Performance and Safety of Lithium Ion Cells

Supported by Mars Program Office and NASA Code S Battery Programs

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Thermal characterization

Electrical characterization by a.c. impedance

VT charge characterization tests

Storage characterization tests (cruise conditions)

Accelerated IEO Tests

Capacity retention tests

Charge rate characterization (at 40°, 25°, 0°, and -20°C)

Discharge rate characterization (at 40°, 25°, 0°, and -20°C)

Cycle life at alternating temperatures (40 and -20°C)

Cycle life performance at low temperature (-20°C)

Cycle life performance at room temperature (25°C)

Evaluation of Lithium-Ion Cells at JPL
## Objectives

### NASA-DOD Interagency Li-Ion Program

<table>
<thead>
<tr>
<th>Technology Drivers</th>
<th>Objectives</th>
</tr>
</thead>
<tbody>
<tr>
<td>High Voltage Batteries (100V)</td>
<td>LEO Missions by 2003 -</td>
</tr>
<tr>
<td>Large Capacity cells (200 Ah)</td>
<td>Aircraft -</td>
</tr>
<tr>
<td>Low Temperature Operation</td>
<td>Military Terrestrial -</td>
</tr>
<tr>
<td></td>
<td>Avionics/NAV, 2003</td>
</tr>
<tr>
<td>High Voltage Batteries (270 V)</td>
<td>LEO Missions by 2003 -</td>
</tr>
<tr>
<td>Low Temperature Operation</td>
<td>Rovers/BV, 2003 -</td>
</tr>
<tr>
<td>Medium Capacity Cells (50 Ah)</td>
<td>Lander, 2004 -</td>
</tr>
<tr>
<td>Long Cycle Life (30,000)</td>
<td>Redundancy -</td>
</tr>
<tr>
<td>Plantarys/C</td>
<td>Demonstrate Technology -</td>
</tr>
<tr>
<td></td>
<td>Sources -</td>
</tr>
<tr>
<td>Ah</td>
<td>Establish U.S. Production -</td>
</tr>
<tr>
<td>Large Capacity cells (50-200)</td>
<td>Batteries -</td>
</tr>
<tr>
<td>10-20 Year Operating Life</td>
<td>Develop High Specific Energy -</td>
</tr>
</tbody>
</table>
Cycle Life of Li Ion Cells - Energy Efficiency

Watt-Hour Efficiency (%)

Cycle Number

Temp = 20°C

Temp = 23°C
Accelerated LEO Cycle Life of Li Ion Cells to Partial DOD
Tolerance to Higher Charge Voltage
Temperature = 23°C
5.0 Amp Discharge Current top 3.0 V
Total Charge time = 24 Hours
Constant Voltage Charging at 4.1 V to 0.001 A cut-off
5.0 Amp Charge Current (C/5) to 4.1 V

Tolerance to Extended Tapered Charge
Charge on Cycling

Charge Capacity (Ahr)

Charge Time (Hours)

23°C

4.1 A (Taper to C/50)
5.0 A Charge Current (C/5)

Cycle # 400
Cycle # 300
Cycle # 200
Cycle # 100
Cycle # 10
Specific Energy (Watt-Hr/Kg)

Temperature = 23°C

- 3.5 Amp Discharge Current (C/2)
- 2.2 Amp Discharge Current (C/3)
- 1.4 Amp Discharge Current (C/5)
- 0.70 Amp Discharge Current (C/10)
- 0.140 Taper current cut-off (C/50)
- 0.700 A Charge current to 4.1 V

Cell Voltage (V)
Specific Energy (Watt-Hr/Kg)

Cell Voltage (V)

Low Temperature Discharge

Temperature = -20 °C

- 3.5 Amp Discharge Current (C/2)
- 2.2 Amp Discharge Current (C/3.3)
- 1.40 Amp Discharge Current (C/5)
- 0.70 Amp Discharge Current (C/10)

0.140 Taper Current to 0.1 V
0.700 A Charge Current to 4.1 V
Charge Capacity (Ah)

Temperature = 20°C

Constant potential charge to C/50
Cell charged to 4.1 V

Low Temperature Charge

Time (Hours)

Charge Capacity (Ah)
Storage Characteristics

Discharge Capacity (Ah)

Cell Voltage (V)

- Capacity After Prolonged Storage (Dec 1999)
- Initial Capacity (Aug 1997)

4.0 Amp Discharge Current (C/5 Rate)
22.120 Ah
24.061 Ah

(0.299% Per Month)
8.9% Capacity Loss
28 Month Testing Period

(91.9% Reversible Capacity)
Storage Characteristics
Need to define specific conditions under which lithium plating can occur (rate

- Are higher charge voltages justified at lower temperature?

\[ \text{Charge Capacity (Ahr)} \]

![Graph of V/T Curves of Li Ion Cells]
DC Polarizations in Li Ion Cell

EIS of a Li Ion Cell

Impedance in a Li Ion Cell
Discharge Capacity (Ah)

Cycle Number

1.0 Amp Charge current (C/5) to 3.0 V
Taper Cut-Off at 0.100 A (C/50)
1.0 Amp Discharge current (C/5) to 4.1 V

Temp = 23°C

Cycling (100% DOD) at 25°C
EIS During Cycling

Cell Fully Charged Prior To Measurements

OCV = ~4.07V

23°C
Variable Temperature Cycling
EIS During Variable Temperature Cycling
Heat Generation Rates on Discharge
- No damage to equipment
- Venting of a pouch (polymer) cell
- No damage to equipment
- No injuries to personnel

(10 Ah)

- Li-ion Cell Venting on Extended LT Cycling (5-

- Li-ion Cell Venting upon Undervent LT External
- Li-ion Cell Venting upon Inadvertent External

Safety Events at JPL
• AC Impedance

• Mars Mission Profile

• Extended storage at 0°C

• 10 month on OCV stand.

• 2 month storage in Open Circuit

• History of the Cell

• Short Circuit Incident
<table>
<thead>
<tr>
<th></th>
<th>Ten Month Storage</th>
<th>Two Month Storage</th>
<th>Initial Storage</th>
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<tbody>
<tr>
<td></td>
<td></td>
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<tr>
<td><strong>SOC (60% and 80%)</strong></td>
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<td><strong>SOC (70% and 90%)</strong></td>
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<td><strong>SOC (80% and 90%)</strong></td>
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<td><strong>SOC (90% and 100%)</strong></td>
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<td><strong>SOC (100% and 110%)</strong></td>
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<td><strong>SOC (110% and 120%)</strong></td>
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<td><strong>SOC (120% and 130%)</strong></td>
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such safety events.

Further improvements in cell design will minimize

hundreds of lithium ion cells of 1-35 Ah sizes.

period of three years of testing more than five

Three minor safety incidents occurred over a

Good storage characteristics.

Excellent low temperature performance (under 20 °C Operation)

Long cycle life (over 10,000 cycles)

High specific energy (>120 W/Wh and >80 Wh/kg)

Lithium ion cells developed under the

Summary