Space Technology-5 Lithium-Ion Battery Design, Qualification and Integration and Testing

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Mission Overview

- ST-5 is a New Technology Mission to further investigation of Space Weather and validation of new technologies

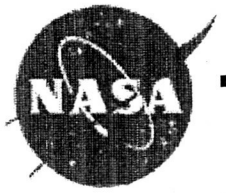
  - Lithium-Ion battery, cold gas micro-thruster, variable emittance coatings, ultra low power logic, miniature transponder, autonomous ground system software
- Scheduled to launch in February 2006 from Vandenberg AFB
- Polar elliptical, Sun synchronous orbit
- Octagonal spinning satellite
- 3 satellite constellation
- Use of triple junction GaAs solar cells at 28% efficiency
- 8.4 V (low voltage compared to nominal 28 V) power bus

Battery Specific Requirements

- Battery Voltage Limits:
  - Maximum End-of-Charge Voltage 8.4 V
  - Minimum End-of-Discharge Voltage 6.0 V
- Battery Capacity (C): 7.5 Ah
- Battery Energy: 54 Wh
- Minimum Voltage after Peak Load: 6.0 V
- Battery Self Discharge: <=8% per month
- Charge retention after 72 hrs of open circuit > 98% x C
- Charge Management:
  - Constant current charge (C/5) to voltage clamp at the battery level
- Charge Capability: Max charge 1C
- Impedance: 90 mΩ

Mission Specific Requirements

- Orbit:
  - Polar elliptical orbit, sun synchronous
  - 2.27 hrs Orbit (seasonal eclipses up to 22 minutes)
- Mission Phases:
  - Storage: 3 Years
  - Ground Test: 100 cycles
  - Mission Life: 3 months requirement with a goal of 6 months
- Thermal: -10 to 40°C
- Charge / Discharge
  - Ground: 3 years, 100 cycles @ 100% DoD
  - Flight: (Approximately six months) 400 cycles @ 60% DoD
- Max. Discharge load: 12 W
- Discharge Capability: 12 W for 22 mins and 14 W for 15 mins during eclipse season

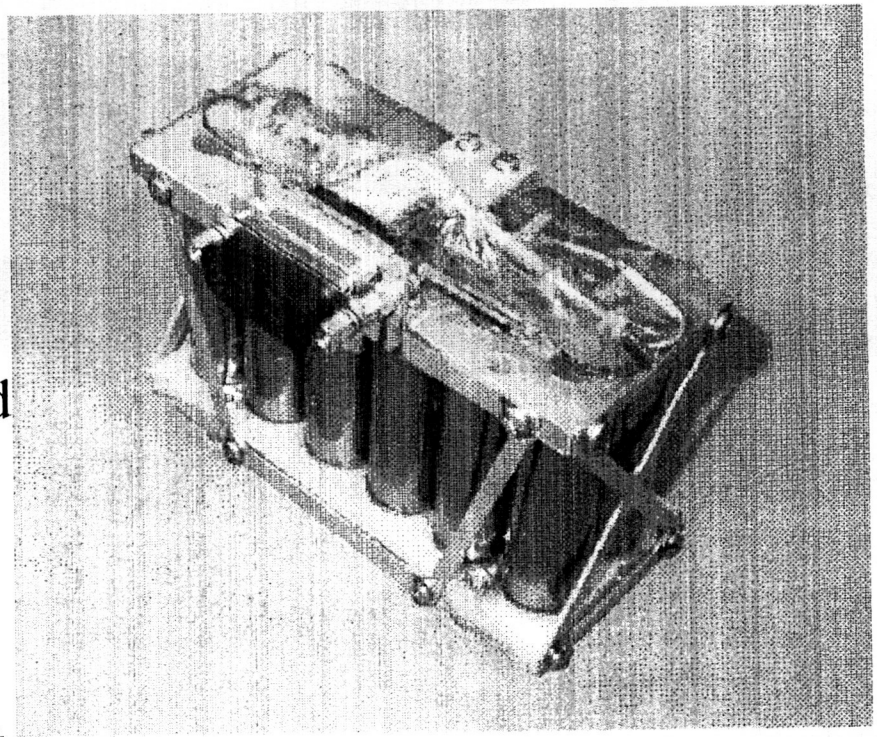


Battery Description

- AEA Technology plc. assembled battery using twelve individual SONY 18650 1.5 Ah cells
- Arranged in a S-P system topology
- 6 parallel strings, each containing 2 cells in series
- 2 cells in series string provide battery voltage (6 to 8.4 V)
- 6 parallel strings provide 7.5 Ah capacity when discharged at 3.75 A to 6 V at 20°C
- Four thermistors for temperature telemetry
  - 3 on different cell locations, 1 on baseplate
- One multi-pin connector
  - To combine power and signal, and to save mass

Battery Mechanical Design

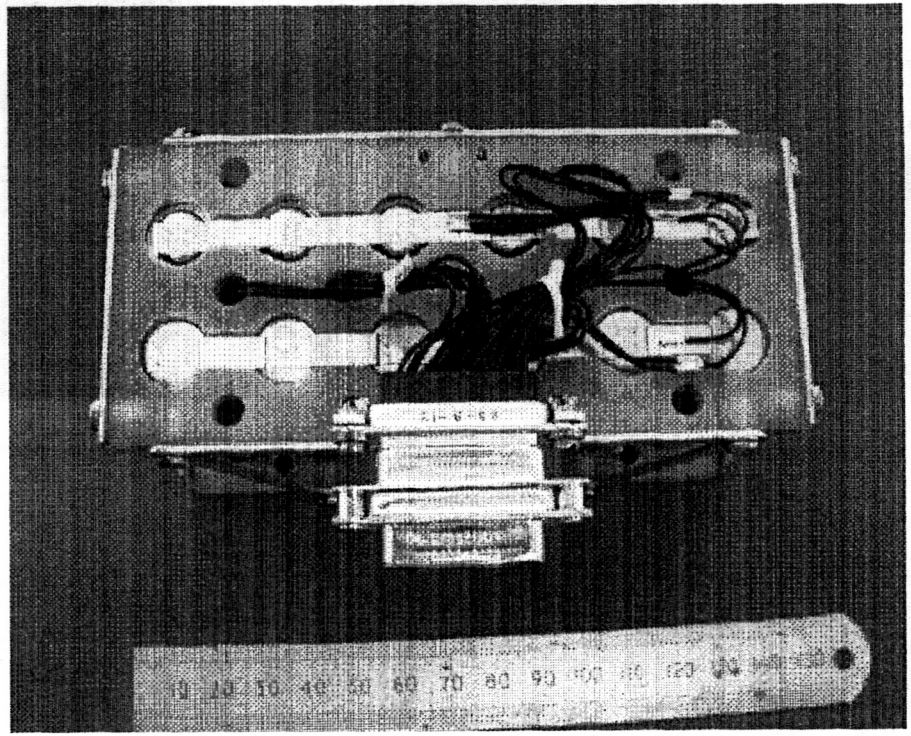
- Tray assembly using two sheets of Glass Fiber Reinforced Plastic (GFRP)
- Isotropic high strength, electrical isolator & low density material
- Cells are bonded into counter bored holes using REDUX adhesive
- Provides a structure that is highly rigid, high bending resistance
- Shear rigidity provided by cross bracing using thin aluminium sheet
- Mechanical interface through lower GFRP tray and 4 titanium feet



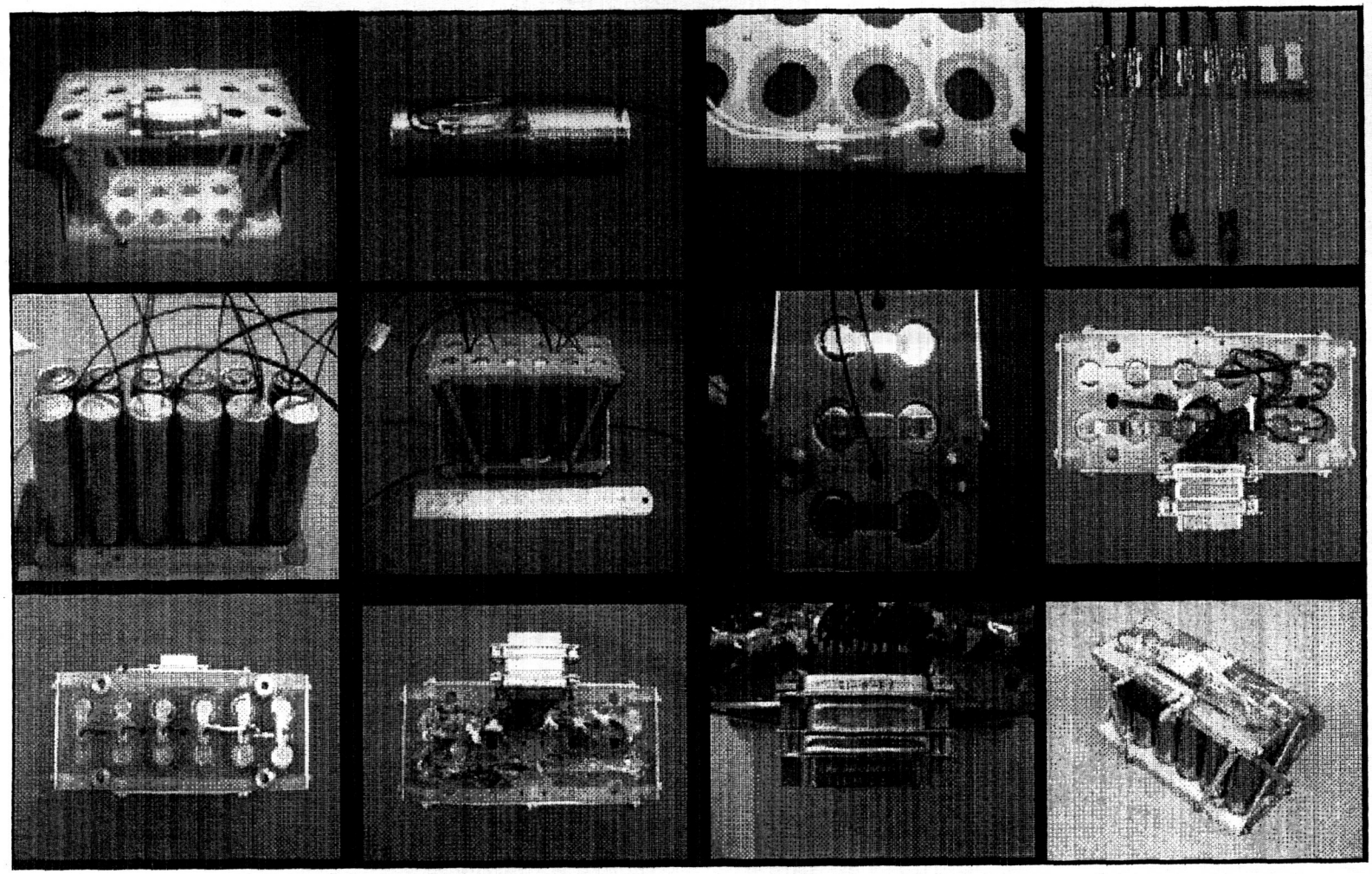
Dimensions: 12.4 cm x 6.3 cm x 8.6 cm
Mass: 0.643 Kg

Battery Mechanical Design, continued

- Cells reversed in orientation to make string using nickel shim tab
- Interconnects between cells pre-formed (provides stress relief)
- Four separate spot welds using robotic spot welder.
- Wiring brought through holes in upper tray and assembled into loom
- Electrical connector attached to upper tray using heli-coiled threaded holes



Battery Assembly Photos



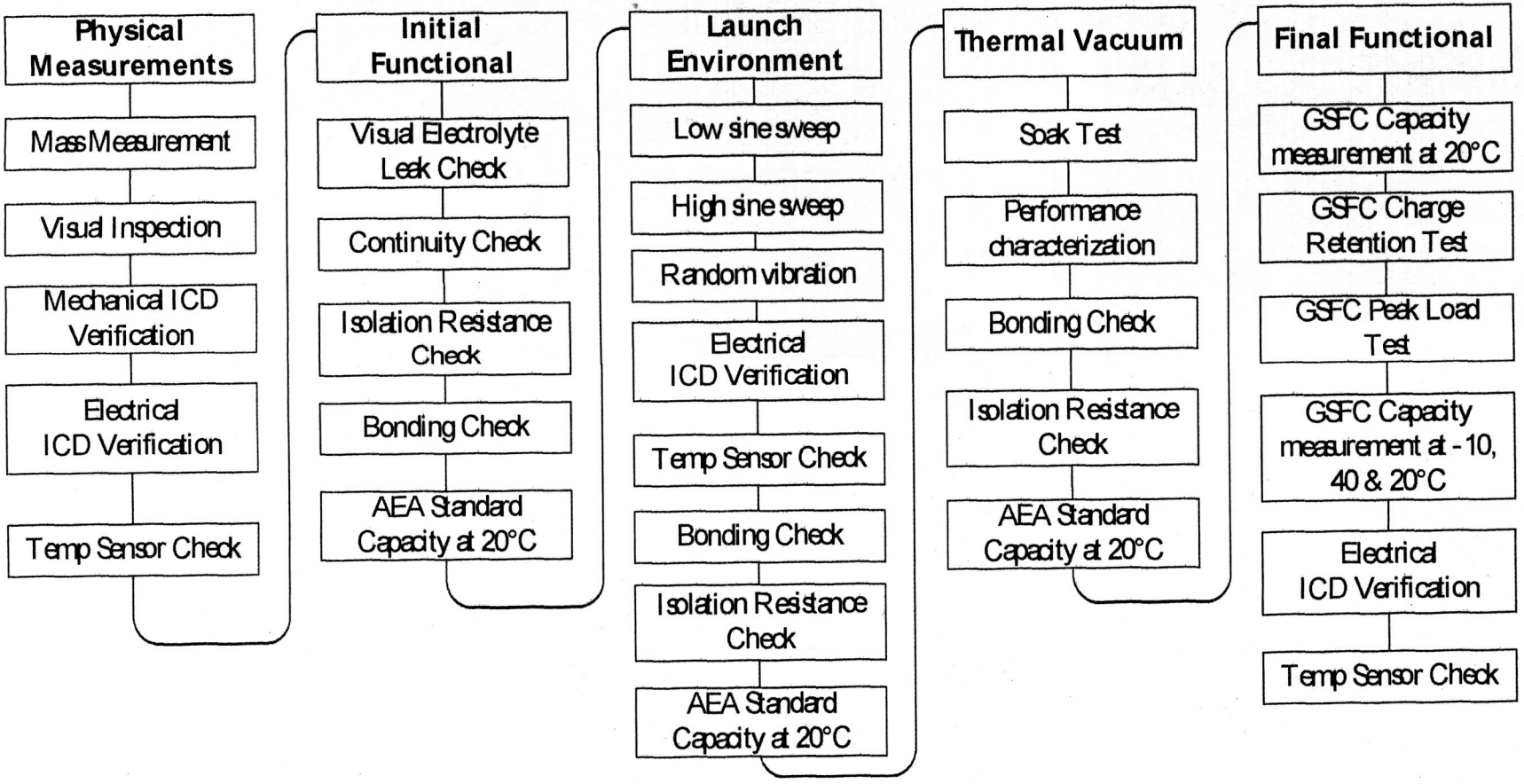
Battery Materials

- Cells: Nickel Plated Steel
- Top / bottom plates: Glass Fiber Reinforced Plastic (GFRP)
- Side / end plates: Aluminum Alloy
- Mounting bush: Titanium
- Tags & Bonding Strips: Nickel
- 26 pin Connector: ITT Cannon (GFE)
- Thermistors: Yellow Stone International (GFE)
- Fasteners: M3 - M2.5 Stainless Steel
- Adhesive: Redux

Battery Materials, continued

- All battery parts, materials and processes have been validated/qualified by AEA Technology on space missions such as PROBA, STRV, MARS Express, Beagle.
- Most of the materials meet the outgassing requirement Total Mass Loss < 1.0% , Collectable Volatile Condensed Materials < 0.1%, generally specified for space battery hardware.
- Nonmagnetic materials will be used for all components with the exception of the SONY cell cases which are nickel plated steel.
- All EEE parts supplied to AEA from GSFC.

Testing - Qualification/Acceptance



Identical flow of tests for both Qualification & Acceptance program, testing at appropriate levels.

Testing - Qualification/Acceptance Data

Physical & Functional Test			
Mass		*0.643 Kg*	
Dimension: L x W x H (cm)		*12.35 x 6.26 x 8.55*	
Battery Voltage (0%SoC)		*5.92V*	
Electrolyte Leak Check		*No leak*	
Isolation		*> 100 MΩ*	
Bonding		*< 9.5 mΩ max.*	
Thermistor Resistance			
TH01	**TH02**	**TH03**	**TH04**
2.50 KΩ	*2.50 KΩ*	*2.49 KΩ*	*2.50 KΩ*

Capacity Measurement		
AEA SCM (C/10 Discharge)		
SCM #1 (Pre-Vibration)	**SCM #2 (Post-Vibration)**	**SCM #3 (Post-Charge Retention)**
8.56 Ah	*8.48 Ah*	*8.32 Ah*

GSFC SCM (C/2 Discharge)			
1st 20°C	**-10°C**	**40°C**	**2nd 20°C**
7.67 Ah	*6.68 Ah*	*7.81 Ah*	*7.60 Ah*

Vibration Test			
Axis	**Resonance**	**Peak G_{rms}**	**Q Factor**
X	*974 Hz*	*33.8 g*	*10.9*
Y	*1034 Hz*	*27.6 g*	*6.4*
Z	*> 2000 Hz*	*14.2 g*	*1.2*

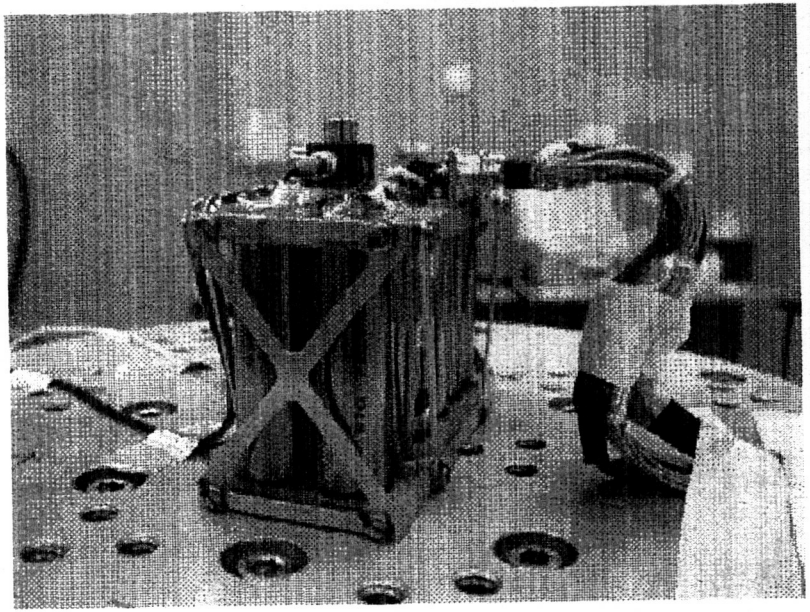
Testing - Battery Qualification/Acceptance Data – contd.

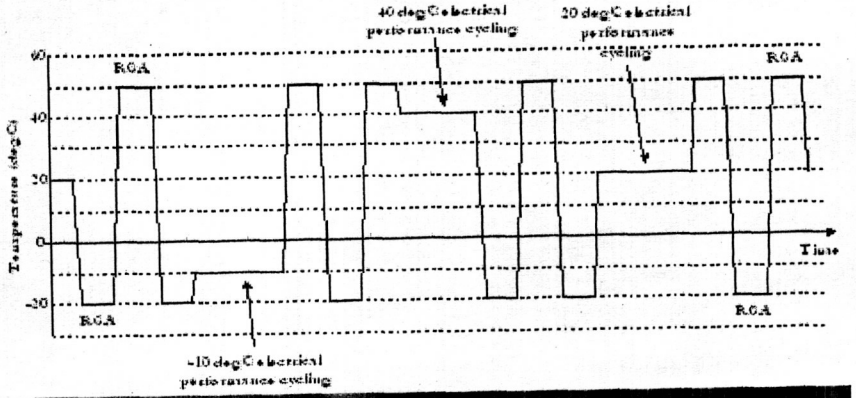
Peak Load Test	
EoD V	*> 7V*

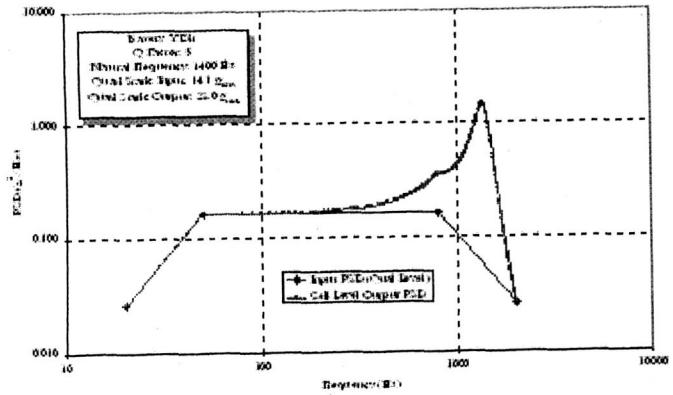
Thermal Vacuum Test			
Thermal Cycle Test			
No. of Thermal Cycles	*3*		
Max. Temperature	*40°C*		
Min. Temperature	*-10°C*		
Performance Cycle Test			
No. of Performance Cycles	3		
Temperature	**EoDV (12W for 60 min)**		
	Cycle 1	**Cycle 2**	**Cycle 3**
40°C	*8.07 V*	*8.08 V*	*8.08 V*
-10°C	*7.86 V*	*7.85 V*	*7.84 V*
Residual Gas Analyzer (RGA) Monitor (leak check)			
Mass Number Range	*1 to 100*		
Electrolyte Trace	*No*		

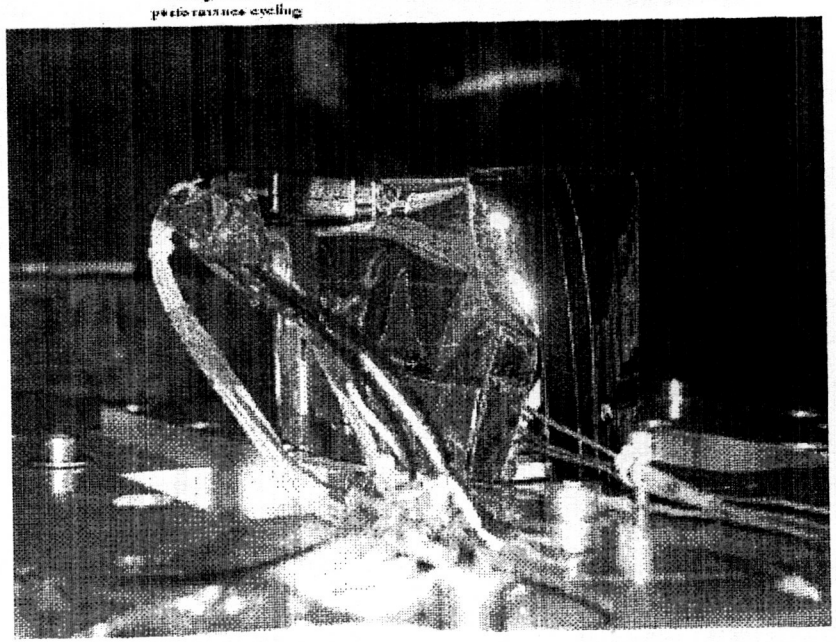
Final Functional Test			
Charge Retention	*98.14%*		
Electrolyte Leak Check	*No leak*		
Isolation	*> 100 MΩ*		
Bonding	*22.3 mΩ*		
Battery Voltage (0%SoC)	*5.71 V*		
Thermistor Resistance			
TH01	**TH02**	**TH03**	**TH04**
2.34 kΩ	*2.33 kΩ*	*2.31 kΩ*	*2.32 kΩ*

Testing - Qualification (Environmental)



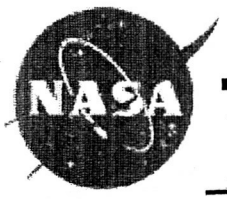






Integration and Testing

- Comprehensive Performance Check
- Temperature Performance



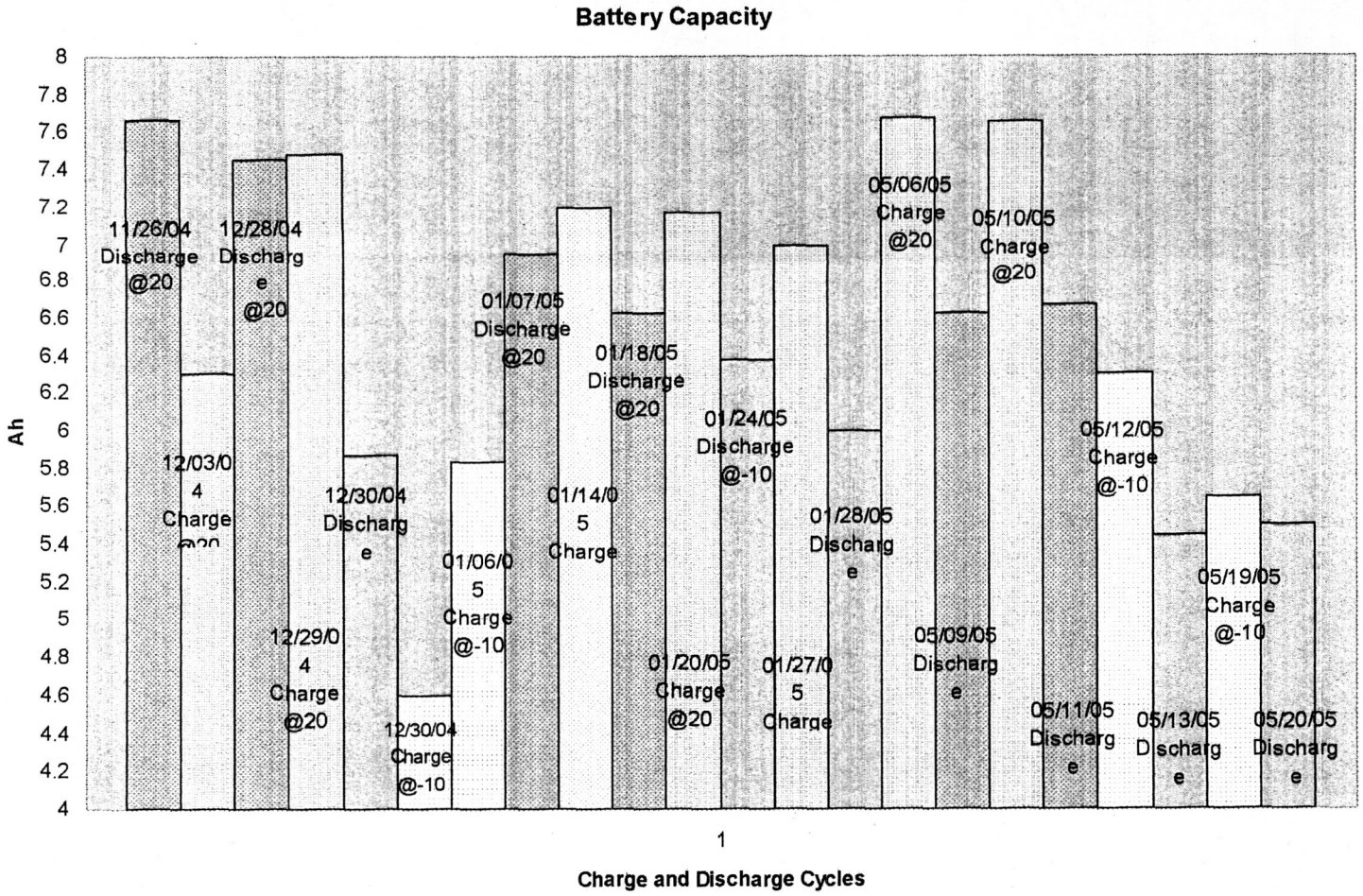
Integration and Testing- Comprehensive Performance Check

- Wiring verification and voltage measurements
- Capacity check
- Mission orbit cycles with typical loads (Room Temp).
- Magnetics Testing
- I&T batteries used on spacecraft through environmental testing
- Flight batteries integrated just prior to launch

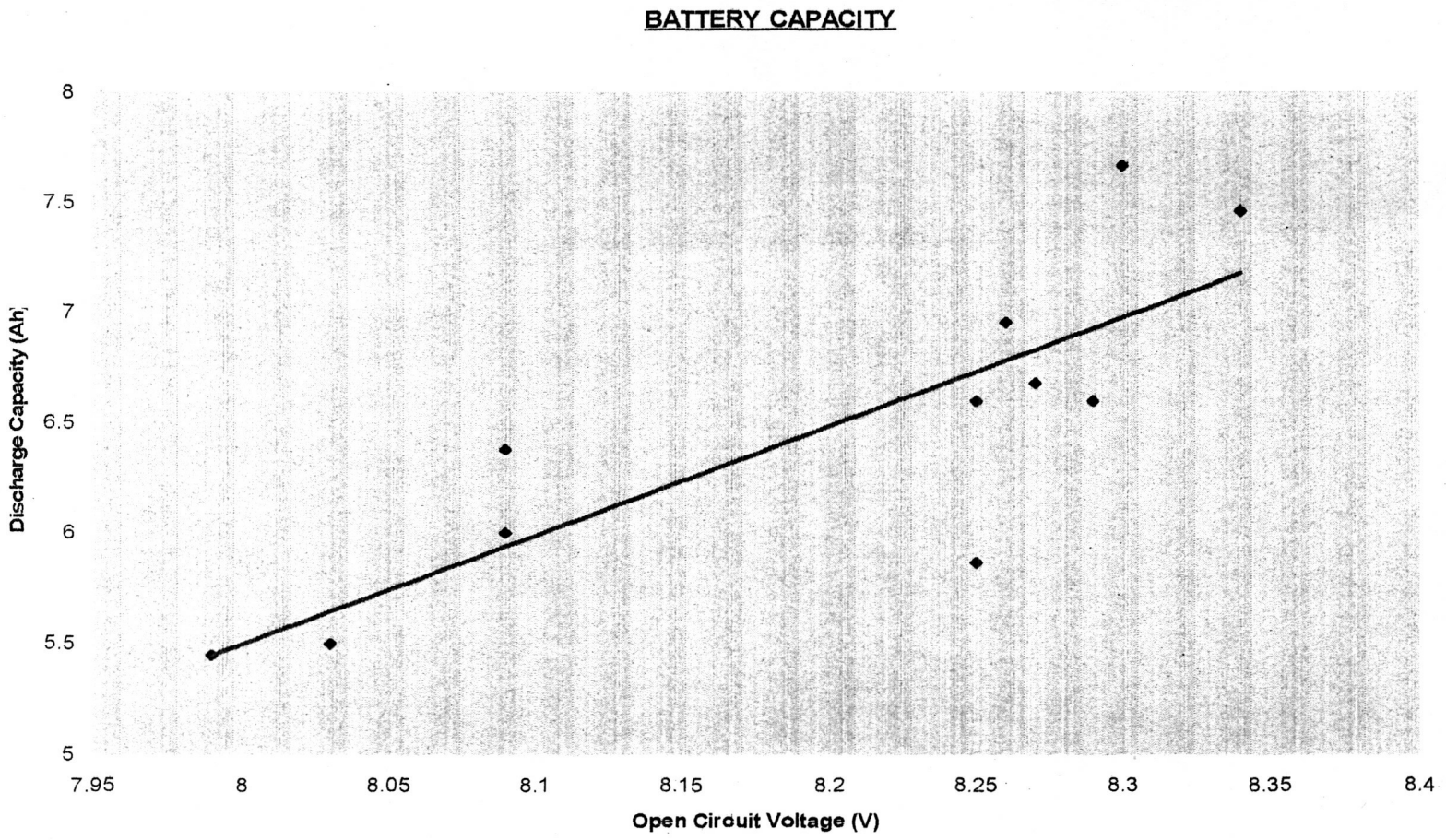
Integration and Testing- Temperature Performance

- To meet the peak load demand
  - Small solar ray area restricted by spacecraft size constraint
- Temperature excursion between -10 to 20°C
  - Determine the available capacity at the lower temperature and between the temperature excursion
- Capacity
  - 1.5 A charge rate, with 8.4 V clamp and less than 100 mA taper current
  - 1.5 A discharge rate, down to 6 V
- Develop an in-orbit Charge Management and Mission Planning

Integration and Testing- Temperature Performance - data



Integration and Testing- Temperature Performance - data



Conclusions

- AEA Technology plc. Built, Qualification/Acceptance Tested and Delivered six (6) ST-5 batteries to GSFC
- Integration and Testing progressing toward the scheduled February 2006 launch
- As expected nominal performance at 20°C and above, and lower capacity below 20°C

  - Available capacity strongly influenced by the predischarge temperature exposure history
- Development of an in-orbit Charge Management and Mission Planning using the Integration and Test data is in progress