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

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• Background
• Battery Description
• Testing
  – Qualification (Environmental)/Acceptance
• Integration and Testing
• Conclusions
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 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

Physical Measurements
- Mass Measurement
- Visual Inspection
- Mechanical ICD Verification
- Electrical ICD Verification
- Temp Sensor Check

Initial Functional
- Visual Electrolyte Leak Check
- Continuity Check
- Isolation Resistance Check
- Bonding Check
- AEA Standard Capacity at 20°C

Launch Environment
- Low sine sweep
- High sine sweep
- Random vibration
- Electrical ICD Verification
- Temp Sensor Check
- Bonding Check
- Isolation Resistance Check
- AEA Standard Capacity at 20°C

Thermal Vacuum
- Soak Test
- Performance characterization
- Bonding Check
- Isolation Resistance Check
- AEA Standard Capacity at 20°C

Final Functional
- GSFC Capacity measurement at 20°C
- GSFC Charge Retention Test
- GSFC Peak Load Test
- GSFC Capacity measurement at -10, 40 & 20°C
- Electrical ICD Verification
- Temp Sensor Check

Identical flow of tests for both Qualification & Acceptance program, testing at appropriate levels.
### Testing - Qualification/Acceptance Data

<table>
<thead>
<tr>
<th>Physical &amp; Functional Test</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mass</td>
</tr>
<tr>
<td>Dimension: L x W x H (cm)</td>
</tr>
<tr>
<td>Battery Voltage (0%SoC)</td>
</tr>
<tr>
<td>Electrolyte Leak Check</td>
</tr>
<tr>
<td>Isolation</td>
</tr>
<tr>
<td>Bonding</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Thermistor Resistance</th>
</tr>
</thead>
<tbody>
<tr>
<td>TH01</td>
</tr>
<tr>
<td>2.50 KΩ</td>
</tr>
<tr>
<td></td>
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<tr>
<td></td>
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</table>

### Capacity Measurement

<table>
<thead>
<tr>
<th>AEA SCM (C/10 Discharge)</th>
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</thead>
<tbody>
<tr>
<td>SCM #1 (Pre-Vibration)</td>
</tr>
<tr>
<td>8.56 Ah</td>
</tr>
<tr>
<td></td>
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</tbody>
</table>

<table>
<thead>
<tr>
<th>GSFC SCM (C/2 Discharge)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1st 20°C</td>
</tr>
<tr>
<td>7.67 Ah</td>
</tr>
<tr>
<td></td>
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</tbody>
</table>

### Vibration Test

<table>
<thead>
<tr>
<th>Axis</th>
<th>Resonance</th>
<th>Peak G&lt;sub&gt;rms&lt;/sub&gt;</th>
<th>Q Factor</th>
</tr>
</thead>
<tbody>
<tr>
<td>X</td>
<td>974 Hz</td>
<td>33.8 g</td>
<td>10.9</td>
</tr>
<tr>
<td>Y</td>
<td>1034 Hz</td>
<td>27.6 g</td>
<td>6.4</td>
</tr>
<tr>
<td>Z</td>
<td>&gt; 2000 Hz</td>
<td>14.2 g</td>
<td>1.2</td>
</tr>
</tbody>
</table>
### Peak Load Test

| EoD V       | > 7V |

### Thermal Vacuum Test

<table>
<thead>
<tr>
<th>Thermal Cycle Test</th>
<th>3</th>
</tr>
</thead>
<tbody>
<tr>
<td>No. of Thermal Cycles</td>
<td>3</td>
</tr>
<tr>
<td>Max. Temperature</td>
<td>40°C</td>
</tr>
<tr>
<td>Min. Temperature</td>
<td>-10°C</td>
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</table>

<table>
<thead>
<tr>
<th>Performance Cycle Test</th>
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</thead>
<tbody>
<tr>
<td>No. of Performance Cycles</td>
<td>3</td>
</tr>
<tr>
<td>Temperature</td>
<td>Cycle 1</td>
</tr>
<tr>
<td>40°C</td>
<td>8.07 V</td>
</tr>
<tr>
<td>-10°C</td>
<td>7.86 V</td>
</tr>
</tbody>
</table>

Residual Gas Analyzer (RGA) Monitor (leak check)
- Mass Number Range: 1 to 100
- Electrolyte Trace: No

### Final Functional Test

| Charge Retention | 98.14% |
| Electolyte Leak Check | No leak |
| Isolation         | > 100 MΩ |
| Bonding           | 22.3 mΩ |
| Battery Voltage (0%SoC) | 5.71 V |

<table>
<thead>
<tr>
<th>Thermistor Resistance</th>
<th>TH01</th>
<th>TH02</th>
<th>TH03</th>
<th>TH04</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>2.34 kΩ</td>
<td>2.33 kΩ</td>
<td>2.31 kΩ</td>
<td>2.32 kΩ</td>
</tr>
</tbody>
</table>
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

BATTERY CAPACITY

Discharge Capacity (Ah)

Open Circuit Voltage (V)

7.95 8 8.05 8.1 8.15 8.2 8.25 8.3 8.35 8.4
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