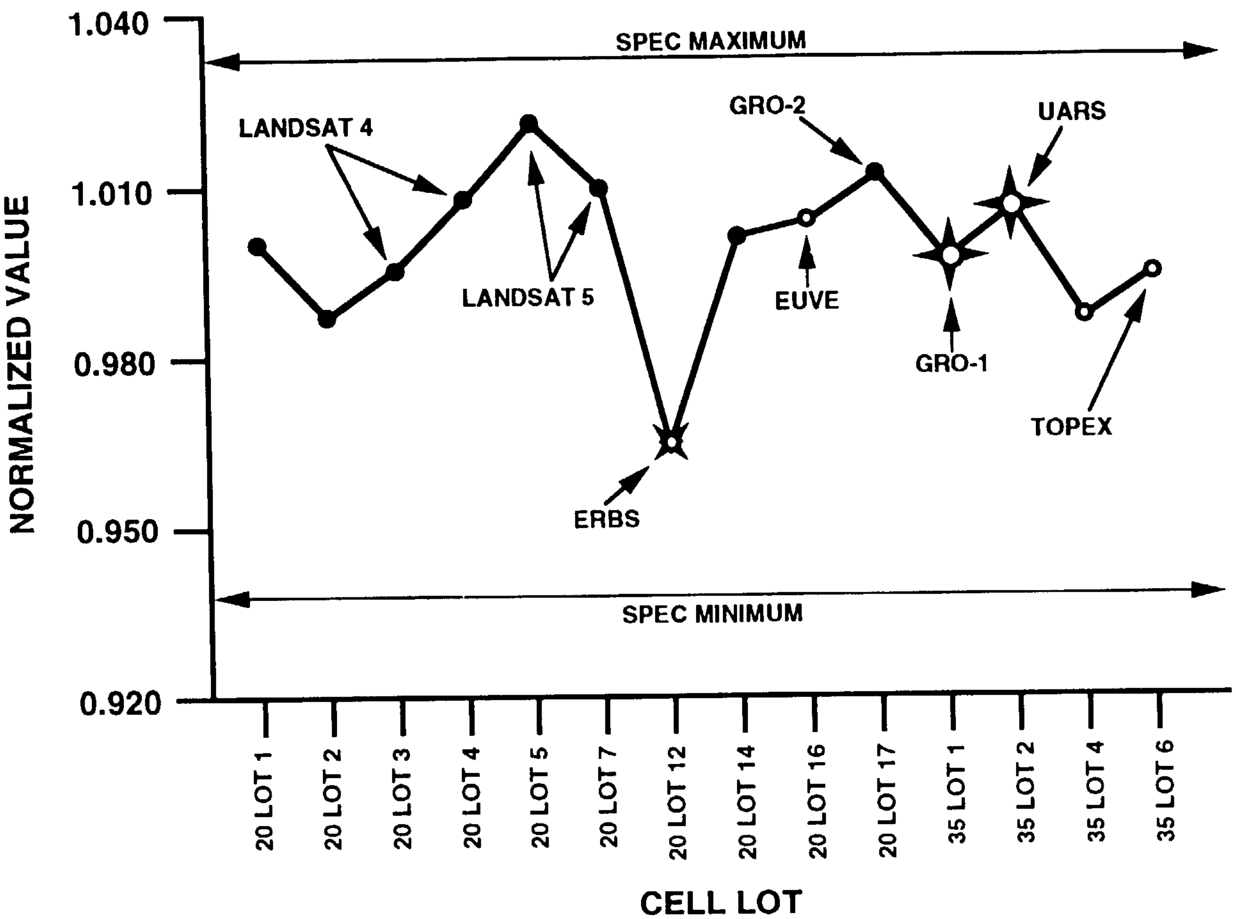
NASA STANDARD 50 A.H. BATTERY CELL HISTORICAL TREND

POSITIVE PLATE LOADING



- NORMALIZED TO 50AB20 LOT 1.
- POSITIVE LOADING HAS REMAINED WITHIN SPEC AND IS, FOR THE MOST PART, VERY TIGHTLY CONTROLLED.
- THE LEVEL OF LOADING IS MOST OFTEN HIGHER THAN NOMINAL.
- THE LOADING SPEC HAS NOT CHANGED SINCE 50AB20 LOT 1.
- NOTE: THIS IS NON-PASSIVATED PLAQUE . (I.E. THE SINTER IS CORRODED BY THE IMPREGNATION PROCESS, A.K.A. NICKEL ATTACK.)
- THERE IS NO KNOWN CORRELATION BETWEEN THE LEVEL OF POSITIVE PLATE LOADING AND ANY PAST OR PRESENT ANOMALOUS NASA STANDARD 50 A.H. CELL LOTS.

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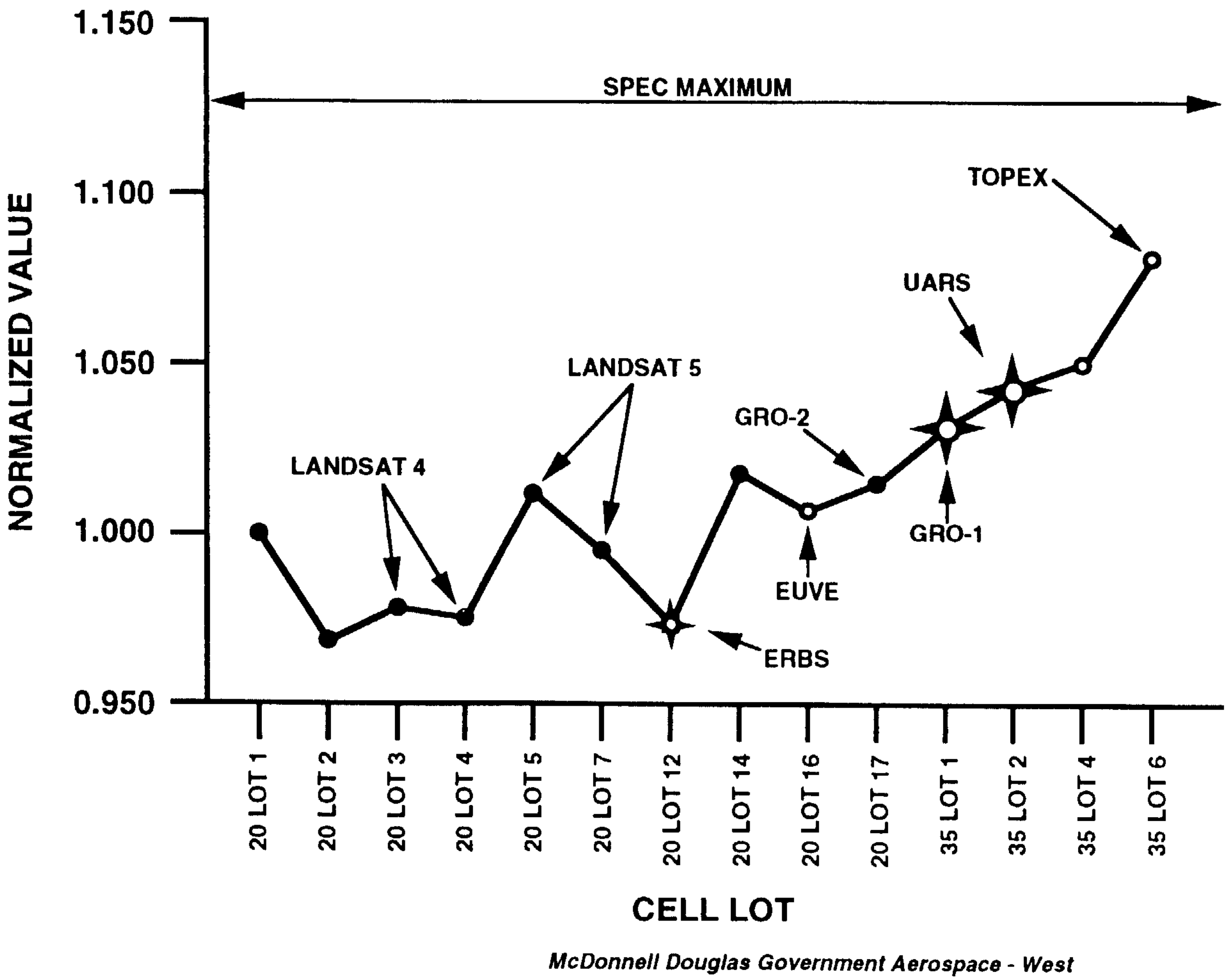
NASA STANDARD 50 A.H. BATTERY CELL HISTORICAL TREND

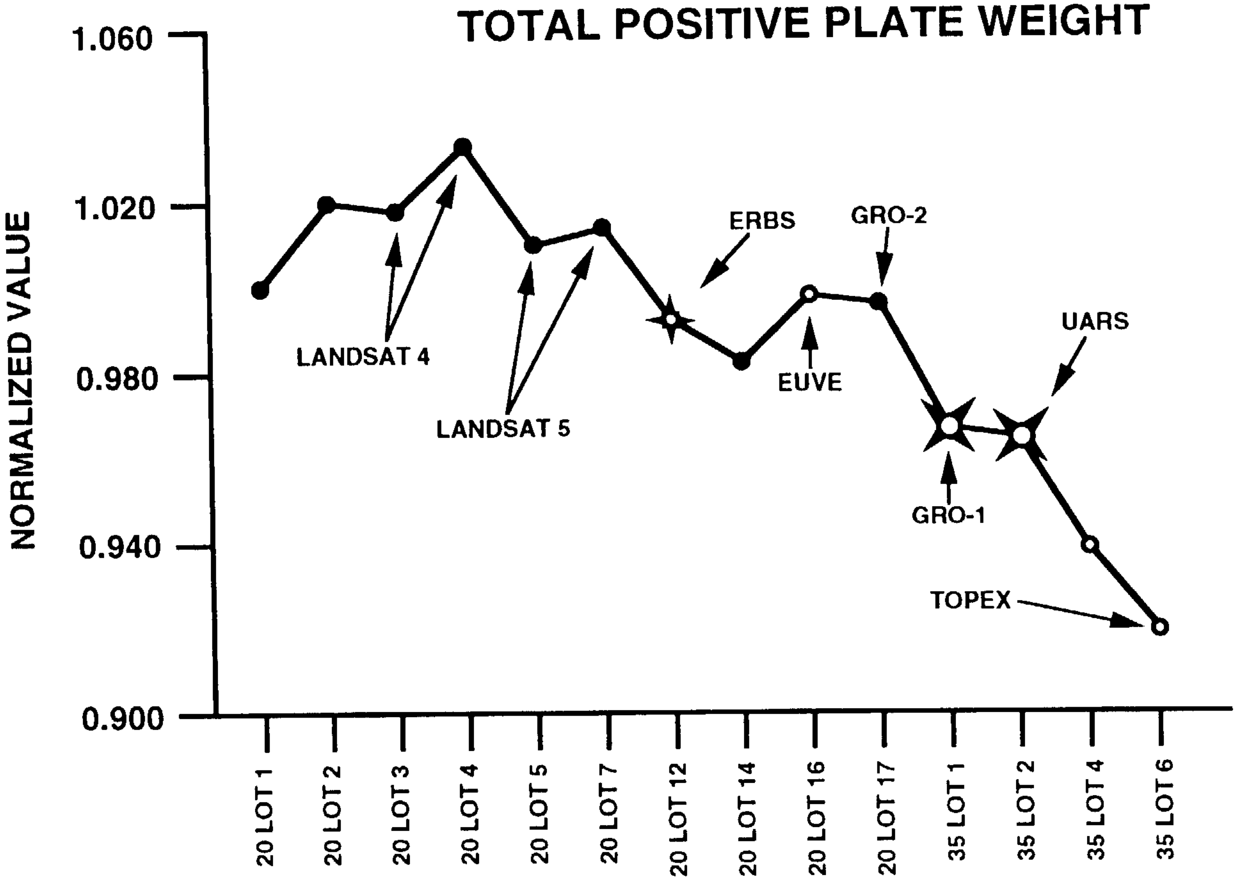
POSITIVE PLATE WEIGHT



- NORMALIZED TO 50AB20 LOT 1.
- NO SPEC MINIMUM.
- NOTE: THIS IS NON-PASSIVATED PLAQUE. (I.E. THE SINTER IS CORRODED BY THE IMPREGNATION PROCESS, A.K.A. NICKEL ATTACK.)
- POSITIVE PLATE WEIGHT HAS INCREASED 8 - 11 % SINCE EARLY LOTS AND IS THE OVERWHELMING FACTOR IN THE INCREASE OF PLATE PACK WEIGHT.
- PROBABLE CAUSE OF THE INCREASE (FROM OTHER DATA NOT PRESENTED HERE): LESS NICKEL ATTACK.
- THERE IS NO KNOWN CORRELATION BETWEEN INCREASED POSITIVE PLATE WEIGHT AND ANY PAST OR PRESENT ANOMALOUS NASA STANDARD 50 A.H. CELL LOTS.

NASA STANDARD 50 A.H. BATTERY CELL HISTORICAL TREND

RATIO OF POSITIVE LOADING WEIGHT TO TOTAL POSITIVE PLATE WEIGHT



- NORMALIZED TO 50AB20 LOT 1.
- NO SPEC MINIMUM OR MAXIMUM.
- THE RATIO FOR MORE RECENT LOTS IS 8 - 10 % LESS THAN OLDER LOTS.
- THERE IS SOME CORRELATION BETWEEN A LOWER RATIO OF POSITIVE LOADING WEIGHT TO TOTAL POSITIVE PLATE WEIGHT AND THE ANOMALOUS NASA STANDARD 50 A.H. CELL LOTS, WITH SOME LOTS STILL TBD.

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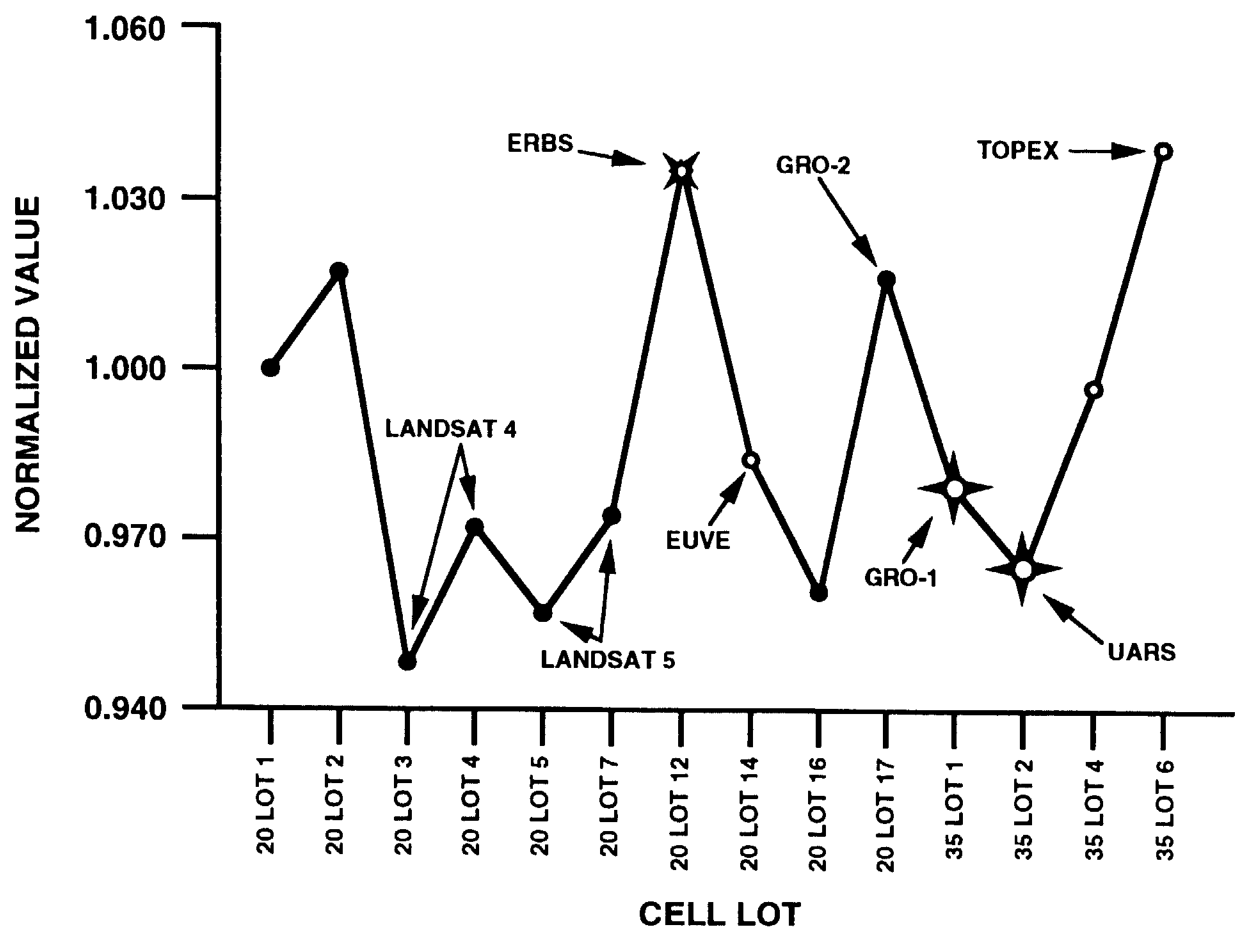
POSITIVE PLATE UTILIZATION



- ALL VALUES ARE LOT AVERAGES AND ARE OBTAINED BY DIVIDING THE LOT-AVERAGE FLOODED-CELL POSITIVE PLATE CAPACITY BY THE MAXIMUM THEORETICAL POSITIVE PLATE CAPACITY (AS DESCRIBED EARLIER).
- NO SPEC MINIMUM OR MAXIMUM.
- UTILIZATION HAS VARIED CONSIDERABLY OVER TIME .
- THERE IS NO KNOWN CORRELATION BETWEEN POSITIVE PLATE UTILIZATION AND ANY PAST OR PRESENT ANOMALOUS NASA STANDARD 50 A.H. CELL LOTS.

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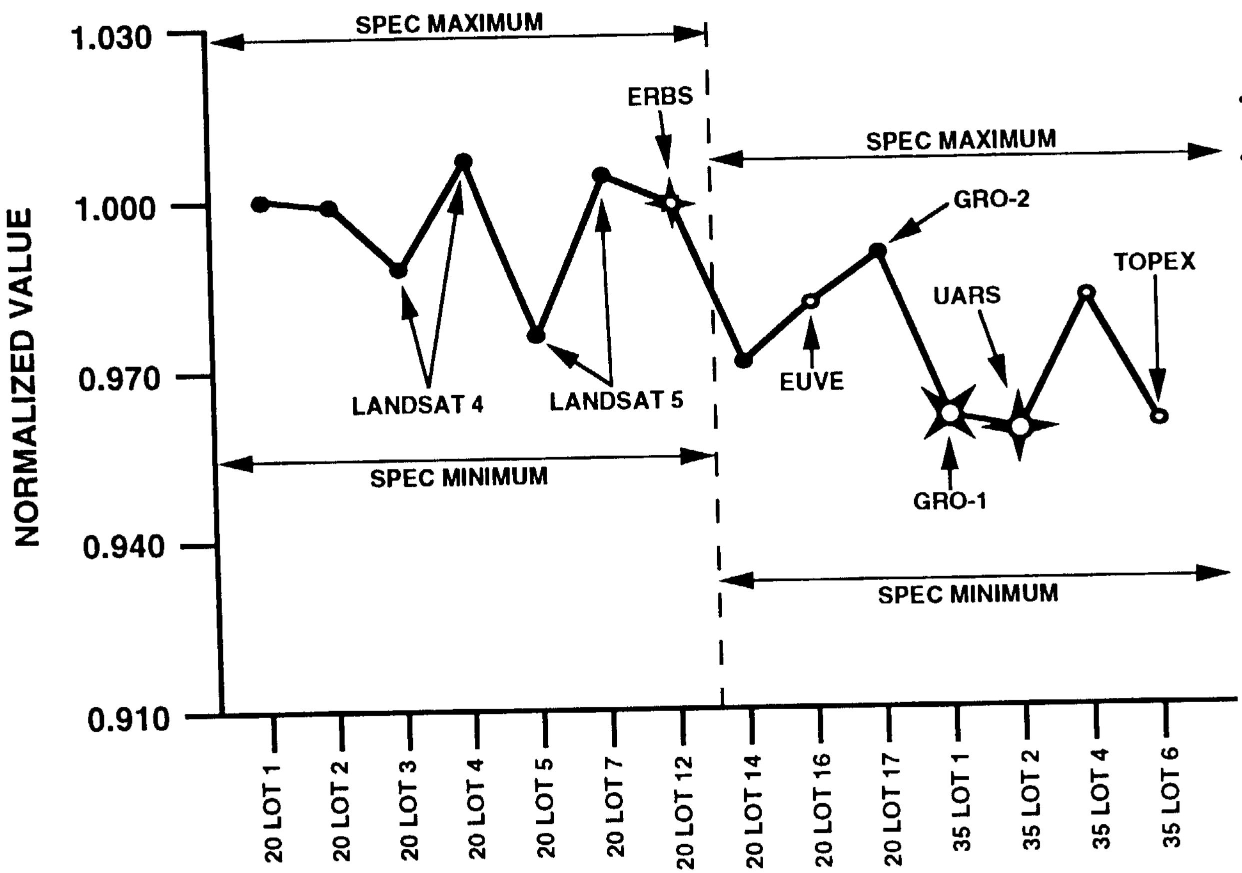
NASA STANDARD 50 A.H. BATTERY CELL HISTORICAL TREND

NEGATIVE PLATE LOADING



- NORMALIZED TO 50AB20 LOT 1.
- THE LOADING SPECIFICATION WAS CHANGED AFTER 50AB20 LOT 12 WITH THE RESULT THAT LOADING IS 2 - 4 % LOWER IN THE MOST RECENT LOTS VERSUS EARLIER LOTS.
- THERE IS NO KNOWN CORRELATION BETWEEN THE LEVEL OF NEGATIVE PLATE LOADING AND ANY PAST OR PRESENT ANOMALOUS NASA STANDARD 50 A.H. CELL LOTS.

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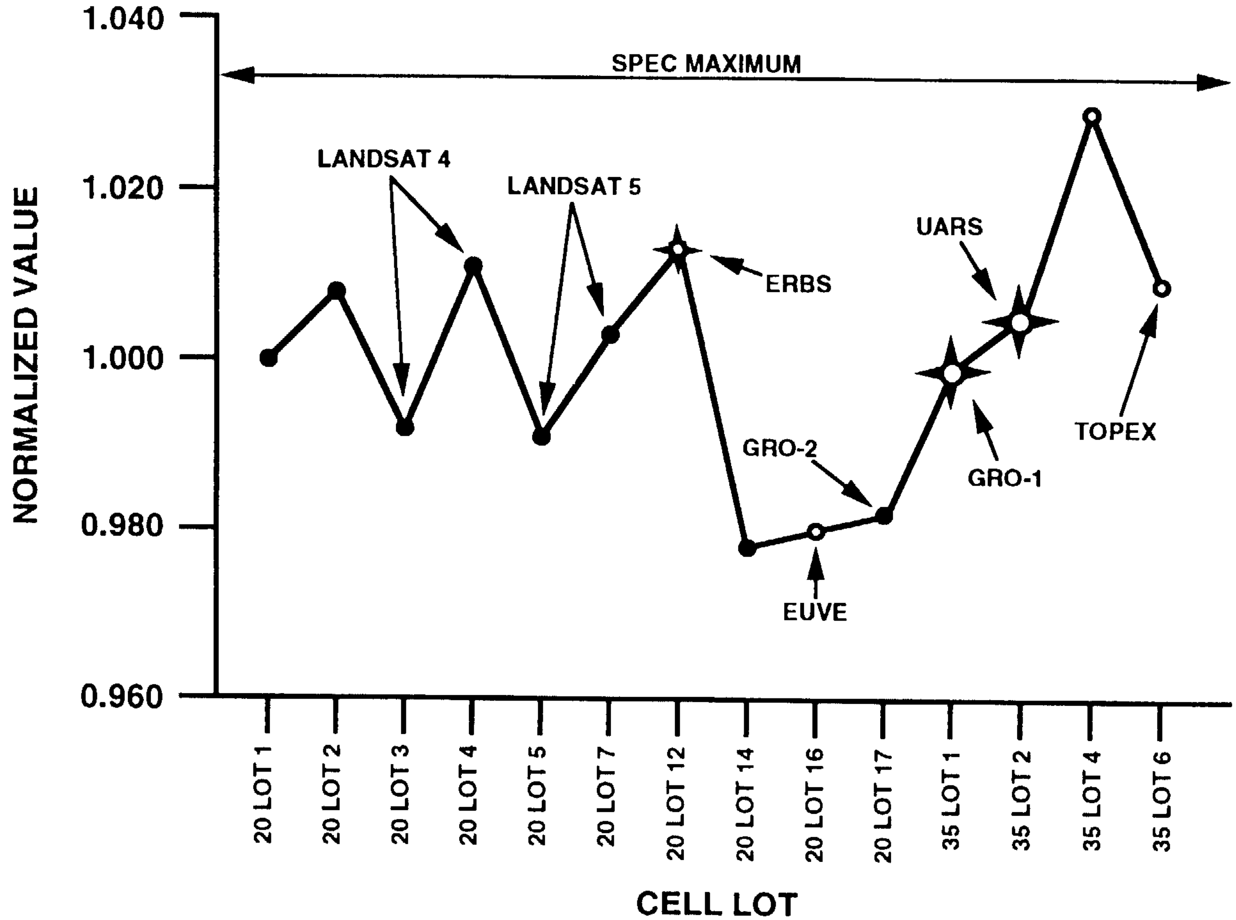
NASA STANDARD 50 A.H. BATTERY CELL HISTORICAL TREND

NEGATIVE PLATE WEIGHT



- NORMALIZED TO 50AB20 LOT 1.
- NO SPEC MINIMUM.
- NEGATIVE PLATE WEIGHT HAS NOT VARIED SIGNIFICANTLY OVER THE LIFE OF THE DESIGN.
- NEGATIVE PLATE WEIGHT INITIALLY DECREASED WITH THE REDUCTION IN LOADING THAT STARTED WITH 50AB20 LOT 14, BUT IT HAS MIGRATED BACK TO THE OLD PLATE WEIGHT DESPITE THE LOWER LOADING.
- THERE IS NO KNOWN CORRELATION BETWEEN NEGATIVE PLATE WEIGHT AND ANY PAST OR PRESENT ANOMALOUS NASA STANDARD 50 A.H. CELL LOTS.

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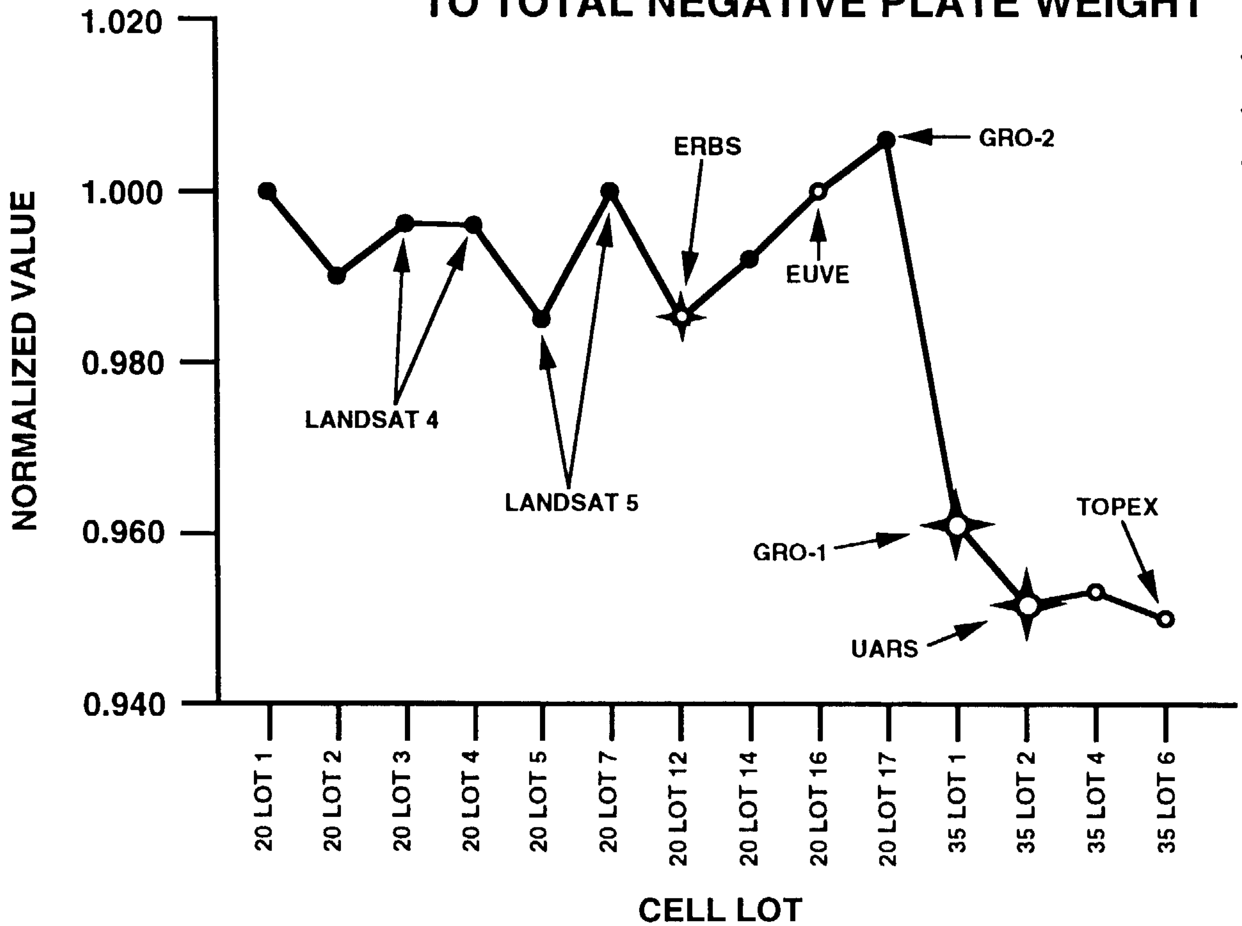
NASA STANDARD 50 A.H. BATTERY CELL HISTORICAL TREND

RATIO OF NEGATIVE LOADING WEIGHT TO TOTAL NEGATIVE PLATE WEIGHT



- NORMALIZED TO 50AB20 LOT 1.
- NO SPEC MINIMUM OR MAXIMUM.
- THIS RATIO CHANGED DRAMATICALLY BETWEEN 50AB20 LOT 17 AND 50AB35 LOT 1 (MID-1985 TO MID-1987).
- RATIO HAS BEEN REDUCING PARTLY AS A RESULT OF THE DECREASED LOADING (YET PLATE WEIGHT HAS INCREASED).
- DIMENSIONS OF THE STEEL SUBSTRATE HAVE NOT CHANGED .
- PROBABLE CAUSE OF TREND: HEAVIER SINTERED PLAQUE.
- THERE IS SOME CORRELATION BETWEEN A LOWER RATIO OF NEGATIVE LOADING TO TOTAL NEGATIVE WEIGHT AND THE ANOMALOUS NASA STANDARD 50 A.H. CELL LOTS, WITH SOME LOTS STILL TBD.

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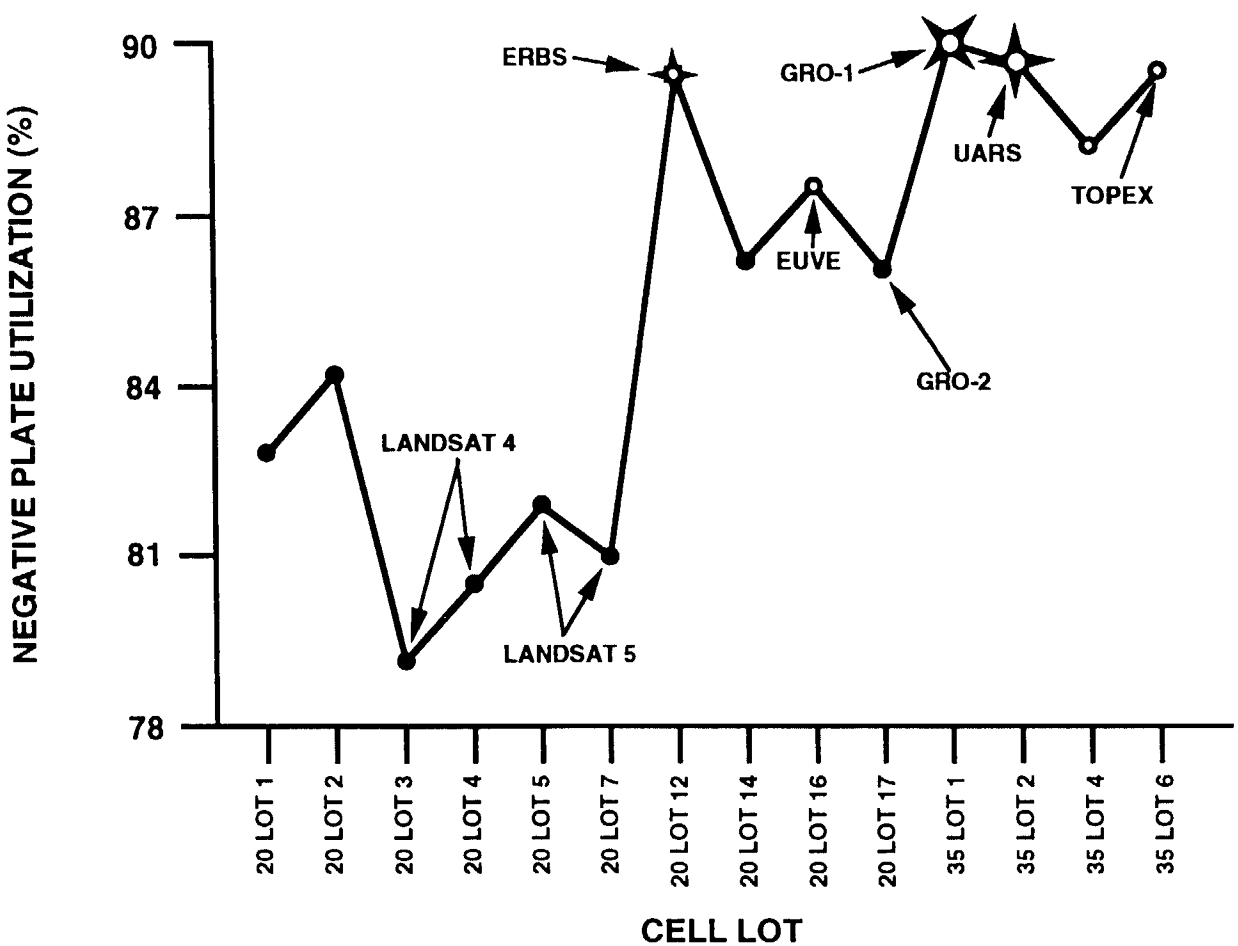
NEGATIVE PLATE UTILIZATION



- ALL VALUES ARE LOT AVERAGES AND ARE OBTAINED BY DIVIDING THE LOT-AVERAGE FLOODED-CELL NEGATIVE PLATE CAPACITY BY THE MAXIMUM THEORETICAL NEGATIVE PLATE CAPACITY (AS DESCRIBED EARLIER).
- NO SPEC MINIMUM OR MAXIMUM.
- UTILIZATION HAS INCREASED BY 5 - 10 %.
- HIGH UTILIZATION (> 88%) CORRELATES WELL WITH HIGH N/P RATIO (> 1.9), A LOW RATIO OF NEGATIVE LOADING WEIGHT TO TOTAL NEGATIVE PLATE WEIGHT, AND THE ANOMALOUS NASA STANDARD 50 A.H. CELL LOTS.
- HIGH UTILIZATION ALSO HAS A FAIR CORRELATION TO LIGHTER LOADING LEVELS.

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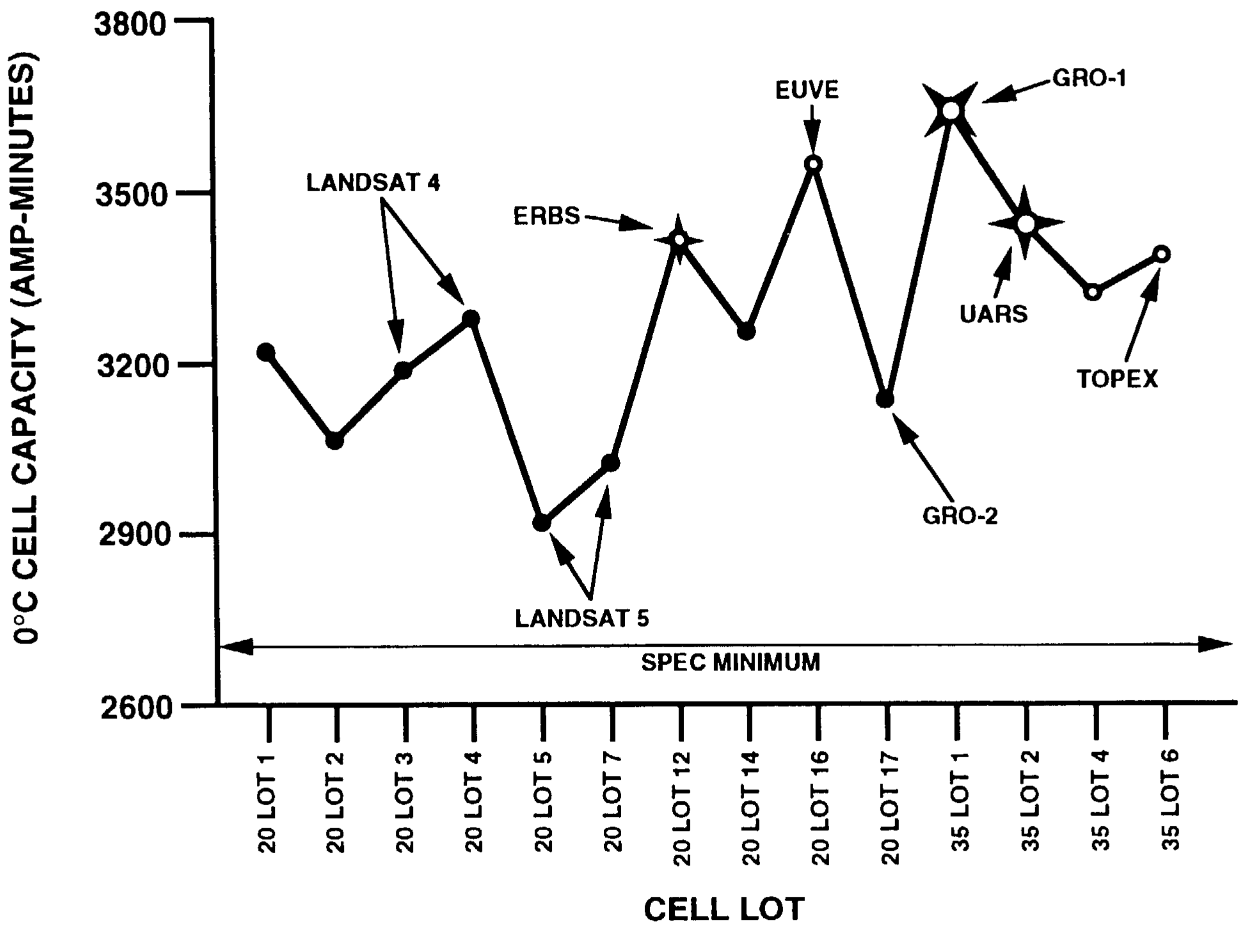
NASA STANDARD 50 A.H. BATTERY CELL HISTORICAL TREND

0°C CAPACITY AT THE CELL LEVEL



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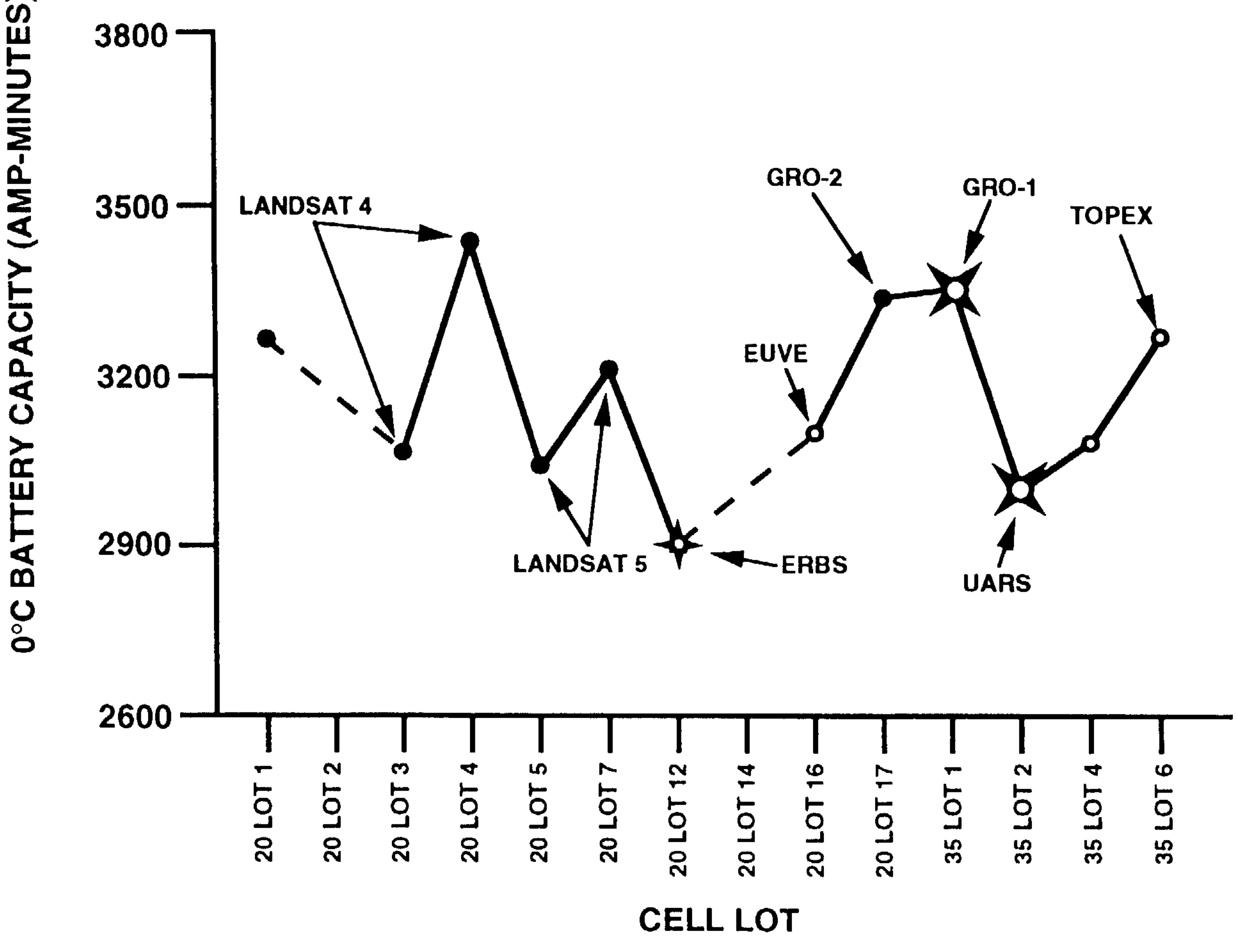
- NO SPEC MAXIMUM.
- CELL 0°C CAPACITY HAS VARIED GREATLY AND HAS SHOWN A GENERAL INCREASE WITH TIME.
- THERE IS A VERY GOOD CORRELATION BETWEEN HIGH CAPACITY AT 0°C (> 3400 AMP- MINUTES) AND ANOMALOUS NASA STANDARD 50 A.H. CELL LOTS, WITH SOME LOTS STILL TBD.

NASA STANDARD 50 A.H. BATTERY CELL HISTORICAL TREND

0°C CAPACITY AT THE BATTERY LEVEL



- BATTERIES FROM 50AB20 LOT 2 AND 50AB20 LOT 14 CELLS WERE NOT TESTED FOR CAPACITY AT 0°C (DESIGNATED AS TEST BATTERIES).
- NO SPEC MAXIMUM.
- SPEC MINIMUM IS TIED TO THE BATTERY CAPACITY MEASURED AT 23°C (MUST BE > 80 % OF THE 23°C CAPACITY). ALL OF THE NASA STANDARD 50 A.H. BATTERIES HAVE MET THIS REQUIREMENT.
- BATTERY CAPACITY HAS ALSO VARIED CONSIDERABLY FROM LOT TO LOT, BUT NOT AS MUCH AS AT THE CELL LEVEL.
- THERE IS NO KNOWN CORRELATION BETWEEN BATTERY CAPACITY AT 0°C AND ANY PAST OR PRESENT ANOMALOUS NASA STANDARD 50 A.H. CELL LOTS

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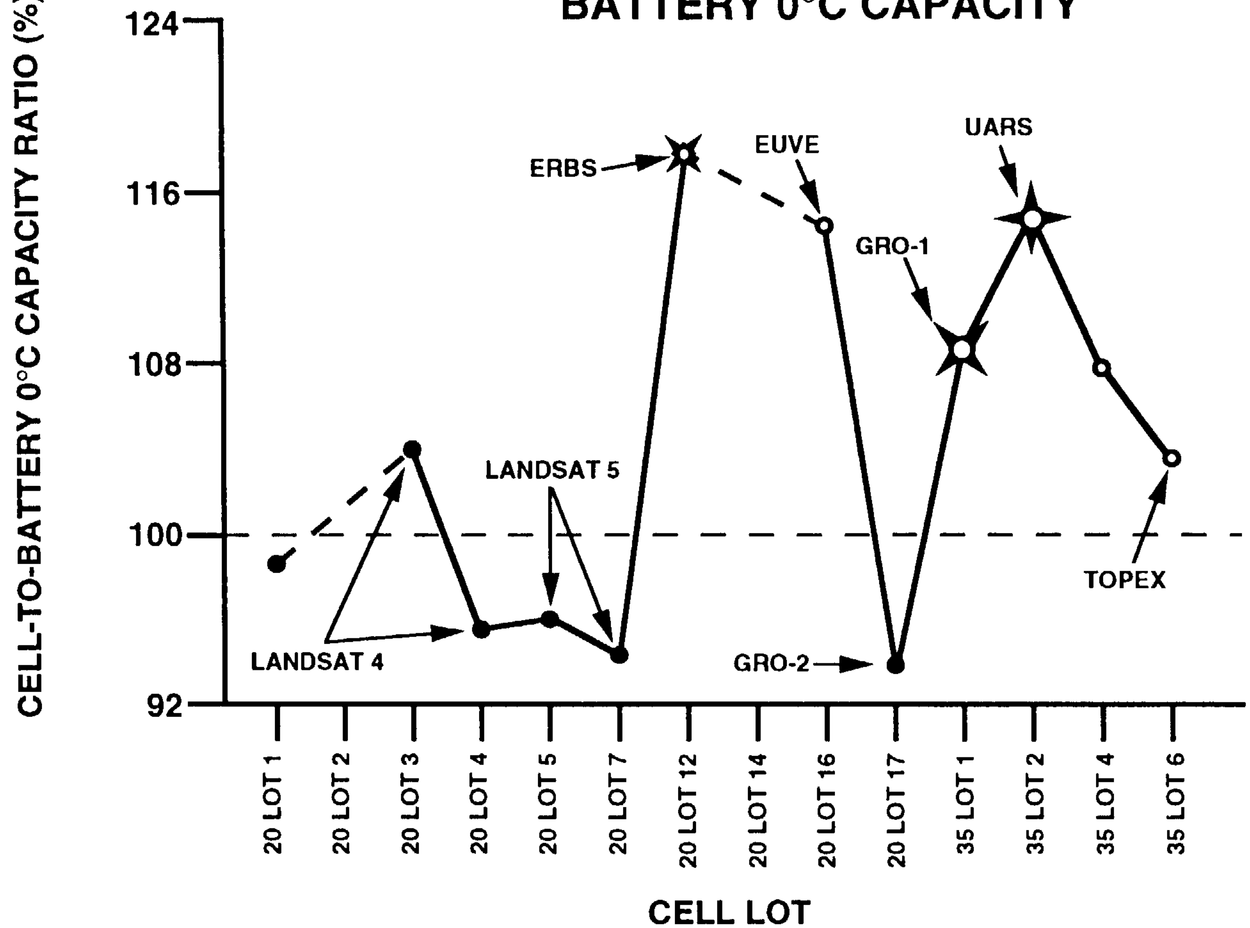
NASA STANDARD 50 A.H. BATTERY CELL HISTORICAL TREND

RATIO OF CELL 0°C CAPACITY TO BATTERY 0°C CAPACITY



- BATTERIES FROM 50AB20 LOT 2 AND 50AB20 LOT 14 CELLS WERE NOT TESTED FOR CAPACITY AT 0°C (DESIGNATED AS TEST BATTERIES).
- NO SPEC MINIMUM OR MAXIMUM.
- THIS RATIO INDICATES HOW MUCH MORE CAPACITY A GIVEN LOT HAD AT 0°C AT THE CELL LEVEL VERSUS AT THE BATTERY LEVEL. IT CAN ALSO BE THOUGHT OF AS "% OF CAPACITY LOST" BETWEEN THE CELL LEVEL AND BATTERY LEVEL.
- RATIOS > 100 % REPRESENT A NET GAIN IN CAPACITY.
- THERE IS A VERY GOOD CORRELATION BETWEEN A CAPACITY LOSS OF > 8 % (AS DETERMINED BY THIS METHOD) AND THE ANOMALOUS NASA STANDARD 50 A.H. CELL LOTS.

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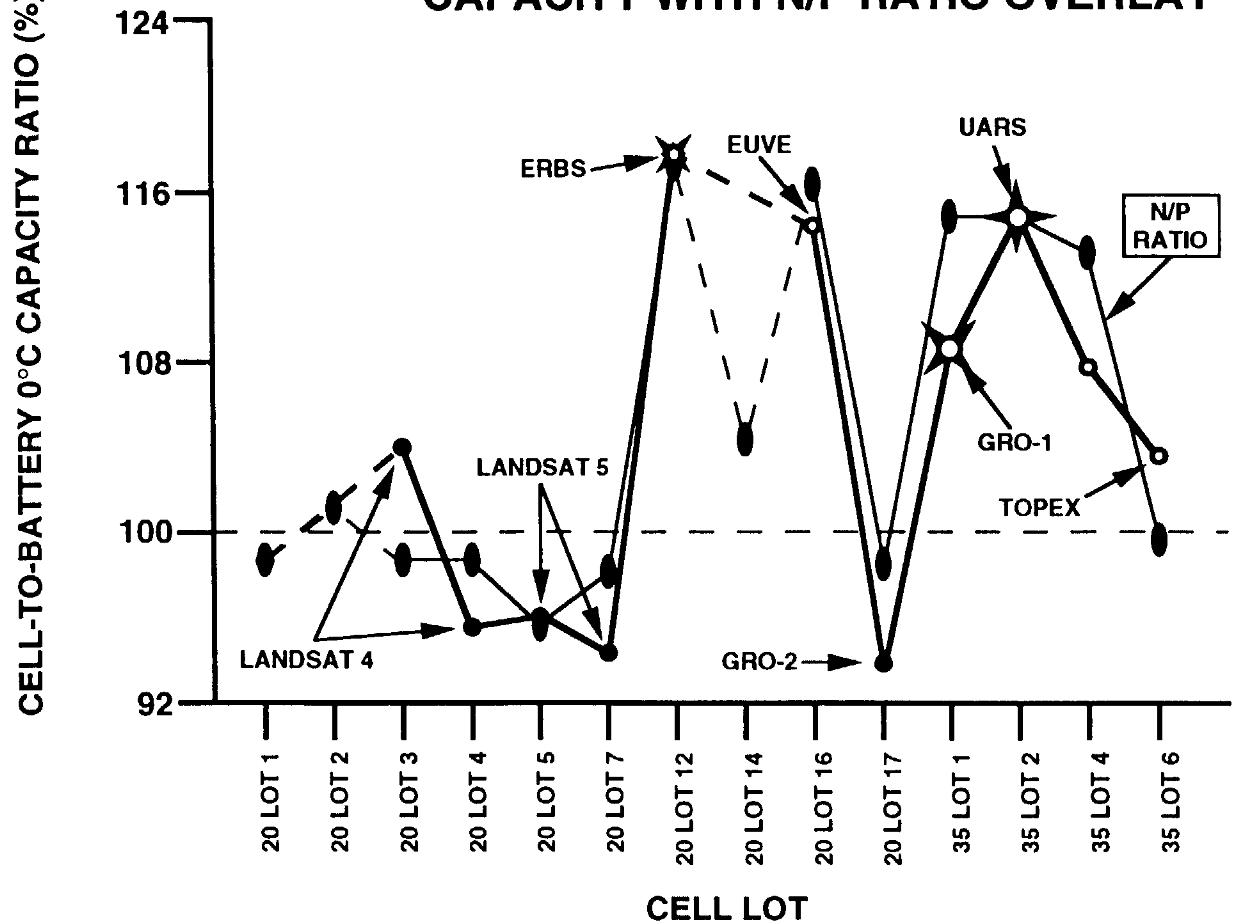
NASA STANDARD 50 A.H. BATTERY CELL HISTORICAL TREND

RATIO OF CELL 0°C CAPACITY TO BATTERY 0°C CAPACITY WITH N/P RATIO OVERLAY



- BATTERIES FROM 50AB20 LOT 2 AND 50AB20 LOT 14 CELLS NOT TESTED FOR CAPACITY AT 0°C (DESIGNATED AS TEST BATTERIES).
- RESEMBLANCE OF THIS RATIO TO THE N/P RATIO (SIZED HERE TO FIT ON THE SAME SCALE) IS REMARKABLE.
- HOWEVER, N/P RATIO IS NOT THE CONTROLLING INFLUENCE. THE FACTOR(S) THAT MAKE THE N/P RATIO HIGH (E.G. HIGH NEGATIVE UTILIZATION) ARE INFLUENCING CAPACITY LOSS.
- EXAMPLE: NASA STANDARD 20 A.H. BATTERY CELL
  - 24AB06 LOT 4 (SOLAR MAX FLIGHT CELLS)
  - N/P = 2.03
  - NEGATIVE UTILIZATION = 81 %
  - 0°C CELL/BATTERY CAPACITY RATIO = 98.2%
  - LIFE: 2 MONTHS SHORT OF 10 YEARS PRIOR TO ORBITAL RE-ENTRY.

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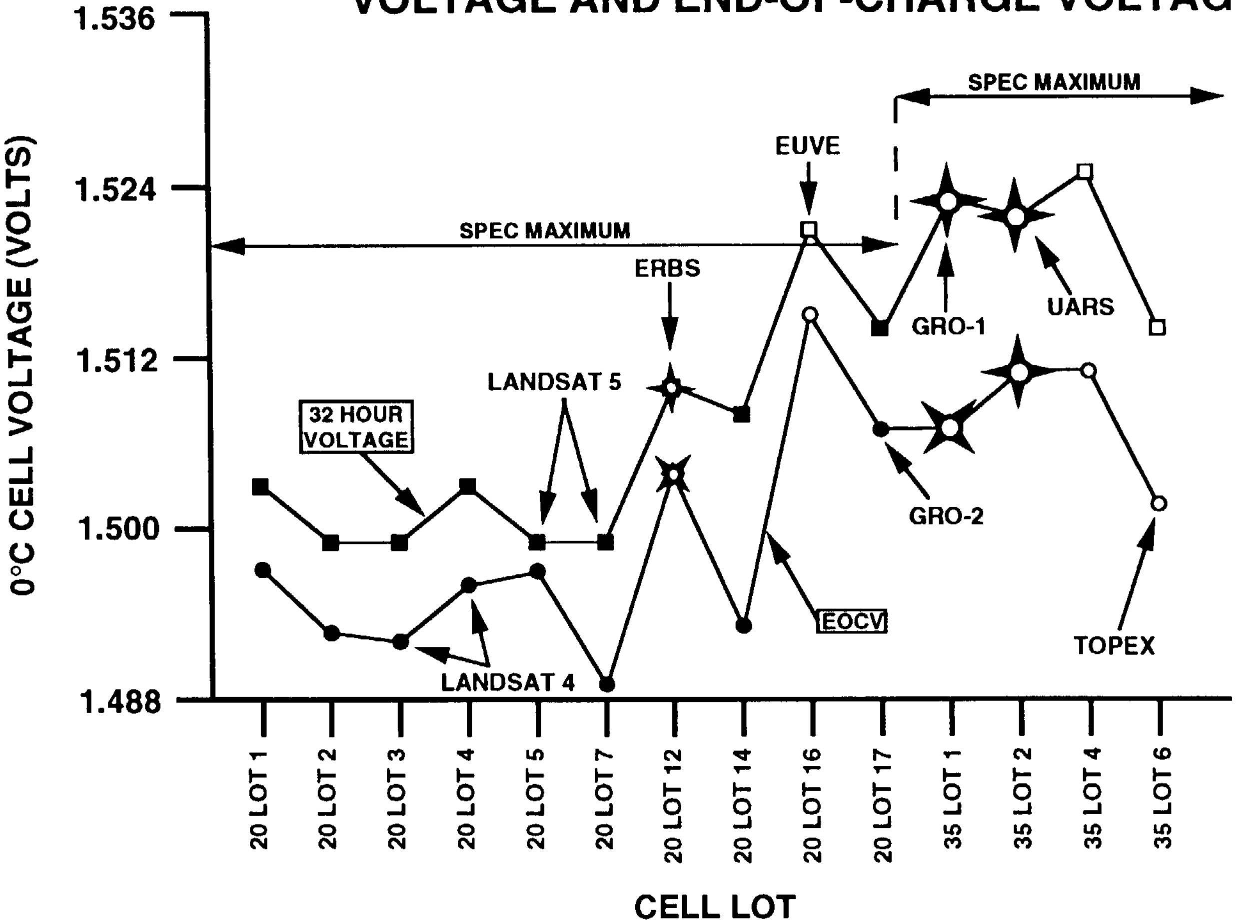
NASA STANDARD 50 A.H. BATTERY CELL HISTORICAL TREND

0°C CELL CAPACITY TEST: 32-HOUR CHARGE VOLTAGE AND END-OF-CHARGE VOLTAGE



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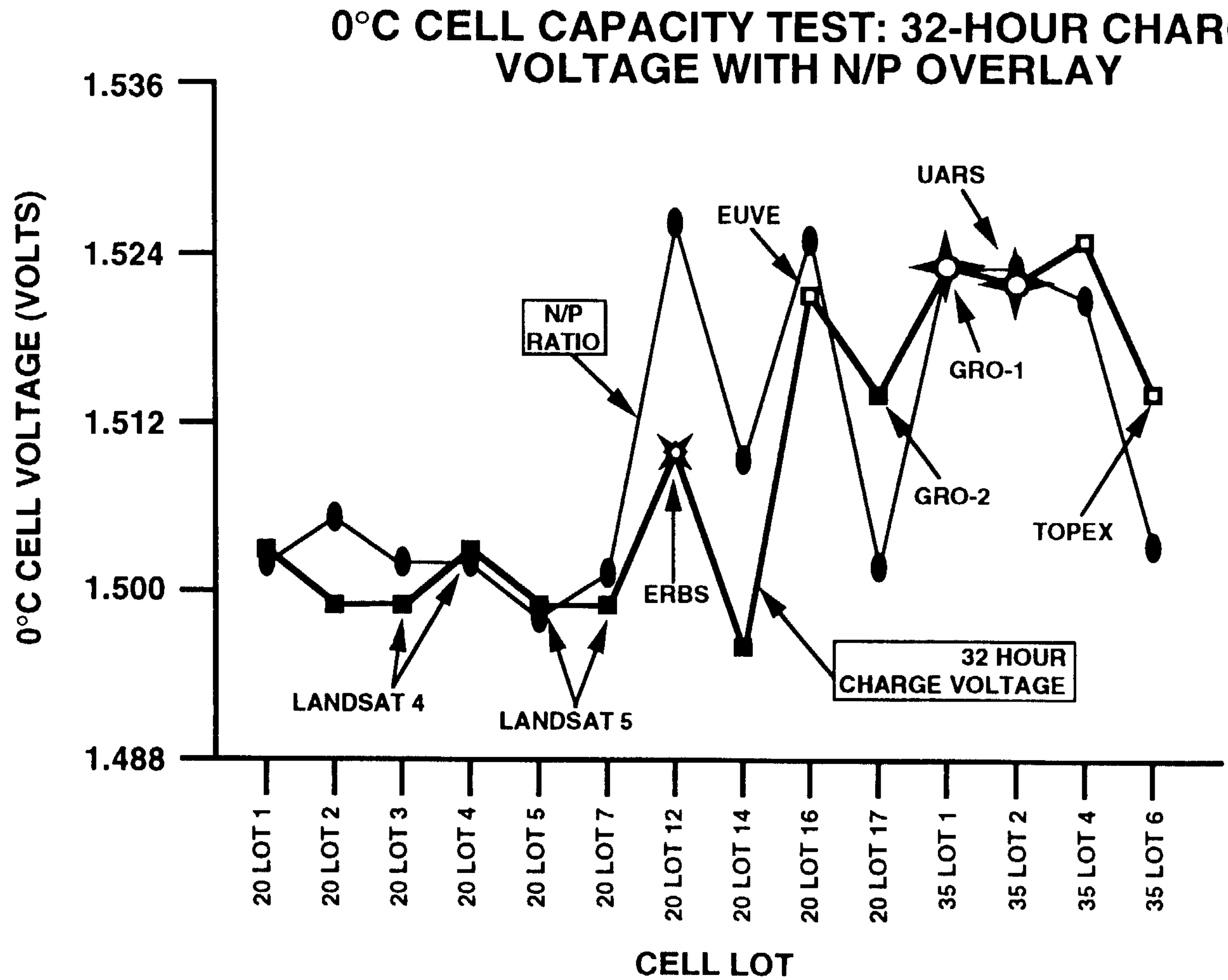
- NO SPEC MINIMUM.
- 32 HOUR CHARGE VOLTAGE IS THE NEAREST AVAILABLE DATA FOR PEAK (ROLLOVER) VOLTAGE.
- BOTH PEAK AND END-OF-CHARGE VOLTAGES AT 0°C HAVE BEEN INCREASING, AND ARE 15 - 20 mV HIGHER THAN EARLIER CELL LOTS.
- THE SPEC MAXIMUM WAS CHANGED IN 1989 TO ACCOMMODATE THIS TREND.
- THE TREND RAISES THE CONCERN THAT RECENTLY MADE CELLS MAY NOT BE AS COMPATIBLE WITH NASA STANDARD V/T LEVELS AS OLDER CELLS.
- THERE IS SOME CORRELATION BETWEEN HIGH VOLTAGE IN THE 0°C CAPACITY TEST AND THE ANOMALOUS NASA STANDARD 50 A.H. CELL LOTS, WITH SOME LOTS STILL TBD.

NASA STANDARD 50 A.H. BATTERY CELL HISTORICAL TREND



- THIS TREND ALSO BEARS A CONSIDERABLE RESEMBLANCE TO THE N/P RATIO.

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PRELIMINARY CONCLUSIONS:

- SEVERAL PLATE AND CELL PARAMETERS HAVE MIGRATED WITHIN THEIR SPEC LIMITS OVER THE YEARS (IN SOME CASES, FROM ONE EXTREME TO THE OTHER).
- SEVERAL PARAMETRIC RELATIONSHIPS, NOT GENERALLY MONITORED AND THEREFORE NOT UNDER SPECIFICATION CONTROL, HAVE ALSO MIGRATED OVER THE YEARS.
- MANY OF THESE CHANGES APPEAR TO HAVE TAKEN PLACE AS A NATURAL CONSEQUENCE OF CHANGES IN GE/GAB MATERIALS AND PROCESSES. THE EXACT NATURE OF THESE CHANGES IS STILL UNDER INVESTIGATION.
- SEVERAL OF THESE FACTORS MAY BE "CONSPIRING" TO AGGRAVATE KNOWN CELL FAILURE MECHANISMS (FACTORS SUCH AS HEAVIER PLATE, LESS TEFLON AND/OR LESS-UNIFORM TEFLON, LESS ELECTROLYTE) BUT ALL ARE STILL IN SPEC (WHERE SPECS EXIST)

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PRELIMINARY CONCLUSIONS (continued)

- THE WEIGHT OF THE EVIDENCE COLLECTED TO CHARACTERIZE THE ANOMALIES AND TO CHARACTERIZE THE NEGATIVE ELECTRODE ITSELF, STRONGLY SUGGESTS THAT ALTERATIONS TO THE STRUCTURE, COMPOSITION, UNIFORMITY AND EFFICIENCY OF THE NEGATIVE ELECTRODE ARE AT THE HEART OF THE BATTERY PERFORMANCE PROBLEMS CURRENTLY BEING EXPERIENCED.

- FURTHER INVESTIGATION AT ALL LEVELS (PLATE, CELL, BATTERY, AND SYSTEM) CONTINUES TO BE WARRANTED; HOWEVER, PLATE AND CELL INVESTIGATIONS HAVE YIELDED THE MOST USABLE AND CORRELATABLE DATA.

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