HUBBLE SPACE TELESCOPE PROJECT

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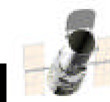

Hubble Space Telescope

Battery Capacity Update

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Abstract :

Orbital battery performance for the Hubble Space Telescope is discussed and battery life is predicted which supports decision to replace orbital batteries by 2009-2010 timeframe. Ground characterization testing of cells from the replacement battery build is discussed, with comparison of data from battery capacity characterization with cell studies of Cycle Life and 60% Stress Test at the Naval Weapons Surface Center (NWSC)-Crane, and cell Cycle Life testing at the Marshal Space Flight Center (MSFC).

Contents

- **On-Orbit Battery Performance**
  - **Descriptions & Test Assets**
  - **Performance & Capacity Maintenance**
  - **Capacity Trending**
- **HST Service Mission 4 (SM4) Replacement (1996 Build)**
  - **Cell Characterization & Life Studies**
  - **Cell DPA Studies**
  - **Battery Capacity Studies**
- ***SM4 Backup Replacement Batteries (2007 Build – On Hold)***
  - ***Lessons Learned From RNH 90-9 Cell Lots***

The contents of this presentation includes an update to the performance of the on-orbit batteries, as well as a discussion of the HST Service Mission 4 (SM4) batteries manufactured in 1996 and activated in 2000. A second set of SM4 backup replacement batteries began manufacturing Jan 11, 2007, for a delivery scheduled for July 2008, but are currently on hold.

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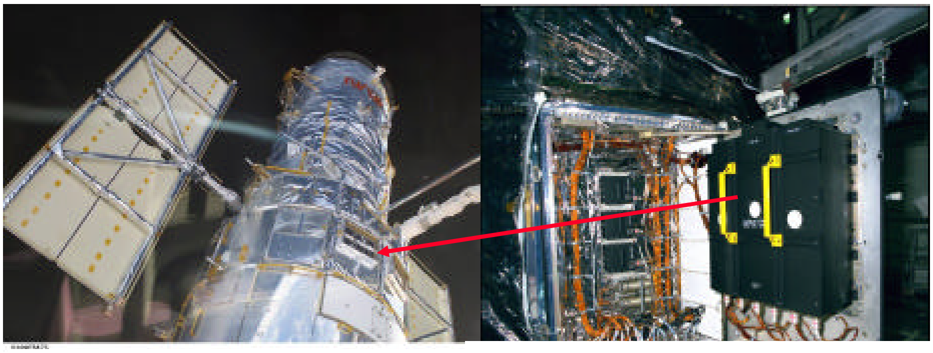
Flight Batteries



- (3) 23-cell NiH_2 Batteries Per Module
  - 22 Cells Electrically in Series
- Battery Capacity: 88 Amp-hr (Ah)
  - 15 A Discharge to 26.4 V at 10 °C
- Battery Module Size (in.):
  - 11.22 X 36.00 X 31.75
- Module Weight(lb.): 500 Max
- Launch: April 24, 1990 (17.6 Years)

LOCKHEED MARTIN

The HST batteries are mounted inside Equipment Bays #2 and #3, with each Bay containing a battery module (right picture) of 3 batteries. The astronaut replaceable modules are mounted on the door of the Bay with J-hooks. The door is equipped with louvers for heat rejection, which results in the design being thermally limited to about 30 Watts per battery.

SM4 will replace the on-orbit batteries during an Aug-2008 Shuttle mission. At that point the current batteries will have had 18.2 Yrs of on-orbit operation with >100K orbital cycles.

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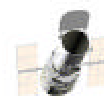
SM4 Battery Dates



- **1996 Manufacture Cell**
  - Colorado Springs Wet Slurry Nickel Plaque
  - EPT-Joplin C-Street EC Impregnation & Assembly
  - Helium Dry Store 1996 – 2000
- **2000 Activation (4 Yrs Dry Storage)**
  - Colorado Springs Wet Slurry Nickel Plaque
  - EPT-Joplin C-Street EC Impregnation & Assembly
- **2008 Launch (August 7, 2008)**
  - 4 Years Dry + 8 Years Wet
  - Storage Life Waivers Required

LOCKHEED MARTIN

The HST replacement batteries for Service Mission 4, were manufactured in 1996 and dry stored under helium until Aug. 2000. The replacement cells are identical to the on-orbit cells, except they use the Colorado Springs Wet Slurry nickel plaque. With the scheduled launch of SM4 on Aug. 7, 2008, these batteries will have 4 years dry storage and 8 years wet prior to on-orbit use. The HST Handling Plan calls for 60 month wet storage, and total dry, wet, and mission life of 14 years. Waivers to the wet life are being processed to allow use of these batteries.

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SM4 Replacement Build

- Range Line Wet Slurry Nickel Plaque
- EPT-Range Line EC Impregnation & Assembly
- 15 Month Schedule Started Jan. 2007 - **Stop Work June 21, 2007 (Budget)**

- Lot 12 – 32 Cells - Replacement Flight Spare Battery - DPA & Life Test Cells	⏭ **Ready For Activation** **Dry Helium Storage**
- Lot 13 – 93 Cells - Replacement Flight Module 1034 - DPA & Life Test Cells	⏭ **Electrodes Prepared** **Ready For Leads** **Bagged – Dry Air**
- Lot 14 – 92 Cells - Replacement Flight Module 1035 - DPA & Life Test Cells	⏭ **Ni Plaque Processed** **Ready For Stamping** **Bagged – Dry Air**

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LOCKHEED MARTIN

With consideration to these restrictions GSFC is incrementally funding a second set of backup replacement batteries on a 15 month build schedule started Jan. 11, 2007 with delivery Jul., 2008. The new backup replacement batteries will utilize EP Range Line Wet Slurry Plaque plate and Range Line impregnation. This new procurement was placed on hold by NASA on Jun. 21, 2007 due to budgetary pressures. The first new lot of 32 cells (one Flight Spare Battery) are in dry storage under helium, ready to be activated. The second lot of 93 cells (one Flight Module) have all electrodes stamped, ready for leads and then stacking. The third lot of 92 cells (second Flight Module) has the nickel positive plaque processed into plates and 30% of the negative plates have been processed. These are all stored under dry air.

HST Flight Modules

Battery Isolation Switch

A total of 6 batteries will replace the on-orbit batteries during SM4. The top left photo shows Battery S/N 1161. The original set of flight modules had 23 cells, of which 22 were electrically active. The SM4 battery set has eliminated cell #15 in the center of the cell and installed a Battery Isolation Switch (BIS) which is used to electrically isolate the individual batteries during handling operations. The bottom left photo shows the three batteries that make up a Flight Module with each battery having individual power (J1) and instrumentation (J2) connectors. Not shown is the J3 cell voltage monitor connector at the rear of the battery for ground testing. The right photo shows one of the replacement modules with the lid in place, but with the astronaut handles yet to be installed. The BIS switch, shown at the 11 o'clock position, is only electrically active when moved to the 12 o'clock position.

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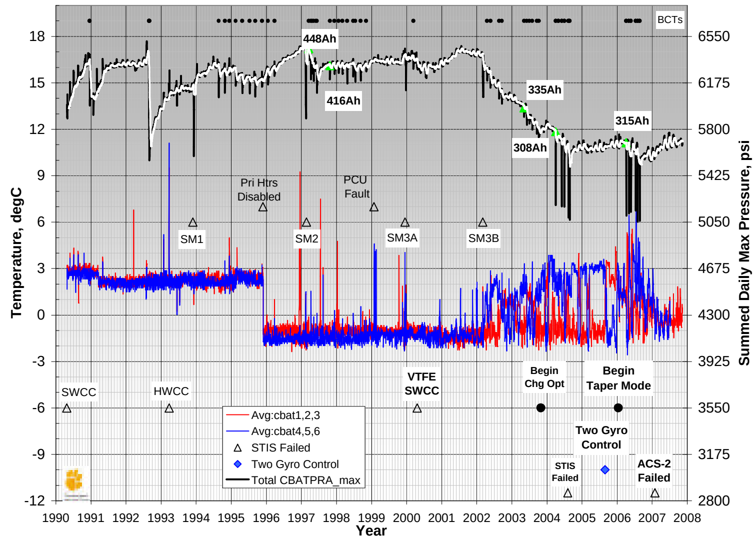
On-Orbit Performance



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HST started operation using Software Controlled Charge (SWCC) which was a high rate charge (solar limited) to a voltage-temperature (VT) cutoff, followed by a step to trickle charge (~1 Amp). In 1993 this was changed to Hardware Control (HWCC). During the 2000 SM3A voltage/temperature improvement kits (VIKs) were installed to lower the safe-mode VT levels by one step. SWCC was again implemented for charge control to shift the orbital relay cycles off the CCC Relays and back to the Trim Relays. During the 1999 Power Control Unit (PCU) fault investigation it was determined that a CCC Relay was more detrimental to operations than a Trim Relay failure. This operational mode was maintained through SM3B when the faulty PCU was replaced, and additional science packages replaced or installed.

The on-orbit maximum daily pressure summed over all six batteries and the average modules temperature are shown on this chart. The PCU was replaced during Service Mission 3B (SM3B) and with additional science packages installed, the system loads increased from 8 Ah to 12 Ah, which resulted in an increased capacity fade rate. This fade is linked to a reduction in recharge ratio in order to limit thermal dissipation. The period from 2004 to present is discussed on the next slide.

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Recent Performance

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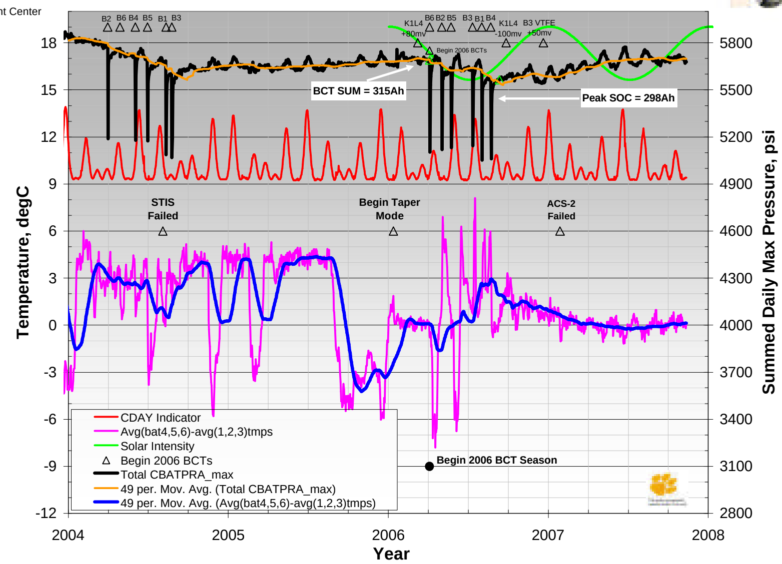

LOCKHEED MARTIN

The sum of the on-orbit maximum daily pressure for all batteries and average temperature delta between the two modules, for the period from 2004 to several weeks ago are shown on this chart.

Note that immediately after the 2000 replacement of the PCU the average temperature delta between the modules became more erratic and was increasing. This impacted the daily maximum pressure, and the overall system capacity. The numbers along the top of this chart show the system capacity going into a recondition period, and following that period.

In 2003 ground studies performed at MSFC using the HST Test Batteries, showed that the system capacity could be increased by controlling the rate of the charge current, which was implemented in 2004 using charge optimization. This resulted in capacity fade stabilizing, however the temperature delta was still unacceptable. The charge algorithm was modified in 2006 to use a transiting to a tapering charge current as the VT trip is hit, instead of a step directly to trickle. This has resulted in the temperature delta being improved, as well as improvement in the system capacity.

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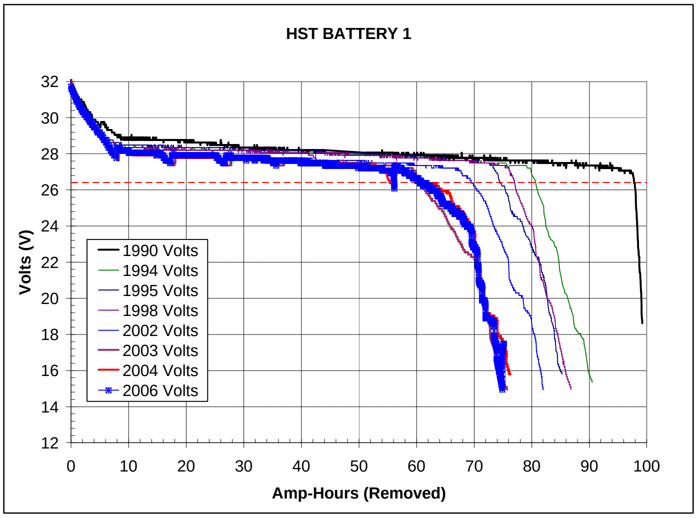
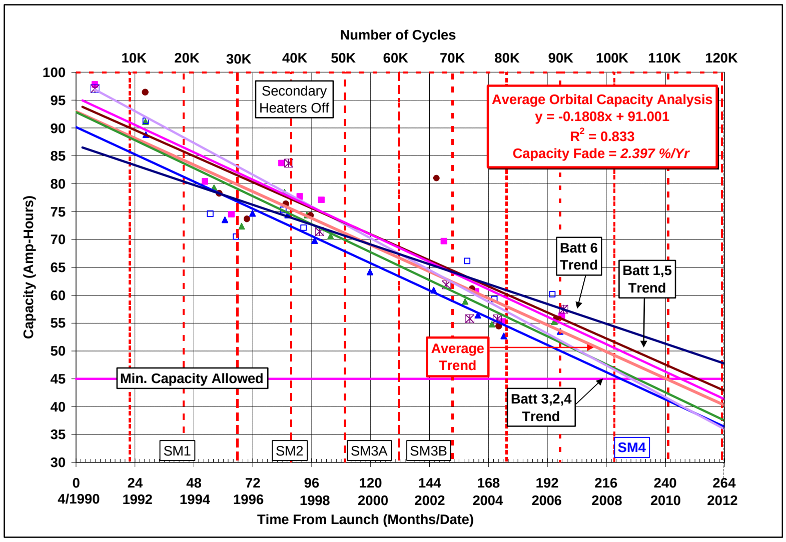
On-Orbital Battery 1



LOCKHEED MARTIN

The Battery Capacity Checks for the on-orbit Battery #1 is shown here which shows voltage plateau degradation and capacity fade, the capacity available to 26.4 V, with evidence of increasing second plateau formation. The capacity fade continues until the 2006 Capacity Check which shows a slightly improved capacity.

HST System Capacity Projection



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This chart shows the trend lines for all 6 on-orbit HST batteries. There appears to be two different trend populations with Batteries 2, 3, and 4 having the highest capacity fade, with a projected replacement needed in Feb. 2009. Batteries 1, 5, and 6 have lower fade rates and would require replacement by 2010 at the earliest. The average trend for all Batteries shows the need for a 2010 replacement date. The 45 Ah minimum capacity allowed is based upon many contingencies, some of which may have to be relaxed to allow HST science operation until the 2008 Shuttle Mission. Note – The dates on this chart begin at launch April, 24, 1990.

Battery System Projections

5 Amp Capacity

From Launch (4/30/1990)	System	Bat 1	Bat 2	Bat 3	Bat 4	Bat 5	Bat 6
Projected Life (Yrs)	20.0	20.5	19.0	18.9	18.8	22.8	23.5
Date (System <45 Ah/Bat)	**Apr-2010**	**Nov-2010**	**May-2009**	**Mar-2009**	**Feb-2009**	**Jan-2013**	**Nov-2013**
R2	0.833	0.885	0.923	0.942	0.929	0.666	0.783
Capacity Fade (Ah/Yr)	2.397	2.460	2.513	2.374	2.851	2.116	1.780

From 80+ Months (1997 -)	System	Bat 1	Bat 2	Bat 3	Bat 4	Bat 5	Bat 6
Projected Life (Yrs)	20.0	19.5	18.9	19.5	18.9	23.5	24.7
Date (System <45 Ah/Bat)	**Apr-2010**	**Nov-2009**	**Mar-2009**	**Oct-2009**	**Mar-2009**	**Oct-2013**	**Dec-2014**
R2	0.775	0.929	0.949	0.956	0.824	0.536	0.912
Capacity Fade (Ah/Yr)	2.480	2.914	2.647	2.216	2.816	2.044	1.665

Since SM3B (4/2002 -)	System	Bat 1	Bat 2	Bat 3	Bat 4	Bat 5	Bat 6
Projected Life (Yrs)	20.0	19.2	26.8	21.4	33.5	17.9	24.6
Date (System <45 Ah/Bat)	**May-2010**	**Jul-2009**	**Feb-2017**	**Sep-2011**	**Oct-2023**	**Mar-2008**	**Nov-2014**
R2	0.347	0.652	0.418	0.914	0.155	0.728	0.441
Capacity Fade (Ah/Yr)	2.474	3.125	0.923	1.635	0.660	5.429	1.682

Latest Recondition	System	Bat 1	Bat 2	Bat 3	Bat 4	Bat 5	Bat 6
Capacity (Ah)	**55.74**	55.30	54.78	53.50	55.73	55.80	59.30
Date	**8/22/06**	8/1/06	5/2/06	7/11/06	8/22/06	5/22/06	4/5/06

- **Cycle Life Science Projection Based Upon Minimum Capacity Requirement of 45 Ah/Battery**
  - **Includes Margins**

This collection of tables summarize the system and individual battery capacity fade rates and projects a date for replacement of that battery.

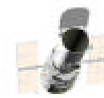
The top table summarizes the data from launch.

The second data set provides a projection since the primary heaters were disabled.

The third set examines the trend since the Power Conditioning Unit was replaced in 2002 during SM3B. Since that time the 6 batteries have undergone 4 reconditioning cycles with those trends given. This projects a near-term replacement if this trend continues.

The last data set lists the date and capacity of the last reconditioning for each battery.

SM4 Replacement Battery NWSC-Crane Testing



- **E602H 5-Cell Pack (8/00 Activation)**

  Cycling Start 8/01 (Stress + Mission)

- **E603H 5-Cell Pack (8/00 Activation)**

  5 Yrs Cold Store

  Cycling Start 2/06 (Stress)

- **RNH 90-9 Comparative Pack Tests**

  10 Yrs Cold Store

  Cycling Started 8/07 (1150 Stress Cycles Completed)

The SM4 cell build included a number of cells to be used to study cell dry storage parameters with cells removed from dry storage at 0, 2, and 4 years, activated and submitted to NWSC-Crane for Stress Cycle Testing and then nominal mission life cycle testing. RNH 90-9 Lot 3 cells from LM having similar plaque, fabrication, and activation processes to the HST cells were used for comparative tests.

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NWSC Pack E602H

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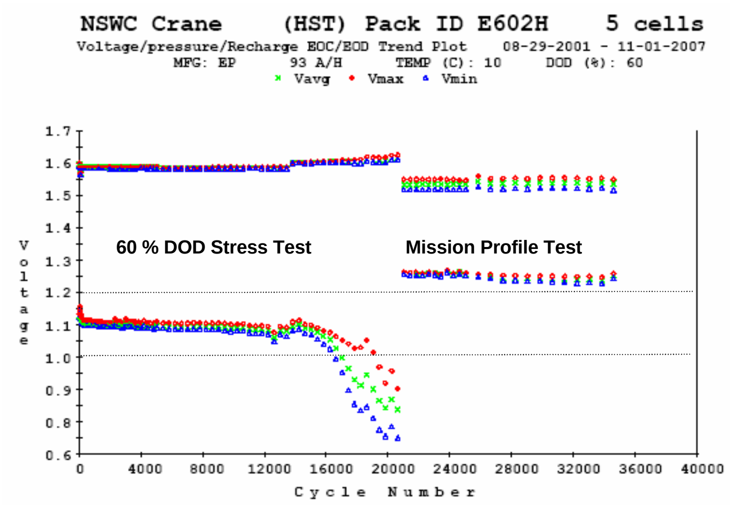

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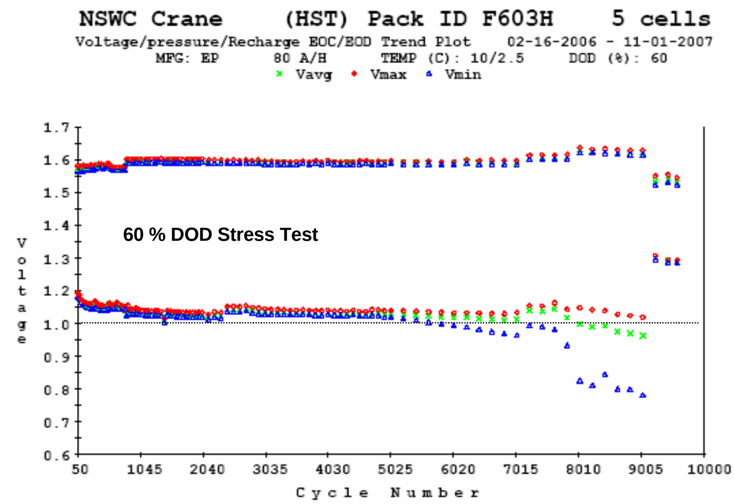
This chart from NWSC-Crane for the SM4 Lot 10/11 Wet Slurry cells activated in 2000 shows ~14,000 60% DOD LEO stress cycles, cell start going below the 1.0 V threshold. The test was converted to a nominal mission profile 15% DOD test at ~21,000 cycles and the test has continued, with 14,000 cycles in the mission profile.

NWSC Pack E603H



This chart from NWSC-Crane for the SM4 Lot 10/11 Wet Slurry cells activated in 2000, BUT with 5 years wet storage shows ~9,200 60% DOD LEO stress cycles, at which time the test was placed into “nominal” mission profile testing. The pack has 750+ cycles in this profile.

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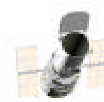


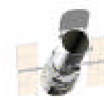
SM4 Replacement Battery MSFC Testing

- **Six 5-Cell Test #1 (Mission Profile)**
  - **3 Packs SM4 Lot 10/11 Cells Activated 6/96**
  - **3 Packs LM 90-9 Cells Activated 7/96**
- **Six 5-Cell Test #2 (Mission Profile)**
  - **Six Packs SM4 Lot 10/11 Cells**
  - **Activated 8/00**
- **Special Pack Testing**
  - **Launch Flow Test**
  - **Hybrid Test**

LOCKHEED MARTIN

The SM4 cell build included a number of extra cells to support studies of cell dry storage parameters with cells removed from dry storage at 0, 2, and 4 years, activated and then submitted to COMSAT and NWSC-Crane for Stress Cycle Testing and nominal mission life cycle testing.

MSFC Pack #1 Test History



2/98 – Cells Arrived @ MSFC

6/98 – Began Eagle Picher Cell Mini-verification Procedure

3/99 – 72-Hr Capacity Charge Retention Check
- Cold Stored For Instrumentation Modified

8/99 -6/00 Additional Characterization Testing
- Cells Demonstrating 2nd Plateau

6/00 – Began Orbital Mission Profile Cycling

11/00 – Stopped Cycling After 2000 Orbits
- Discharged All Cells To < .1 Volt, Cold Storage

8/05 – Cells Removed From Cold Storage
- Mission Profile Life Cycle Testing Resumed (>7500 Cycles)

RNH-90-3 SM4 HST wet slurry cells and RNH-90-9 LMSSC wet slurry cells, fifteen of each, all manufactured in the June-July 1996 timeframe using Colorado Springs wet slurry plaque, subsequently activated, and submitted to NASA-MSFC for characterization studies and mission cycle life testing.

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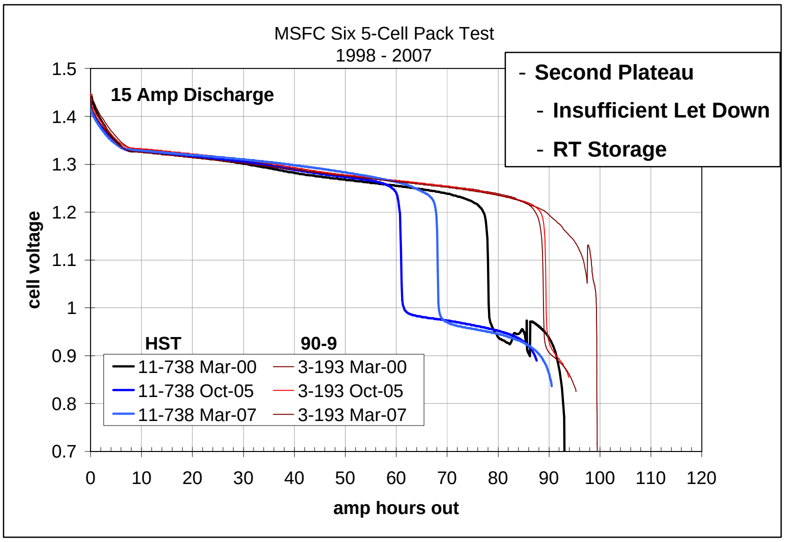
MSFC SM4 Pack #1 Study



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This chart compares the 2000 10 °C Capacity Test for the 1998 Test Packs versus the 2005 Capacity Test. Shown are a representative HST Lot 11 cell versus a Lot 3 90-9 cell manufactured at the same time. Note that the HST cell exhibits significant second plateau, while the 90-9 cell does not. This has been attributed to cell reversal during cycling and subsequent room temperature storage. These curves are repeated by all the HST cells and all the Lot 3 90-9 cells. Packs #1 and 2 contained Lot 2 90-9 cells, which also exhibited high second plateau capacity similar to the HST cells.

MSFC SM4 Pack #2 History

1/01 – Cells Arrive At MSFC And Assembled Into 5 Cell Packs

2/01 –Initial Capacity Cycles And Began Orbital Cycling`

3/01 – Orbit 500

- **Capacity Test**
- **Baseline Capacity Test**
- **Resumed Cycling**

5/01 - Orbit 1360

- **Repeat Capacity Tests**

9/01 - Orbit 3000

- **Capacity Tests**
- **Discharged & 0 °C Cold Store**

After 4 years of dry storage the flight cells were activated in Aug-00 at which time additional six 5-cell packs comprised entirely of HST Lot 10 and 11 Flight Build cells were assembled and subjected to capacity and mission profile testing.

MSFC SM4 Pack #2 History (Cont.)

3/02 –Six Month Cold Store - Capacity Tests – Cold Store

8/02 –Six Month Cold Store – Capacity Test – Cold Store

11/02 – 12/02 Capacity Tests

- **Baseline 72-hr Charge Retention Test**
- **14 Day Isothermal Charge Retention Test**
- **Baseline Capacity Test**

1/03 - Launch Scenario Capacity Test - Resume Cycling

8/03 – Launch Scenario Capacity Test - Resumed Cycling

- **Mission Profile Life Cycling (>25,000 Cycles)**

Post SM4 Power Budget Cycle Testing

The six 5-Cell Pack Test #2 was used to evaluated storage conditions and the thermal launch flow scenario to verify the on-orbit arrival capacity prediction.

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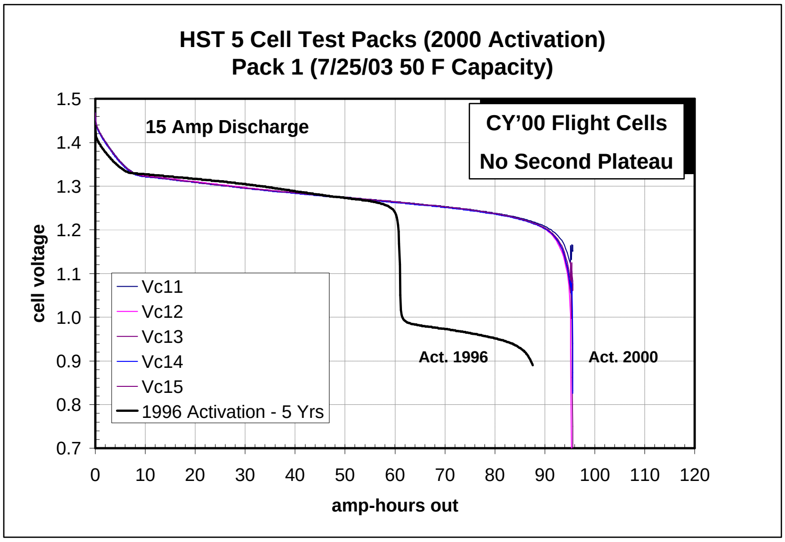
MSFC SM4 Pack #2 Study



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This chart details a 10 °C Capacity Test conducted in 2003 on SM4 Cells, activated in 2000, and placed into six 5-Cell Test Packs for cycling at MSFC. Compared to the Test Packs activated in 1996, the data for these packs do not show the second plateau lower capacity seen previously, due to improved handling plan and capacity measurements (no cell reversal).

SM4 Replacement Battery LM-COMSAT Testing

- **5-Cell Test Pack (6/96 Activation)**
  - 60% DOD Stress Test

- **Cell DPA (10 ea. Lot 10, 10 ea. Lot 11)**
  - Dry Stored Cells
  - Wet Cells Upon Activation (1996, 1998, 2000)
  - Wet Cells Cold Stored for 1, 5, & 7 Yrs
  - Comparative RNH 90-9 Lot 3 Cells (3/97 Activation)

The SM4 cell build included a number of cells to be used to study cell dry storage parameters with cells removed from dry storage at 0, 2, and 4 years, activated and submitted to COMSAT and NWSC-Crane for a number of Stress and nominal mission life cycle testing.

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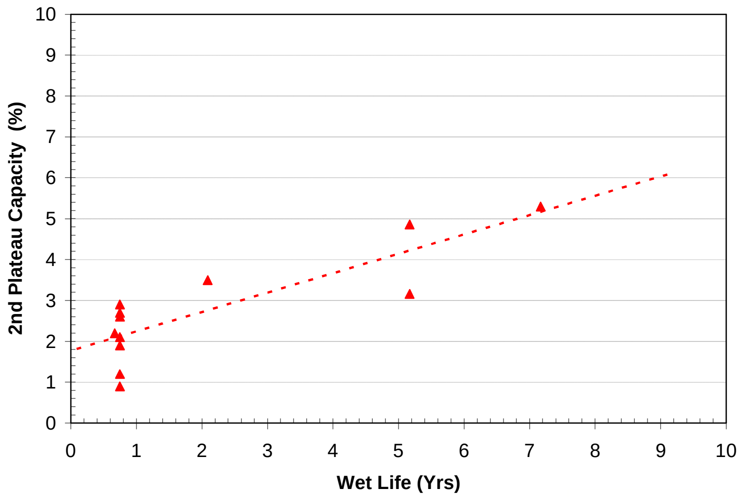
SM4 DPA Studies

					CELL CAPACITY (C/2)			Precharge Capacity - Ni Plates		
CELL ID	Act. Date	DPA Date	Dry Store Life (Yrs)	Wet Store Life (Yrs)	10 °C Ah to 1.0V	2nd Plateau Ah	20 °C Ah to 1.0 V	Electrical Ah (Stack)	Chemical Ah (Plate)	Total Ah
10-564	Jun-96	Aug-97	0	1.2	92.5	1.0				
10-572	Jun-96	Aug-97	0	1.2	90.8	0.3				
10-599	Jun-96	Aug-97	0	1.2	89.8	0.5	79.6			
11-625	Jun-96	Aug-97	0	1.2	90.8	0.6				
11-692	Jun-96	Aug-97	0	1.2	92.1	0.8				
11-749	Jun-96	Aug-97	0	1.2	92.9	0.6				
11-755	Jun-96	Aug-97	0	1.2	92.1	0.8				
11-757	Jun-96	Aug-97	0	1.2	91.6	0.4	81.5			
10-515	May-98	Jan-99	2	0.7	84.2	4.5	75.3	1.4	11.8	13.2
11-744	May-98	Jan-99	2	0.7	93.5	0.6				
11-754	May-98	Jan-99	2	0.7	84.5	3.9				
10-511	May-98	Jun-00	2	2.1	93.4	4.9	81.0	0.0	7.9	7.9
10-621	Aug-00	May-01	4	0.8	85.0	0.8	73.2	3.1	13.4	16.5
11-740	Aug-00	May-01	4	0.8	89.3	3.1	83.1	1.4	15.7	17.1
10-583	Aug-00	Oct-05	4	5.2	92.3	7.7	76.8	0.3	9.6	9.9
11-643	Aug-00	Oct-05	4	5.2	91.6	7.3	75.9	0.3	11.4	11.7
10-605	Aug-00	Oct-07	4	7.2	94.7	5.8	82.4	0.2	9.7	9.9
11-718	Aug-00	Oct-07	4	7.2	95.1	6.0	82.5			
3-142	Mar-97	Aug-06	0	9.4	102.5	2.3	92.26	0.5	11.5	12.0
3-172	Mar-97	Aug-06	0	9.4	98.8	0.7	87.01	1.7	15.7	17.4
3-102	Mar-97	Oct-07	0	10.6	103.3	1.2	91.5	0.5	8.3	8.8
3-165	Mar-97	Oct-07	0	10.6	102	1.1	90.3			

HST SM4 Cells in significant numbers have been submitted to COMSAT Labs for DPA analysis. The results show some impact upon the positive nickel electrode due to wet storage time. RNH 90-9 Lot 3 Cells, also manufactured with Colorado Springs nickel plaque during the same 1996 time frame, were transferred to HST from LMSSC for this wet life study.

Note that the cell capacity at 10C increases with age by about 10% over the 8 years of wet life age.

SM4 DPA Studies
2nd Plateau Capacity

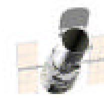


Electrical cell capacity testing at 10 C of the cells, prior to DPA, show an increase of the second plateau capacity of about 6% over the 8 year wet life period.

SM4 DPA Studies
Cell Reversal (C/40)

	Act.	DPA	VOLTAGE (V) at		
	Date	Date	**0.5 min**	**2.5 min**	**5 min**
HST 10/11					
S/N 10-621	Aug-00	May-01	-0.185	-0.298	-0.332
S/N 11-740	Aug-00	May-01	-0.125	-0.268	-0.329
S/N 10-583	Aug-00	Oct-05	-0.10	-0.42	-0.56
S/N 11-643	Aug-00	Oct-05	-0.06	-0.43	-0.56
S/N 10-605	Aug-00	Jul-07	-0.2	-1.42	-1.52
S/N 11-718	Aug-00	Jul-07	-0.2	-1.4	-1.51
LM 90-9					
S/N 3-142	Mar-97	Aug-06	-0.11	-0.26	-0.39
S/N 3-172	Mar-97	Aug-06	-0.08	-0.23	-0.35
S/N 3-102	Mar-97	Jul-07	-0.01	-0.3	-0.38
S/N 3-165	Mar-97	Jul-07	-0.01	-0.29	-0.36

Cells are submitted for DPA, since 2001, have been subjected to a wake-up cycle which, after cell drain, is followed by a 5 minute cell reversal test at rate of C/40. This chart summarizes the cell potential during reversal, as a function of reversal time. Note that all tests showed voltages above -0.6 V, representative of nickel precharge, after 5 minutes of reversal, EXCEPT this years test of HST cells with 7 years wet life. These cells showed a slight shoulder during the very beginning of the discharge which suggests very marginal nickel precharge still remaining.



SM4 DPA Studies
Gas Analysis

10 C Capacity	S/N 11-718	S/N 3-165
C/2 (Ah)	87.91	97.89
C/10 (Ah)	99.48	99.11
Chrg. Retn (Ah)	75.76	85.75
Chrg Retn (%)	85.95	87.6

Gas Analysis	S/N 11-718	S/N 3-165
Chamber Volume (cc)	1422.84	1422.75
Cell Volume (cc)	708.71	643.46
Cell Pressure (psia)	**0.78**	**1.36**

	P (%)	P (%)
Hydrogen	**2.00**	**0.02**
Helium	0.04	0.01
Methane	0.40	0.04
Water	52.00	0.40
Nitrogen	41.00	73.00
Oxygen	**3.60**	**25.00**
Argon	8.97	1.10
Carbon Dioxide	0.21	0.03
Wet Life (Yrs)	**7.2**	**10.6**

- **Capacity Increasing**
- **Increasing 2nd Plateau**
- **Nominal Vacuum All Cells**
  - **Indication of Ni-Precharge**
- **Positive Electrode (Ni)**
  - **Some Swelling**
  - **Blistering with Wet Life**
- **Negative Electrode (H2) - Nominal**
- **Separator - Nominal**
- **Electrolyte Distribution - Nominal**

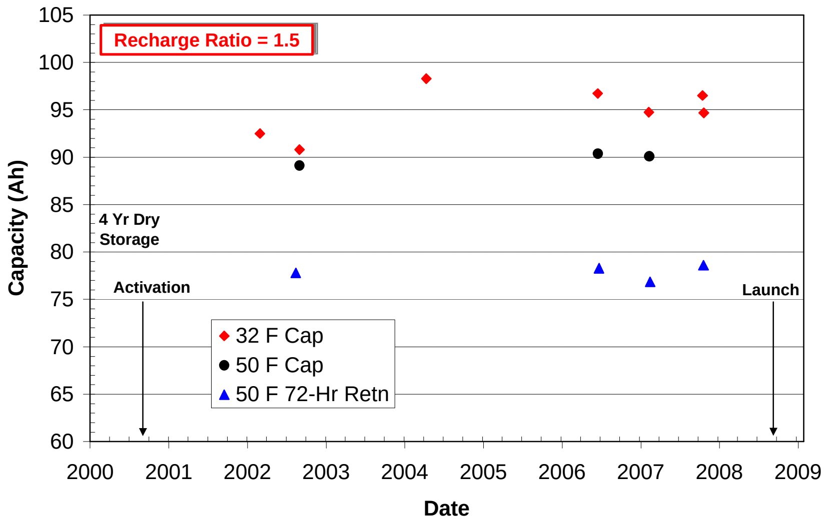
COMSAT Labs has measured the volume of gas in DPA cells by quickly placing a plastic tubing over the fill tube which was breached with a Dremel saw. The gas is measured using a Wet Test Meter, which is a water displacement device.

Two cells as part of the 2007 DPA were submitted to Aerospace Corporation for a more precise gas analysis. This analysis involves placing the cell into a vacuum tight container, evacuating it, puncturing the cell with a sharp auger, and then measuring the quantity of gas released and its components.

An internal cell pressure of 0.78 psia was observed with the HST 11-718 cell, while the RNH 90-9 3-165 cell was 1.78 psia. These results indicate that both cells still have nickel precharge. The cell gas analyzed by RGA with the results tabulated above.

HUBBLE SPACE TELESCOPE PROJECT

SM4 Flight Spare Battery

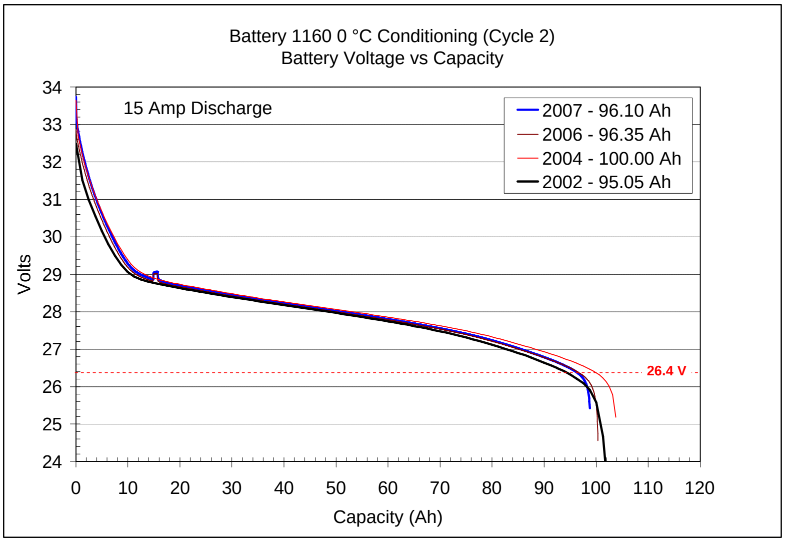


The SM4 Flight Spare Battery (S/N 1160) and the two Flight Modules (S/N 1161 – 1166) were received at GSFC in Jan-04 for cold storage. The SM4 FSB has been subjected to capacity testing in 2006 and 2007 to evaluate the condition of the battery. This chart details the capacity testing both at Eagle Picher and at GSFC. There is no apparent degradation due to cold storage with the observed results typical of test variances.

Goddard Space Flight Center

HUBBLE SPACE TELESCOPE PROJECT

SM4 Flight Spare Battery



LOCKHEED MARTIN

This chart shows the battery capacity curves at 0 °C over the testing period. Note that there is no sign of a second plateau in these curves, which was confirmed by individual cell voltage data.

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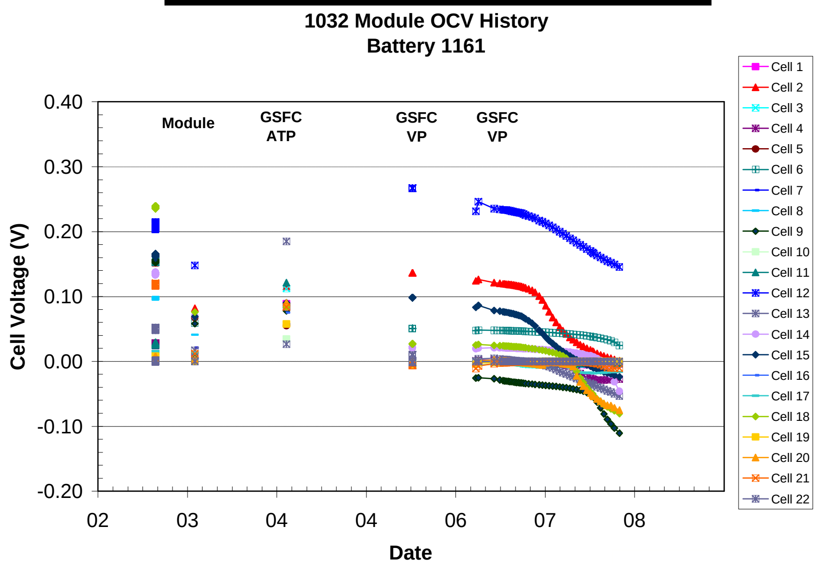
SM4 Flight Modules



Since early 2006 the individual cells potential of the two Flight Modules and the Flight Spare Battery have been monitored with these assets at OCV in cold storage. Surprisingly there are some cells with declining cell potentials which can not be explained. The example here is of one of 6 batteries in the Flight Modules which demonstrated this trend. The Flight Spare Battery has not demonstrated this signature. The data points prior to 2006 are taken at periodic voltage checks or during the thermal equilibration period prior to a ATP test sequence.

Summary

- On Orbit Batteries Require Replacement by 2009
- SM4 Replacement Batteries
  - 1996 Manufacture & Dry Store 4 Years
  - Activated in 2000
  - Capacity Tests are Positive on Flight Spare Battery
    - Capacity Increase, As Expected
    - Minimal Second Plateau (~5 %)
  - Flight Modules – Test Scheduled ~Feb. 2008
- Backup SM4 Replacement Battery Set
  - Very Tight Manufacture Schedule
  - Work Stopped - On Hold

Analysis of On-Orbit battery performance indicates SM4 replacement of batteries should be performed in 2008 in order to maintain science operations with adequate safety margins. The SM4 cells were manufactured in 1996, dry stored until 2000, and then activated. These batteries will have total age of 12 years when and if they are placed onto HST. A replacement set of SM4 batteries have entered the manufacturing process at Eagle Picher. A normal 24 month production cycle must be squeezed to 15 months in order to meet the scheduled launch date, not earlier than Aug. 2008. This production was placed on hold due to NASA budgetary pressures.

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