EPI Sodium Sulfur Program

- NaS program initiated in 1986.
- EPI selected by USAF as sole developer for NaS LEO cells.
- Over 200 cells constructed for a variety of applications.
- Developed a $\beta^+$ electrolyte production capability.
<table>
<thead>
<tr>
<th>Cell Sizes Manufactured</th>
<th>50 AH</th>
<th>40 AH</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.4&quot; D X 12.3&quot; L</td>
<td>600 gms (1.31 lbs)</td>
<td>500 gms (1.10 lbs)</td>
</tr>
</tbody>
</table>
ARIES OF IMPROVEMENT

- Resistance
- Cathode Performance
- Parts Count
- Weight
- Seals
# Performance Improvement Demonstrated (16 Amp Discharge)

<table>
<thead>
<tr>
<th></th>
<th>Weight (grams)</th>
<th>Avg. Volts (Discharge)</th>
<th>Resistance (mOhms)</th>
<th>Spec. Energy (Whr/Kg)</th>
<th>Energy Dens. (Whr/L)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Baseline</td>
<td>509</td>
<td>1.64</td>
<td>17.6</td>
<td>119.1</td>
<td>266.9</td>
</tr>
<tr>
<td>Intermediate</td>
<td>506</td>
<td>1.74</td>
<td>10.6</td>
<td>127.3</td>
<td>283.6</td>
</tr>
<tr>
<td>Improved</td>
<td>500</td>
<td>1.89</td>
<td>6.7</td>
<td>139.8</td>
<td>307.8</td>
</tr>
<tr>
<td>State-of-the-Art</td>
<td>455</td>
<td>1.95</td>
<td>5.8</td>
<td>158.5</td>
<td>334.0</td>
</tr>
</tbody>
</table>
50 AHR Cell — "Improved" Design

- 8,400 Cycles (>95% LEO, 60% DOD)
- On test 33 months
- Discharge resistance 8.3 milliohms (7.3 milliohms BOL)
- F1% 16.1 (14.0 BOL)
- Capacity 53.3 Ahr (52.1 BOL)
IMPROVED CELL PERFORMANCE (LEO 60% DOD)

- Volts
- Watts
- Amps

Cycle 8148
Discharge (54 A)
Open Circuit
Charge (45/30/25/22.5/20/17.5/15 A)

F1(%) = 19.81

Minutes
EAGLE EP Picher
Electronics Division
Joplin, MO

ADVANCED SYSTEMS OPERATION

SODIUM-SULFUR GROUP

IMPROVED CELL PERFORMANCE (CAP 95% DOD)

- CYCLE 8338 F1(%) = 16.12
- CYCLE 1119 F1(%) = 13.26

VOLTS

AMPS

DISCHARGE (25 A/2 A/25 A) CIRCUIT

OPEN CONSTANT CURRENT CHARGE (15 A/5 A)

MINUTES
SODIUM-SULFUR GROUP

SINGLE CELL TEST MILESTONES

- Over 11,000 cycles to date
- 43 month calendar life
- 3,130 AHR/cm² in cell testing
- 5,900 AHR/cm² in sodium-sodium testing
- Discharge resistance < 5 milliohms
- F1 of less than 5 (low rate charge)
Environmental Testing Accomplished

- Shock ........................................ 30g's, 11ms
- Acceleration .............................. 15g's, 5 min.
- Random Vibration ............... 0.25g²/Hz, 300-1200Hz
  (0A=19.5g RMS)
- Sine Vibration ......................... 7.5g peak, 5-2000Hz
- Humidity ................................. MIL-STD-810B, Method 507
- Freeze/Thaw ......................... 20 Cycles
STATE-OF-THE-ART CELL

TYPICAL CELL PERFORMANCE (LEO 60% DOD)

![Graph showing typical cell performance with Volts and Amperes as axes, and a description of the stages: discharge (40 A), open circuit, constant potential charge (25 A limit).]
ENTRY LEVEL BATTERY

- Effort funded internally 1990-1991
- Three cell module
- 1,000 cycles achieved
  Constant current charge/discharge
  Nominal 60% DOD (=30Ahr)
- 30 Whr/Kg
- Calendar life: 6 months
**Next Generation Battery Performance Projections**

- 35 Amp-Hour cells
- 20 cell series string
- Battery OCV: 42 Volts
- Battery working volts: 38 Volts
- Weight: 13.5 Kg
- Volume: 30 L
- Energy Density: 100 Whr/Kg, 45 Whr/L
STATE-OF-THE-ART CELL

TYPICAL THREE CELL GROUP

DISCHARGE (20 A)  OPEN CIRCUIT  CONSTANT CURRENT CHARGE (20 A)

MINUTES

VOLTS

AMPS

0  15  30  45  60  75  90  105  120  135  150  165  180

0  .2  .4  .6  .8  1  1.2  1.4  1.6  1.8  2  2.2  2.4  2.6  2.8  3

0  10  20  30  40  50  60
STATE-OF-THE-ART CELL

TYPICAL THREE CELL GROUP

VOLTS

AMPS

MINUTES

EAGLE PIPHER Electronics Division
Joplin, MO

1992 NASA Aerospace Battery Workshop -677- Advanced Technologies Session
SUMMARY

Sodium Sulfur cell and battery designs continue to evolve with significant improvement demonstrated in:

- Resistance
- Rechargeability
- Cycle Life
- Energy Density
- Electrolyte Characterization