HST Replacement Battery
Initial Performance

Stan Krol, Greg Waldo
Lockheed Martin Information Systems & Global Services

Roger Hollandsworth
Lockheed Martin Space Systems Company
Introduction

- The Purpose Of This Presentation Is To Highlight The Findings From The Assessment Of The Initial SM4 Replacement Battery Performance


- The Assessment Examines The Battery Voltage, Current, Thermal, Pressure, State Of Charge And Impedance Performance.
SM4 Battery Replacement

- The HST original Nickel-Hydrogen (NiH2) batteries were replaced during the Servicing Mission 4 (SM4) after 19 years and one month on orbit.

- The replacement batteries were installed during EVA2 (Bay 2) and EVA5 (Bay 3).
  - Bay 2 contains battery (SN): 1 (1161), 2 (1162) and 3 (1163)
  - Bay 3 contains battery (SN): 4 (1166), 5 (1165) and 6 (1164).

- Aliveness Tests and Functional Test were executed successfully with no liens
Battery Description

- 22 Electrically Series Connected RNH 90-3 NiH$_2$ Cells
- Wet Slurry Nickel Positive Electrodes & Double Layer Zircar Separator
  - Nickel Precharge
  - 1990 Original: Dry Sinter – Hydrogen Precharge
- Battery Isolation Switch (BIS) (EVA Operated Only)
- Current Sensor
- Individual Cell Heaters
  - 2 Independent Heater Circuits, Primary And Redundant
- 2 Independent Strain Gauge Pressure Monitoring Circuits
- Temperature Monitoring Circuit (Telemetered)
- 4 Charge Control Thermistors (Not Telemetered)
- Individual Cell Voltage Monitoring Test Connector J3 (GSE Only)
Battery Description (continued)

Nameplate capacity: 88AH

Battery Isolation Switch
Battery Description

The Six Batteries Are Housed Within Two Modules (S/N 1032 & 1033). Each Module Consists Of 3 Electrically Independent Ni-h2 Batteries Mounted To A Battery Module Base Plate.

- Size: 36” H x 32” W x 15” H
- Weight: 475 lbs each module

- Fabrication: January 1995-96
- Dry Stored for 4 Years
- Activation: September 2000
- Passively Stored Until April 2009
- Wet Stored 9 Years

J-Hook – Attach to Bay Door
**Battery 0°C Capacity**

**2002 Battery ATP vs. 2009 Can Ops**

- **2002 Battery ATP (Blue Line)**
- **2009 Can Ops (Red Line)**
- **2002 Amps (Orange Line)**
- **2009 Amps (Green Line)**

**Battery Voltage (V)**
- 2002 - 96.14 Ah
- 2009 - 91.08 Ah

**Discharge Capacity (Ah)**
- 2nd Plateau

**Current (A)**
- -4 to 12
Battery 0°C Capacity Trend

- Maximum Capacity (15V)
- Battery Capacity (26.5 V)
- 2nd Plateau Capacity (Delta)

Graph showing capacity trend over time with markers indicating data points for each year from 2000 to 2009.
Battery 0°C Cell Capacity

Current (A)

Cell Voltage (V)

Discharge Capacity (Ah)

2nd Plateau

B1CV1, B1CV2, B1CV3, B1CV4, B1CV5, B1CV6, B1CV7, B1CV8, B1CV9, B1CV10, B1CV11, B1CV12, B1CV13, B1CV14, B1CV15, B1CV16, B1CV17, B1CV18, B1CV19, B1CV20, B1CV21, B1CV22, B1CV23, Amp1
The Table Below Shows The Battery Pressure Based SOC’s At The Time Of Installation, Release And Release +30 Days (DOY 169 / 09) and present (DOY 301/09)

<table>
<thead>
<tr>
<th>Battery</th>
<th>Install SOC (Ah)</th>
<th>Release Full SOC (Ah)</th>
<th>DOY 169/09 Full SOC (Ah)</th>
<th>DOY 301/09 Full SOC (Ah)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>52.3</td>
<td>67.7</td>
<td>86.2</td>
<td>87.5</td>
</tr>
<tr>
<td>2</td>
<td>53.3</td>
<td>66.8</td>
<td>84.9</td>
<td>87.8</td>
</tr>
<tr>
<td>3</td>
<td>49.0</td>
<td>62.3</td>
<td>80.4</td>
<td>82.1</td>
</tr>
<tr>
<td>4</td>
<td>58.0</td>
<td>73.4</td>
<td>92.2</td>
<td>92.0</td>
</tr>
<tr>
<td>5</td>
<td>52.5</td>
<td>66.9</td>
<td>86.4</td>
<td>89.0</td>
</tr>
<tr>
<td>6</td>
<td>56.9</td>
<td>67.9</td>
<td>90.4</td>
<td>88.8</td>
</tr>
</tbody>
</table>
State Of Charge (SOC) Performance

- At The Time Of HST Release, The Battery SOC Was 484 Ah
- SOC Continues To Increase And As Of DOY270 Is Above 525 Ah.

Individual Battery and System State Of Charge
(DOY 139-301, 2009)
The 1990 Dry Sinter Voltage Profile Differs From The Other Profiles:
- Software Step-to-trickle Charge Scheme Was Used vs. The Software Taper-charge Scheme
- Less Powerful SA1 vs. SA3
- Battery Temperatures:
  - 1990: ~ 0°C
  - 2008: ~ 0°C
  - 2009: ~ -2°C

Orbit Day Duration Was Matched For All Profiles

Battery Currents Were Approximately Matched (Within 2A Amps During Discharge) For All Profiles

The Battery Voltage Profiles Indicate That The Replacement Batteries Maintain A Higher Voltage Throughout The Orbit Night Discharge Period Than The Original Batteries Had Just After HST Deploy Mission.

The Plot Also Indicates The Degradation Of The Voltage Profile Between 1990 And 2008 For The Previous Batteries.

At This Time, The On-Orbit Plateau Voltage Is Unknown And Can Only Be Determined By An Extended Discharge Period.
Battery Voltage Comparison

(Wet Slurry {SM4} vs Dry Sinter {1990 and 2008})

- Load Current (A)
- Voltage (V)

Normalized Time

SA1 and Step to Trickle (K2 Level 3 {~33V})
SA3 and Taper Charge (K1 Level 4-100mV (32.6V))
The Battery Impedance is computed using the change in battery voltage divided by the change in battery current during the night to day transition.

The impedance of the replacement batteries exhibits lower impedance than the original batteries at the beginning of life and after 18 years on orbit.

Impedance includes 22 mohm harness resistance.
Battery Impedance

(Dry Sinter {1990 and 2008} and Wet Slurry {2009})
Minimum Voltage Performance

Daily Minimum Battery Voltage {End of Orbit Night} (DOY 139 - 308, 2009)

- Minimum End Of Orbit Night Battery Voltages (28.2V) Indicate 0.85V Margin Vs. Ground System Limit Of 27.35v.

- When Compared To The Bus Voltage Limit Of 26.37V This And Accounting For The 0.8V Diode Drop There Is (28.2 – (26.37 + 0.8)) = 1.03V Of Margin Vs. The Bus Voltage Ground Limit.
Battery Thermal Performance

- The Battery Temperatures Range Between -5°C And -2°C With Excursions To 0°C, When The Redundant Heaters Activate in the Low Load Configuration.
  - The Redundant Heaters Typically Cycle Between One And Two Times Within A 24 Hour Period
  - The Primary Heaters Remain Disabled To Allow The Batteries To Operate At Reduced Temperatures

- In the High Load Configuration, The Daily Average Temperatures Range Between -1°C and 2°C

- HST Experienced Solar Beta Peaks On DOY 155 and 200 Which Resulted In A Peak Orbit Day Duration Of 69.3 Minutes and 67.9 Minutes
  - Historically, The Batteries Have Tended To Heat-up During And/Or Following A Solar Beta Peak
  - No Heat-up Was Associated With These Events. The Lack Of Heat-up For This Recent Event May Be Attributed To The Good Condition Of The New Replacement Batteries And The Charge Control System Configuration
  - As The SOC Continues To Increase, The Batteries May Become More Sensitive To Such Beta Peaks
Battery Thermal Performance

Battery Temperatures {Daily Mean}
Orbit Day Duration
(DOY 139 - 308, 2009)

EPS Configured for High NCS Load
The Battery Load Share Is Well Balanced And Generally Within 16.2 To 17.2%. (larger transients are due to low load condition)

- Mean Load Share Deviation Among The Batteries Is 16.6 To 16.8%.

Battery Loadshare Since SM4

(DOY 139 - 308, 2009)
The Mean Battery Recharge Ratios Range From 1.05 To 1.10.

Battery Recharge Ratios
(DoY 139 - 308, 2009)

- Bat1 RR: 1.10
- Bat2 RR: 1.07
- Bat3 RR: 1.06
- Bat4 RR: 1.07
- Bat5 RR: 1.08
- Bat6 RR: 1.05

Lack of system reset due to low load corrupts calculation.
Conclusion

- Replacement Batteries, Installed Into HST During Servicing Mission 4, Are Performing Well Within Specification.
- The Batteries SOC Provides Good Science Margin.
- The Voltage Performance Maintains The End User Equipment Well Within The Operational Input Voltage Specification.
- Voltage Performance Supported By Favorable Battery Impedance
- Charge System Providing Recharge Ratios That Maintain And Improve The Battery SOC While Maintaining Battery Temperatures Below 0°C
- Recharge Ratio And Temperatures Are Within Optimal Ranges

• The Batteries and the Charge System Are Healthy
ACKNOWLEDGEMENTS

• This Work Was Supported by NASA Contract Mod 593 Dated 2 June 1987
  • Directed LMSC to Design, Develop and Deliver Nickel-hydrogen Battery Modules
  • For the Hubble Space Telescope Low Earth Orbit Mission
    • Per NAS 8-32697 and NAS 5-5000.