Li-Ion Battery Technology Assessment for Future NASA Planetary Missions

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Outline

- Potential NASA Applications
- Planetary Mission Battery Requirements
- Interagency Li-Ion Battery Program
- Technology Assessment
- Summary and Conclusions
Potential NASA Applications

Planetary Landers

GEO Spacecraft

Astronaut Equipment

Europa Orbiter

LEO Spacecraft
Mars 2003 Lander

Battery Requirements

- Voltage: 24-32
- Capacity: 68 Ah
- Operating Temp.: -20-40 C
- Cycle Life: 300
- Calendar Life: Three years
- Sp. Energy: > 100 Wh/kg
- Energy Density: >240 Wh/l

Mission Objectives

- Platform for instruments and technology experiments designed to provide key insights to decisions regarding human missions to Mars.
- In-situ demonstration test of rocket propellant production.
- Martian soil properties and surface radiation environment

Technology Challenges

- Battery Operation after Two years Active storage.
- Low Temperature Performance
Mars Scout Missions

Battery Requirements

- Voltage: 24-32
- Capacity: 6-8 Ah
- Cycle Life: 20-30 K, at 20-30% DoD
- Calendar Life: Five years
- Sp. Energy: > 100 Wh/kg
- Energy Density: >240 Wh

Launch Date: Jan 2003
Flight Time: Nine Months

Mission Objectives

- Lander robustness

Technology Challenges

- Battery Operation after Two years
- Active storage
- Low Temperature Performance
Mars 2005 Lander/Rover

Battery Requirements

- Voltage: 24-32
- Capacity: 140 Ah
- Operating Temp.: -20-40 C
- Cycle Life: > 300
- Calendar Life: Three years
- Sp. Energy: > 100 Wh/kg
- Energy Density: >240 Wh/l

Launch Date: April 2005
Flight Time: Nine Months

Mission Objectives

- Platform for instruments and technology experiments designed to provide key insights to decisions regarding human missions to Mars.
- In-situ demonstration test of rocket propellant production.
- Martian soil properties and surface radiation environment

Technology Challenges

- Battery Operation after Two years Active storage
- Low Temperature Performance
Mars Microsats

Battery Requirements

- Voltage: 24-32
- Capacity: 6-8 Ah
- Cycle Life: 20-30 K, at 20-30% DoD
- Calendar Life: Five years
- Sp. Energy: > 100 Wh/kg
- Energy Density: >240 Wh/l

Mission Objectives

- Developing a communications capability to provide a substantial increase in data rates and connectivity from Mars to Earth;
- Developing an in situ navigation capability to enable more precise targeting and location information on approach and at Mars.

Technology Challenges

- Long Cycle Life
- Low Temperature Performance
Mars Sats

Launch Date: Jan 2003
Flight Time: Nine Months

Mission Objectives
- Developing a communications capability to provide a substantial increase in data rates and connectivity from Mars to Earth.
- Developing an in situ navigation capability to enable more precise targeting and location information on approach and at Mars.

Battery Requirements
- Voltage: 24-32
- Capacity: 20 -35 Ah
- Cycle Life: 20-30 K, at 20-30% DoD
- Calendar Life: 7-9 years
- Sp. Energy: > 100 Wh/kg
- Energy Density: >240 Wh/l

Technology Challenges
- Long Cycle Life
- Low Temperature Performance
Europa Orbiter

Launch Date: January 2006
Flight Time: 6-8 Years

Mission Objectives

- Determine the presence or absence of a subsurface ocean
- Characterize the three-dimensional distribution of any subsurface liquid water and its overlying ice layers
- Understand the formation of surface features, including sites of recent or current activity, and identify candidate landing sites for future lander missions.

Battery Requirements

- Voltage: 24-32
- Capacity: 6-8 Ah
- Cycle Life: < 400
- Calendar Life: 6-8 Years
- Sp. Energy: > 100 Wh/kg
- Energy Density: > 240 Wh/l

Technology Challenges

- Long Calendar Life
- Radiation Tolerance
Solar Probe

Launch Date: 2007
Flight Time: 3.8 - 1st Perihelion; 4.5 - 2nd Perihelion

Mission Objectives

- Determine the acceleration processes and find the source regions of the fast and slow solar wind at maximum and minimum solar activity.
- Locate the source and trace the flow of energy that heats the corona;
- Construct the 3-d density configuration from pole to pole, and determine the subsurface flow pattern, the structure of the polar magnetic field and its relationship with the overlying corona.

Battery Requirements

- Voltage: 24-32
- Capacity: 6-8 Ah
- Cycle Life: < 400
- Calendar Life: 5-7 Years
- Sp. Energy: > 100 Wh/kg
- Energy Density: > 240 Wh/l

Technology Challenges

- Long Calendar Life
Interagency Li-Ion Battery Program

Objectives

- Develop aerospace quality, high energy density and long life lithium-ion cells and batteries

- Establish U.S. production sources

- Demonstrate technology readiness
  - Rovers and Landers by 2000
  - Aviation / UAV’s by 2001
  - DOD terrestrial applications by 2001
  - GEO missions by 2002
  - LEO missions by 2004
Interagency Li-Ion Battery Program
Performance Targets

<table>
<thead>
<tr>
<th></th>
<th>LANDERS</th>
<th>ROVERS</th>
<th>GEO ORBITER</th>
<th>LEO/PLA ORBITER</th>
<th>AIRCRAFT</th>
<th>UAV</th>
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<td>10, 20, 35</td>
<td>10, 20, 35</td>
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<td>C/5-C/2</td>
<td>C/2</td>
<td>C/2-C</td>
<td>C</td>
<td>C/5-C</td>
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<td>&gt;500&gt;60%</td>
<td>&gt;2000&gt;75%</td>
<td>&gt;30,000&gt;30%</td>
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Based on 100%DOD at BOL
Li-Ion Battery Technology Assessment
Li-Ion Battery Technology Assessment

Objectives

• Assess viability of using lithium-ion technology for future NASA applications.

• Demonstrate technology readiness for near term planetary missions.
  • Mars Landers
  • Mars Rovers
  • Mars Micro Sats
  • Outer Planetary Missions
Li-Ion Battery Technology Assessment
Test Plan Outline

• Electrical Performance Characterization
  - Range of charge and discharge rates (C/2, C/3.3, C/5 and C/10)
  - Range of temperatures (-30, -20, 0, 23, 40°C)
  - Pulse capability (40 and 60A)
  - Impedance measurements

• Cycle Life Performance
  - Room temperature cycle life (23° +/- 2°C)
  - Low temperature cycle life (-20°C)
  - High temperature cycling (40°C)
  - Variable temperature cycling

• Storage Characteristics
  - 2 Month storage test (0 and 40°C, 50 and 100% SOC)
  - Accelerated storage test: at different SOC (50, 70, 100% SOC),
    temperatures (25, 40, 55°C), and storage conditions.

• Mission Simulation Testing
Li-Ion Battery Technology Assessment
Test Cells

- Yardney
  - Baseline 5 Ah Cells
  - First generation 20 Ah Cells for Mars Lander
  - Second generation 20/25 Ah cells for Mars Lander
  - First generation 8Ah Cells for Rover
  - MSP 01 25/35 Cells

- BlueStar
  - Baseline 20 Ah Cells
  - First Generation 25 Ah Cells for Mars Lander
  - Second generation 25/35 Ah Cells for Mars Lander
  - First Generation Rover Cells (6-8 Ah)

- Eagle Picher
  - Baseline 15/20 Ah cells
  - First Generation 50 Ah Cells-Aircraft

- SAFT
  - Baseline D cells
  - First Generation Rover Cells (8-9 Ah)
Cells were found to deliver > 140 Wh/kg at RT

Cells were found to deliver about 100 Wh/kg at -20C

Cells can accept charge at -20C

Similar performance capability observed with both 8 and 25 Ah cells

Cell from all vendors showed similar capabilities
Li-Ion Battery Technology Assessment
Cycle Life Studies

- Cells delivered >1000 cycles at 100dod and RT
- Cells completed more than 700, 100% dod cycles at-20C
- Observed similar performance capability in both 8 and 25Ah cells
- Cells from all vendors similar capabilities
- Cycling cells at low and high temperatures was found effect low temp performance
Lithium-Ion Cell Technology Assessment
Effect of Charge Voltage Upon Cycle Life Characteristics

4.20 V Charge Voltage
5.0 Amp Charge current (C/5)
C/50 Taper Current Cut-Off
Temp = 23°C

Capacity fade rate = 0.035 %/cycle
89% of Initial capacity after 300 cycles

4.10 V Charge Voltage
5.0 Amp Charge current (C/5)
C/50 Taper Current Cut-Off

Capacity fade rate = 0.025 %/cycle
Lithium-Ion Cell Technology Assessment
Leo Cycle Life Assessment Studies

(a) 15 A Discharge current (0.6 C)
30 min Discharge (7.5 Ahr)
(b) 10 A Charge current (0.4 C)
4.1 V Con. potential charge
60 min Charge period

Temperature = 23°C

BS C074
Li-Ion Battery Technology Assessment
Effects of Storage Conditions

- Storage of cells at low temperatures was found to minimize self discharge

- Storage of cells at low temperatures was also found to minimize irreversible capacity losses on storage

- Storage of cells at lower stages of charge were found to minimize irreversible capacity losses on storage
Mars 01 Lander Battery Development Status

- Launch environmental withstand ability
- 10 month cruise storage capability
- Mars surface operational capability
  - Met EDL Performance Requirements
  - 50 A Pulse operations at 0 C
  - 60 simulated Sol operational capability at -20 to 40 C (testing continuing)
- Three year calendar life
Summary and Conclusions

- Li Ion cells meet the Mars mission requirements in
  - Cycle Life Performance
    - Room Temperature = Excellent (>90% @ 200 cycles)
    - Low Temperature (-20) = Sufficient
    - High Temperature (40°C) = Sufficient (>70% @ 200 cycles)
  - Discharge Rate Capability at Various Temperatures
    - Room Temperature = Excellent
    - Low Temperature (-20) = Sufficient (~ 24 Ah @ C/5 rate)
    - High Temperature (40°C) = Excellent
  - Storage Characteristics
    - Demonstrated minimal reversible capacity loss (2 months)
    - Identified temperature as most crucial storage parameter
    - Demonstrated efficacy of storage “on the buss”
  - Mission simulation (Variable Temperature Cycling)
    - Identified potential performance limiting conditions (worst case)
    - Implemented characterization test to quantify behavior