On-Orbit Health Check of Hubble Space Telescope Nickel-Hydrogen Batteries

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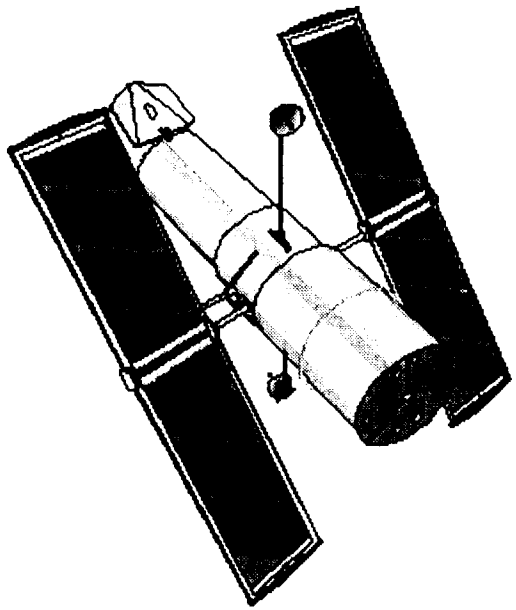
NASA AEROSPACE BATTERY WORKSHOP
Dec. 3 - 5, 1996

Introduction

- Background
- Objective of Capacity Check/Reconditioning
- Battery Reconditioning Circuitry
- Reconditioning Procedure
- Results of Reconditionings
- Conclusions



Background

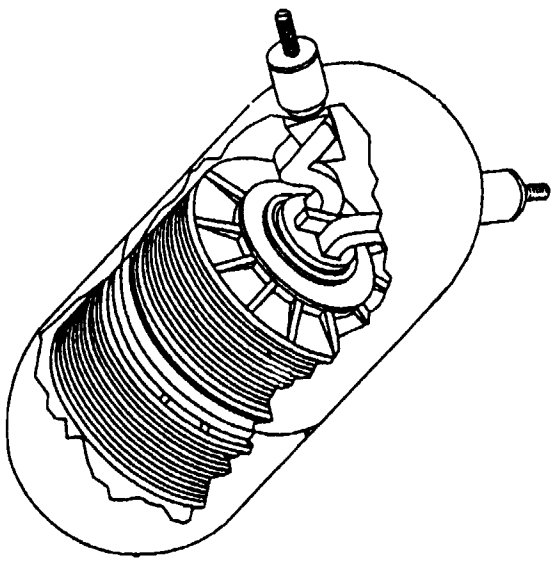
- The Hubble Space Telescope is a one-of-a-kind spacecraft that pushes technology to its limits. Housing an 8-foot (2.4 meter) mirror and several sophisticated cameras and detectors, the telescope is the largest orbital astronomy observatory ever placed in space.
  - Launch date - April 24, 1990
  - Deployment - April 25, 1990
  - First Servicing Mission - December 4, 1992
  - Second Servicing Mission - February, 1997

Background

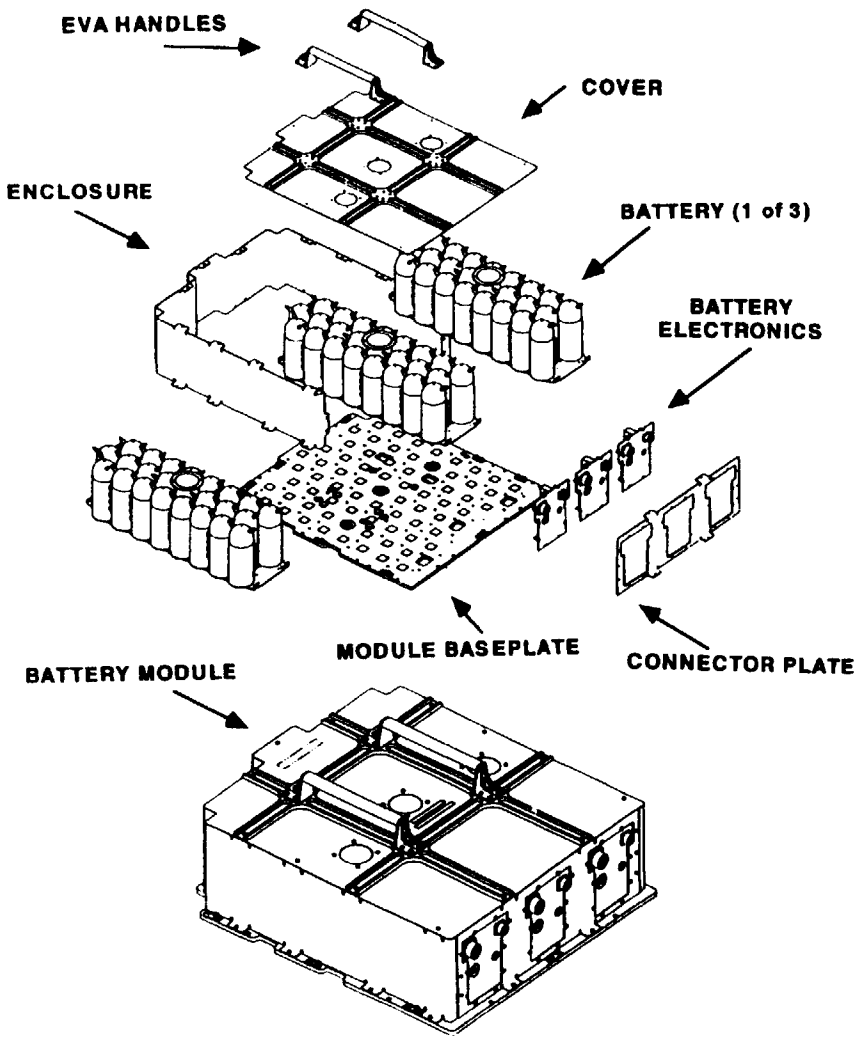
- Battery Design
  - Two Modules Each Containing Three 88 Ah NiH_2 Batteries (Six total)
    - Manufactured by: Eagle Picher / Lockheed
    - 23 Cells in Each, Only 22 Cells Are Electrically Connected (Position #22 Inactive)
      - Dry sintered nickel positive electrodes stacked with the platinum negative electrodes, zirconium oxide cloth separators and gas screens on a polysulfone core.

Background

- Positive Plate Fabrication
  - Flight Spare Module (FSM) in Feb. - June, 1988
  - Flight Module 2 (FM2) in June - Nov. 1988
- Cell Activation
  - FSM in Jan. 1989
  - FM2 in Mar. 1989



Background


EVA HANDLES
COVER
ENCLOSURE
BATTERY (1 of 3)
BATTERY ELECTRONICS
MODULE BASEPLATE
CONNECTOR PLATE
BATTERY MODULE

Background

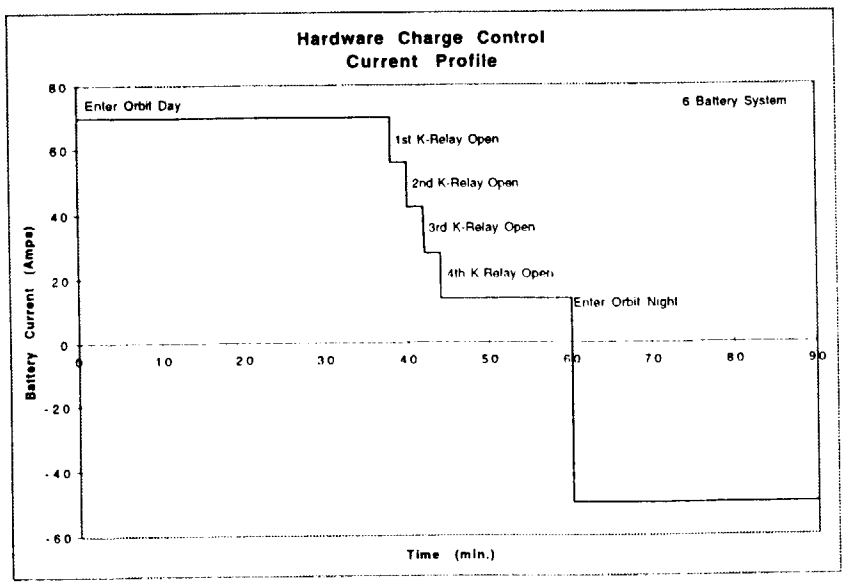
- Each Battery Has the Following Dedicated Monitors and Controls:
  - One Temperature Monitor for Telemetry
  - Four Charge Control Thermistors
  - One Primary and One Backup Heater System With Controllers
  - One Current Monitor (-25 to +25 Amps)
  - Two Cell Pressure Monitors (0 to 1500 PSI)
    - One telemetered through the Data Interface Unit (DIU) A side, the other through the DIU B side
      - Only one read at a time

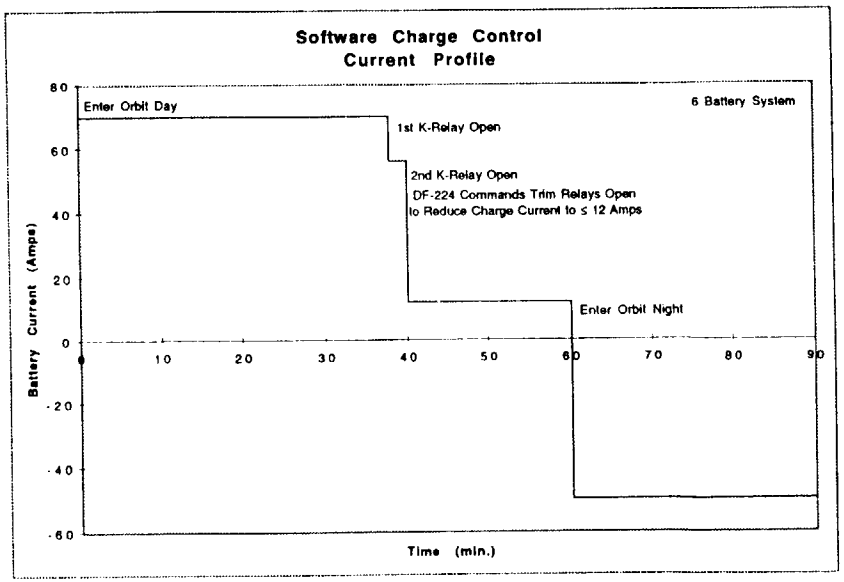
Background

- Charge System
  - Charge Managed for Each Battery by Charge Current Controllers (CCC)
    - Provide Multilevel Control of Battery Charging Based on Voltage and Temperature Characteristics
    - Control Relays Inside the Power Control Unit (PCU)
  - Charge Modes
    - Hardware Charge Control
      - Utilizes CCC "K" relays to remove Solar Panel Assemblies (SPA's) from batteries
      - Relays open based on battery voltage & temperature (Taper Charge)

Background

- Software Charge Control
  - DF-224 controlled
  - Initiated when two CCC "K" relays open
  - Commands SPA Trim Relays open to drop charge current down to the database defined level (Trickle Charge)





Background

- Battery History
  - Batteries were Charged and Installed Prior to Transfer to Launch Pad
    - Standard Baseline Charge used During Development and Testing of Cells and Batteries
      - Charge 10 Hours @ 9 amp rate (~C/10)
      - Charge 14 Hours @ 4 amp rate (~C/24)
  - Launch Delay
    - Batteries Removed for Reconditioning and Recharge
    - At Time of Release in Orbit, Pressure-based Capacity ≈ 61.7Ah / battery

Background

- Current Status
  - Six and One Half Years of Nominal Performance
  - Hardware Charge Control Operation Mode @ K1L4, K2L3
  - Completed 35982 Eclipse Orbits
  - Depth of Discharge Ranges Between 5 and 8.5%
  - System Capacity ≈ 461 Ah
  - Average Recharge Ratio ≈ 1.05
  - Last Reconditioning - March 25, 1996
    - Battery 3, Coulombic Capacity to 26.4V ≈ 74.7 Ah

Objective of Reconditioning

- The Reconditionings:
  - Determine Actual Battery Capacity for Trend Analysis and Mission Planning
  - Provide Verification of the Accuracy of the Pressure Transducers
  - Provide Data to Assess Battery Health
  - Reduce Battery Pressure
  - Restore Cell Balance

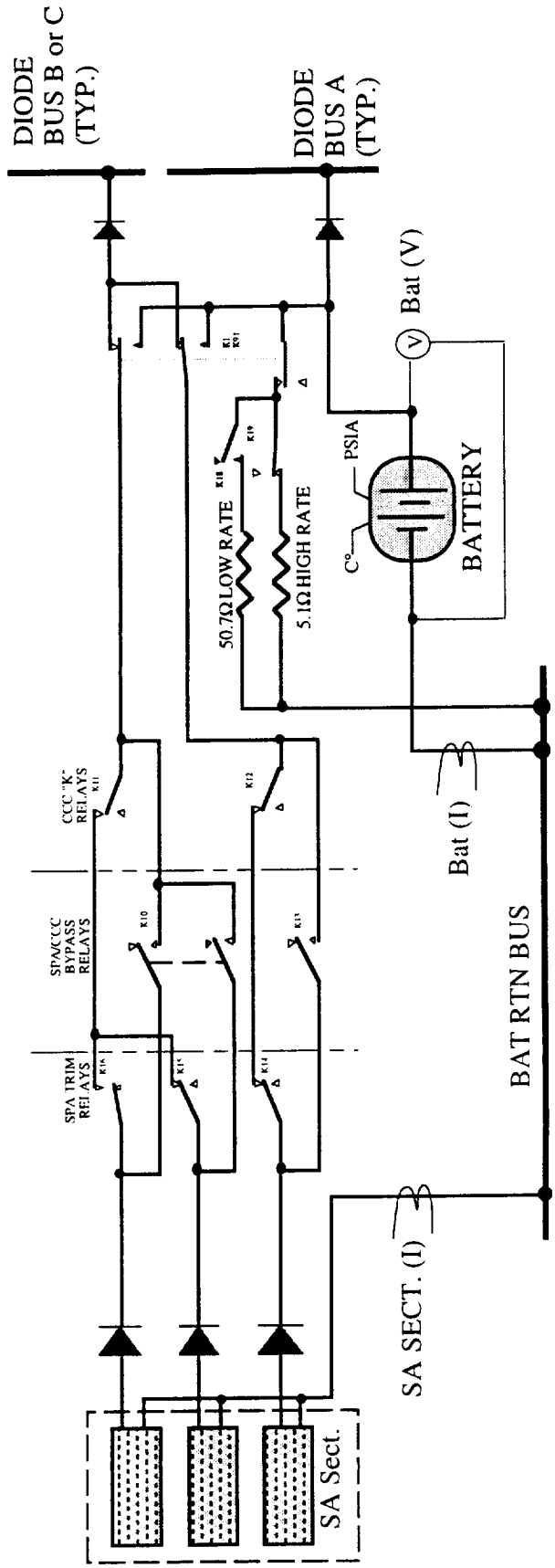
Battery Reconditioning Circuitry

- Switching Circuitry
  - Contained in the HST Power Control Unit
    - Two Parallel 25 Amp Latching Relays Isolate the Test Battery by Connecting the Solar Array (SA) Section Directly to the Diode Bus
    - Two 15 Amp Latching Relays Connect the Battery to Either the "High Rate" or "Low Rate" Reconditioning Resistor
      - SA section must be switched from the battery first
      - Discharge is autonomously terminated if HST enters safemode

Battery Reconditioning Circuitry

- Reconditioning Resistors
  - Constructed Using Heater Elements
  - "Low Rate" 50.7Ω ±3%
  - "High Rate" 5.1Ω (10 X 50.7Ω ±3% in parallel)

Battery Reconditioning Circuitry



Reconditioning Procedure

- Test Preparation
  - Normalize Test Conditions to Previous Test of the Specified Battery
    - Sun-to-Orbit Ratio (within ±2 minutes)
    - SA / Sun Incidence angle (±10°)
  - Other Preparations
    - Schedule TDRSS Support to Configure, Initiate, Monitor and Reconfigure HST for the Test

Reconditioning Procedure

- Schedule At Least One 15 min. Forward Link / Orbit During Discharge for Contingency Test Termination.

– "Go For Test" Conditions

- Two Orbits of Charge In Which Full Charge Cut-off Attained
- **DO NOT Interrupt Science!**

Reconditioning Procedure

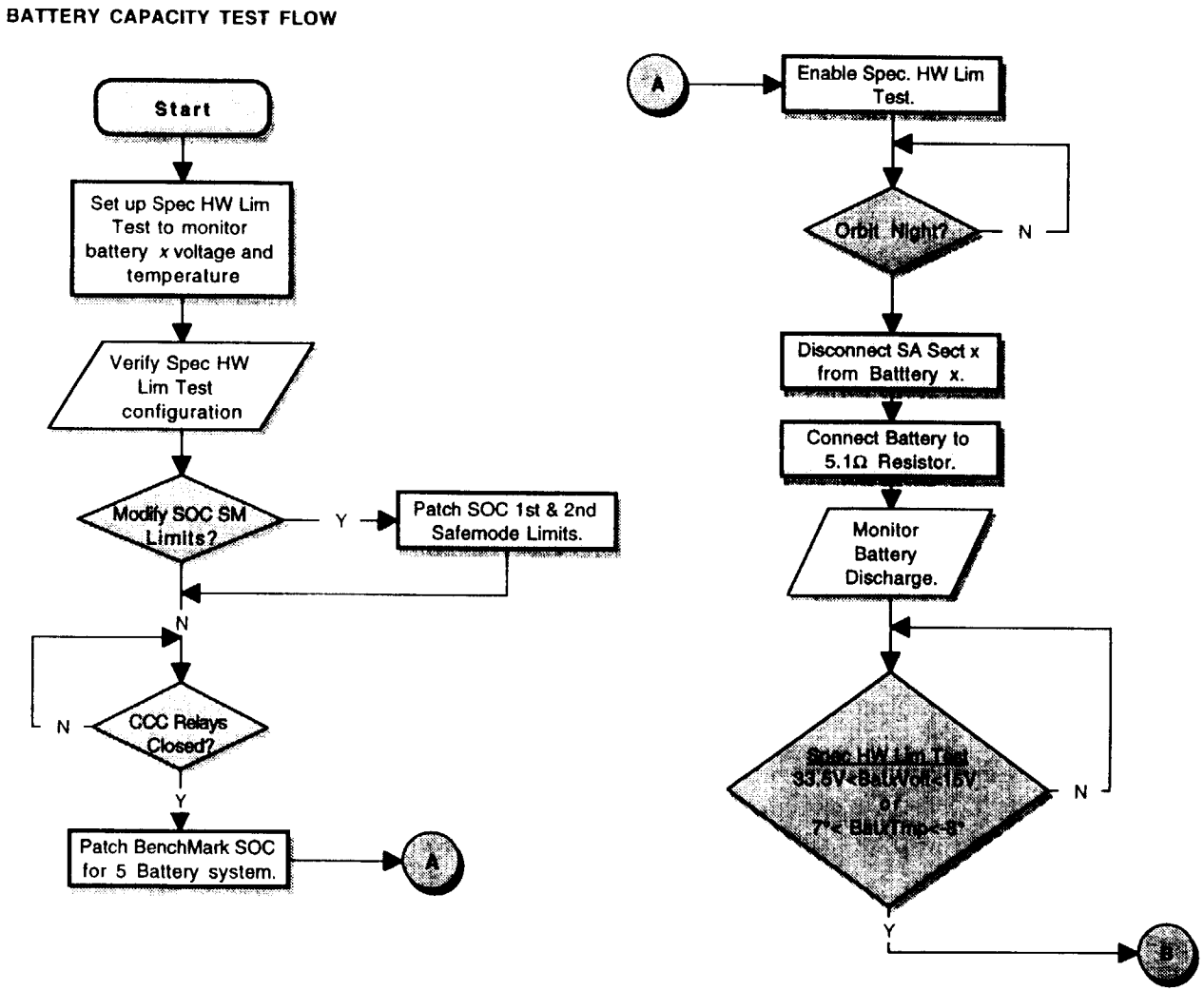
- Test Procedure
  - The Battery is Reconditioned to 15V
    - Autonomously Terminated by the "Special Hardware Limit Test"
    - Battery is Discharged "High Rate" Through the 5.1Ω Resistor
      - Average current = 5.4 Amps
      - Duration of discharge is about 15 to 18 hours
  - Data is Monitored and Collected During Discharge
    - Current, Voltage, Temperature and Pressure

Reconditioning Procedure

- Criteria For Test Termination
  - Flight Software State of Charge (SOC) Below 275 Ah for the 5 Battery System *
    - Benchmark SOC for 5 Battery System = 345 Ah
  - -8.0C° > Test Battery Temperature > 7.0°C **
  - 15.0V > Test Battery Voltage > 33.5V **
  - HST Safemode Entry ***

* Terminated Manually
**Terminated by Special HW Limit Test
***Terminated by Safemode Macro

Reconditioning Procedure



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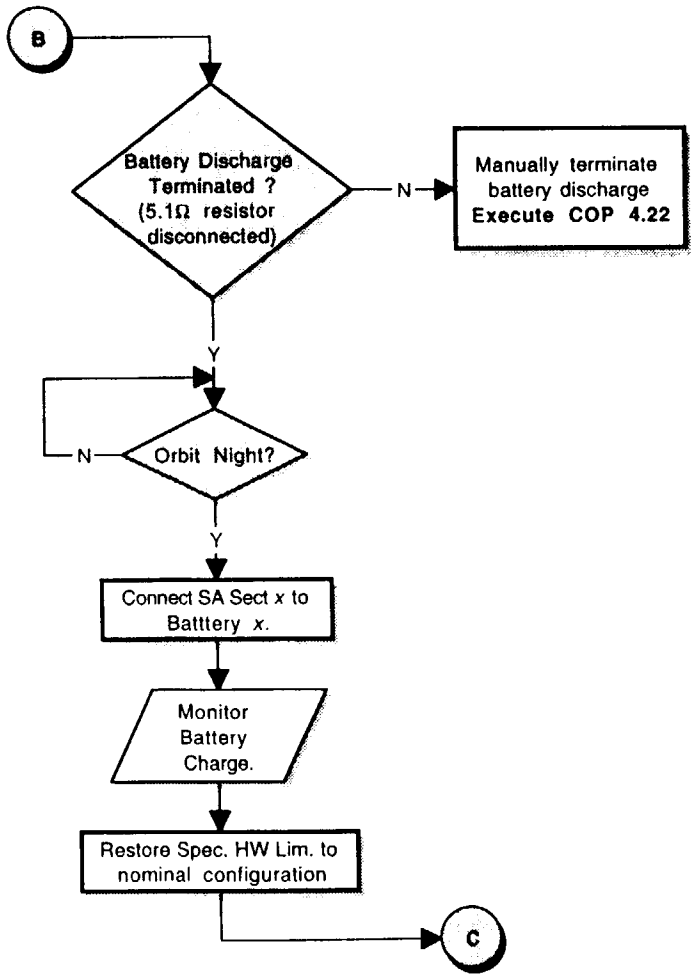
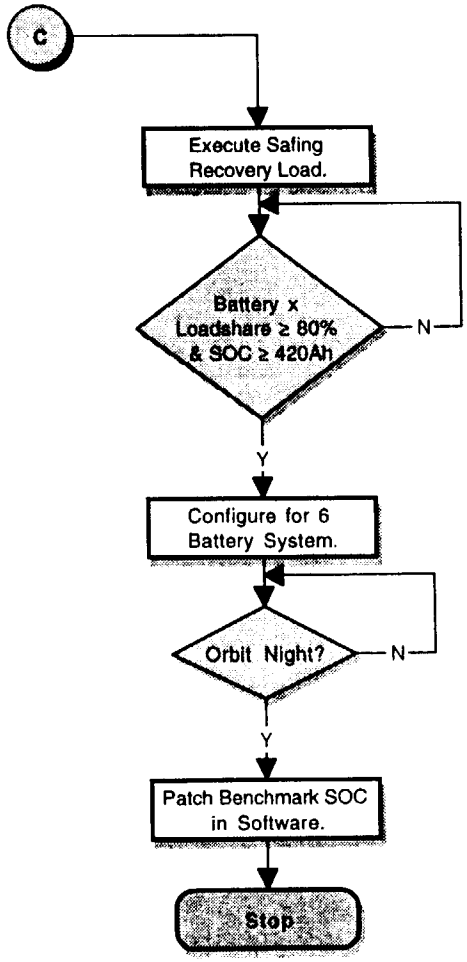




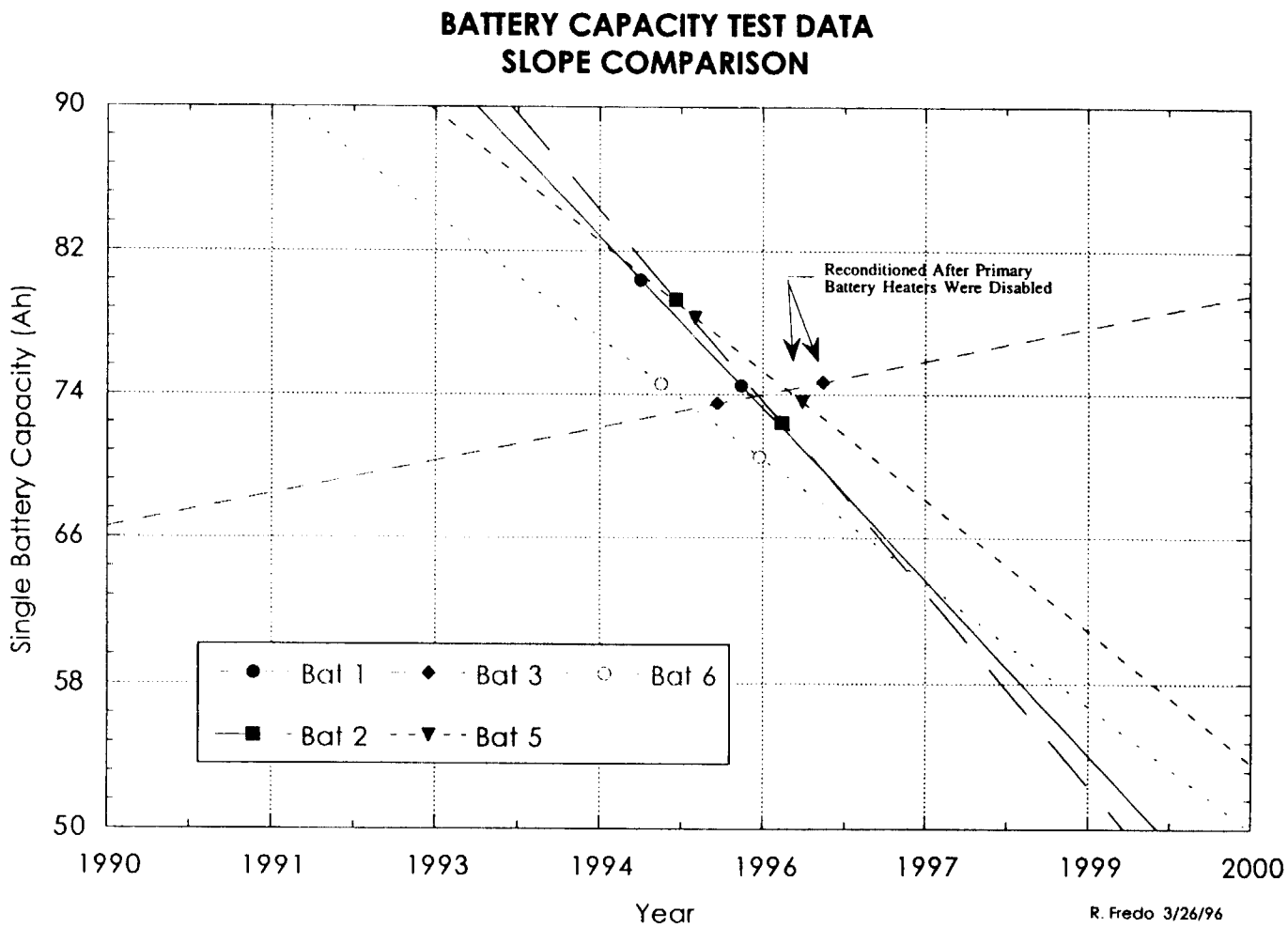
Results of Reconditionings

- Capacity
  - Batteries Reconditioned During April 1990 through Sept. 1992 Yielded (Current Integrated) Capacity Between 85.6 and 94.2 Ah
    - Indicated (Pressure Based) Capacity Prior to Reconditioning Ranged Between 88 and 102.6 Ah
      - Pressure transducers are recalibrated following each battery reconditioning
  - Capacity Recovery Very Gradual, Never Reached Original Level
    - Average Loss of ≈ 4.8 Ah/bat/year

Results of Reconditionings

- Decrease in Capacity Led to Disabling Primary Battery Heaters, Nov. 1995
  - Two Battery Reconditionings Since Heaters Disabled
    - Battery #5, yielded a decrease of 4.6 Ah in capacity, Jan. 1996 (previously tested Feb. 1995)
    - Battery #3, yielded an increase of 1.2 Ah in capacity, Mar. 1996 (previously tested April 1995)

Results of Reconditionings



Results of Reconditionings

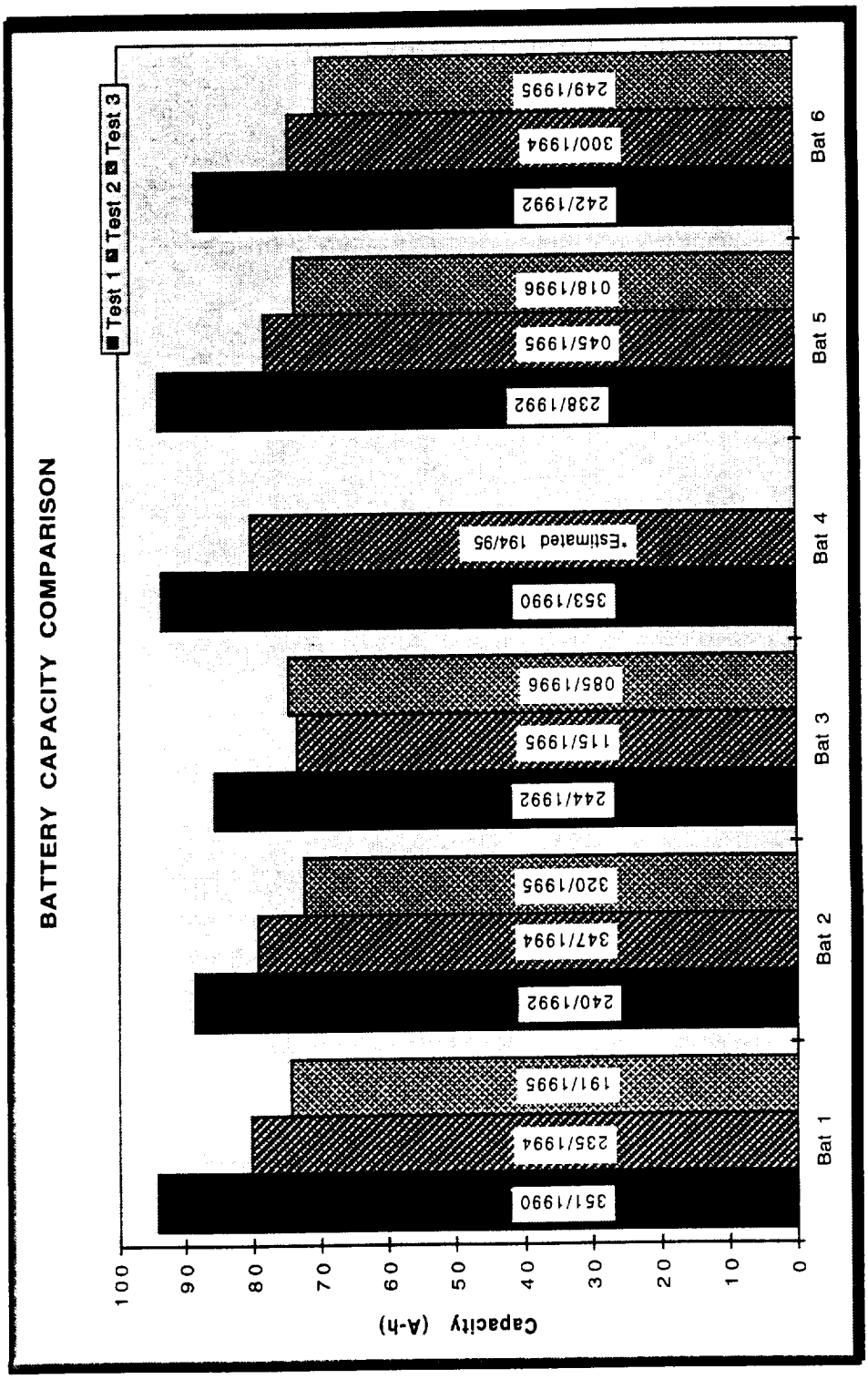
- Cell Balance
  - Reconditionings Following the Lowering of Charge Levels (Dec. 1993) Exhibit a Sluggish Voltage Knee in Contrast to an Earlier Sharp Knee
    - Indicates Cell Imbalance in the Battery
- Residual Pressure
  - Increases in Residual Battery Pressure @ 15V Typically Range Between 6 and 19 PSI
    - Most Recent Data Yielded an Increase of 0 PSI

Results of Reconditionings

Battery #	Date of Test (MM/YY)	Battery Pressure min - max (psi)	Pre-test Cap Pressure Based (A-h)	Post-test Cap Current Integrated (A-h)
Launch - CCC 1-6 K2 V-T level 2, CCC 1-6 K1 V-T level 3, Software Charge Ctrl; 4/28/90 - CCC 1-6 K2 V-T level 3				
1	Dec-90	980 - 1115	93	94.2
4	Dec-90	937 - 1044	88	93.4
5	Aug-92	991 - 1101	102.6	94
2	Aug-92	1053 - 1163	94	88.5
6	Aug-92	977 - 1094	93.9	88.3
3	Aug-92	951 - 1071	92.3	85.6
3/25/93 - CCC 1-6 K1 V-T level 4, Hardware Charge Ctrl 12/10/93 - CCC 4 K2 V-T level 2; 1/31/94 - CCC 4 K2 V-T level 1 4/5/94 - CCC 5 K1 level 3 (short between +E hot and +B return.)				
1	Aug-94	1017 - 1136	94.4	80.4
6	Oct-94	979 - 1079	86.5	74.6
2	Dec-94	895 - 1046	82.2	79.3
1/8/95 - SA Slew minimization 1/20/95 - CCC 5 K1 level 4 (healed short between +E hot and +B return.)				
5	Feb-95	1036 - 1032	94.8	78.3
3	Apr-95	956 - 1035	82.1	73.5
1	Jul-95	1011 - 1119	81.5	74.5
4	*	999 - 1085	100.1	80.4
6	Sep-95	979 - 1052	74.2	70.5
2	Nov-95	885 - 962	76.4	72.4
11/27/95 - Pri Battery heaters disabled				
5	Jan-96	863.9 - 1094	78.7	73.7
3	Mar-96	945 - 1029	74.5	74.7

* The Battery 4 Capacity is an estimate based on the other 5 battery tests. No test of battery 4 was conducted due to PCU relay failures.

Results of Reconditionings



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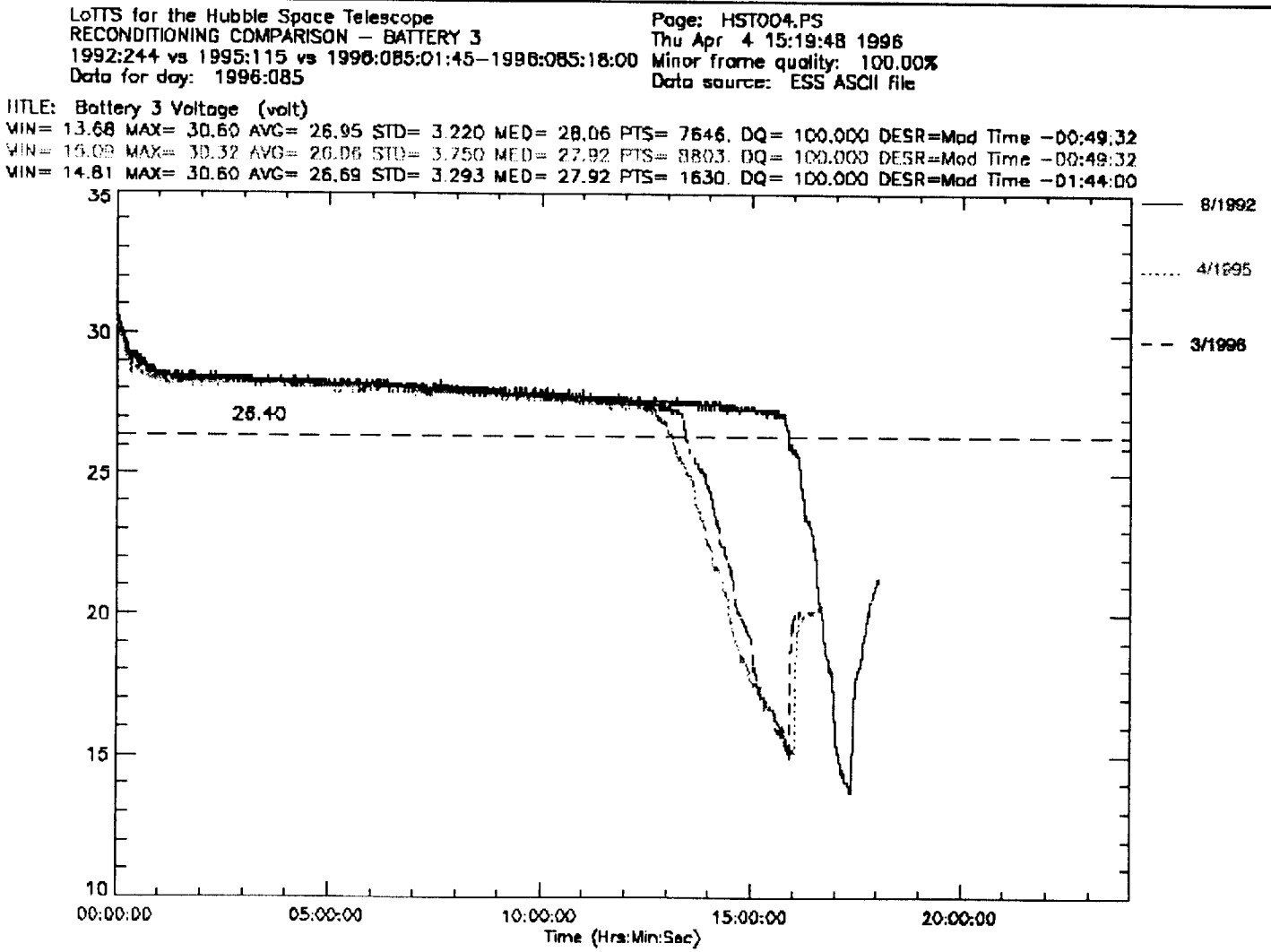

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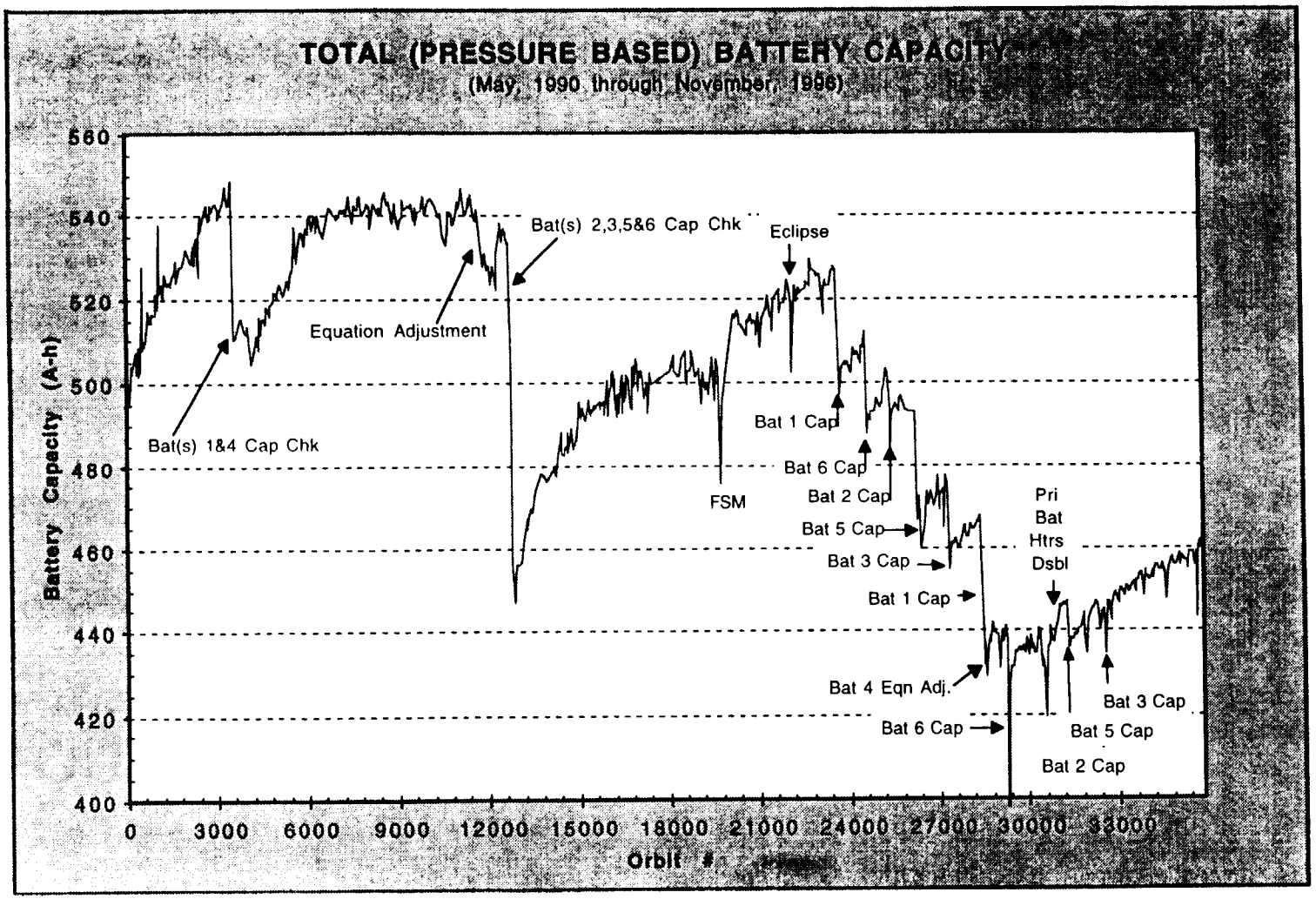

Conclusions

- Battery Capacity, From Reconditioning Data, Decreased Over Time (1990 - 1996)
  - Battery Temperatures Were Decreased by Disabling Primary Heaters, Nov. 1995
    - Allows Batteries to be Charged to Higher Voltage
    - Last Reconditioning Indicated Improvement, Mar. 1996
  - Development of New Charge Scheme is in Progress to Mitigate the Battery Degradation

Conclusions

- Health-Check, Capacity Data Indicated no Need to Refurbish Batteries in the Second Servicing Mission - Feb. 1997
- Reconditioning Decreased the Battery Operating Pressures
- Calculated Battery Capacity, Based on the Pressure Transducers, was Found to be Inaccurate
  - Recalibrated Pressure the Transducers