

BIPOLAR NICKEL-HYDROGEN BATTERY DESIGN

C. W. KOEHLER, A. Z. APPLEWHITE, & Y. KUO

FORD AEROSPACE & COMMUNICATIONS CORPORATION

PALO ALTO, CA. 94303

INTRODUCTION

Ford Aerospace & Communications Corporation and Yardney Battery Division are now completing the design of a bipolar nickel-hydrogen battery stack. This initial design is the first of three design phases being conducted on the Advanced Nickel-Hydrogen Battery Development Program. The program is sponsored by the NASA-Lewis Research Center and the technology is being considered as one of the energy storage concepts for the Space Station.

The initial stacks which will soon begin fabrication were designed with several objectives in mind (Reference 1):

- o Maximization of reliability and life
- o High specific energy and energy density
- o Reasonable cost of manufacture, test, and integration
- o Ease in scaling for growth in power requirements

To meet these objectives the battery design must provide for careful material and thermal management (Reference 2).

This paper presents the results of the design effort which has resulted in the initial bipolar nickel-hydrogen battery design. Specifically, this paper will discuss the thermal and mechanical design of the battery. The electrochemical design considerations of the battery are described in Reference 3.

THERMAL DESIGN

The thermal design of a bipolar nickel-hydrogen battery is critical to the life and reliability of the battery. Materials balance and electrical performance are quite dependent on the thermal design. Thermal imbalances between individual cells can lead to premature failure of the battery since the transfer of materials from cell to cell via the gas or vapor phase is possible. A warmer cell can lose water to the cooler cells and thus dry out causing it to be less efficient. This inefficiency will result in higher heat dissipation during electrical cycling which will compound the temperature differences between this cell and the others of the bipolar stack. The runaway condition will ultimately result in battery failure.

Not only should cell-to-cell temperature gradients be eliminated but intracell gradients must be minimized. Large temperature gradients over the electrode surface would result in performance imbalances which could be detrimental to long term performance. The following thermal performance goals have been established for the bipolar nickel-hydrogen battery design:

- o Operational temperature range: 0 to 25°C
- o Cell-to-cell temperature gradient: 1°C (maximum)
- o Intracell temperature gradient: 5°C (maximum)

The cell-to-cell temperature gradient of 1°C is for equivalent locations on each cell.

To meet these thermal requirements the bipolar battery stack will be edge cooled. The electrodes will be rectangular in shape and a flat cooling panel containing a pumped cooling fluid will be assembled onto the two long sides of the stack. The bipolar conduction plate of each cell will have sufficient thickness to conduct the heat generated by the inefficiencies of the cell to the cooling plate. Cooling plates on opposite sides of the cell stack will contain fluid flowing in opposite directions. This counterflow cooling also helps minimize intracell temperature gradients.

The temperature gradient across a cell is dependent on the cell heat dissipation and the heat path thermal conductivity. The battery design is based on a 75Ah cell operating at 80% depth of discharge in a typical low earth orbit having a 90 minute period. Reference 4 discusses the considerations which affect the thermal design utilizing edge cooling. Specifically, the battery weight and volume can be optimized by selecting the nickel electrode width and sizing the bipolar conduction plate thickness so that the thermal requirements are met.

Ford Aerospace has analyzed the thermal design of the battery as a function of nickel electrode width and battery depth of discharge. Two depths of discharge were considered, 40% and 80%. Significant weight differences result in these two designs mainly due to the thicker bipolar conduction plates required for the higher depth of discharge (Reference 5).

Figure 1 shows the effect the nickel electrode width has on the bipolar conduction plate thickness for the two depths of discharge being considered. Both curves result in equivalent thermal performance with respect to operating temperature range and temperature gradients.

Since the bipolar conduction plate is in direct electrical contact with the cell the plate must be isolated from the cooling plate. Unfortunately, electrical insulators are poor thermal conductors. The poor thermal conductivity coupled with the small conduction area at the bipolar conduction plate/cooling panel interface makes it necessary for a special intermediate thermal conductor known as an 'L' fin. The concept, shown in Figure 2, provides the thermal contact area necessary for the thermal conduction of the waste heat from the cell edge to the cooling plate. The 'L' fin is electrically isolated from the bipolar conduction plate. Heat is trans-

ferred from the bipolar conduction plate to the 'L' fin through a larger insulated contact area then directly to the fluid cooling channel.

MECHANICAL DESIGN

The cell frame is the only component in the stack design which controls material management, particularly electrolyte isolation and water. In a bipolar battery stack relatively short distances in the stack direction perpendicular to the electrode area results in sizeable voltage differences making electrolyte isolation very important. An electrolyte bridge between two cells will electrically short the two cells and all cells in between.

The cell frame must be capable of sealing the electrolyte within the frame. Features in the frame, such as an o-ring and groove detail can seal the frame. Alternatively, compression of stack on the frame surfaces can be used to make a seal.

As shown in Figure 2, the 'L' fin must be insulated from the bipolar conduction plate with which it is directly in contact. If this insulation material is semi-rigid and has hydrophobic properties then an electrolyte seal can be established by compressing the cell stack and the insulation material. The 'L' fin is bonded to the cell frame and the cell frame is bonded to the bipolar conduction plate at the lower frame interface. Thus the cell frame seal is made by either compression of the insulation material or a bonded interface.

End plates at the top and bottom of the cell stack will provide the stack compression via tie rods. The stack components will be under approximately 23 psi of compression while the cell frame seal will be under approximately 230 psi of compression. The bipolar conduction plate in contact with the compression seal will be teflon coated, thus enhancing the hydrophobic characteristics of the compression seal.

The cell frame must also provide gas access to the hydrogen electrode. This is accomplished by allowing the hydrogen gas screen under the negative electrode to protrude to the outer edge of the cell frame's narrow side (Figure 2). The amount of gas screen under the cell frame will be teflon coated as will the bipolar conduction plate in this area. The hydrophobic surfaces in these areas are the only electrolyte barrier.

As the cell goes into overcharge oxygen will be generated at the nickel electrode. The cell stack components must recombine this oxygen with hydrogen producing water. It is important to recombine the oxygen in the cell where it was generated. If the oxygen were allowed to escape the cell it was generated in this cell would effectively be losing water and other cells would gain water where it finally recombines. This would result in drying out of one cell and potential flooding of others.

To prevent this from occurring each cell will have a recombination site and electrolyte reservoir for oxygen recombination. The nickel electrode, located between the recombination site/reservoir and hydrogen electrode will produce oxygen on overcharge. The asbestos separator, having

high oxygen bubble pressure, will force the oxygen to the recombination site/reservoir area and to recombine there. The water will flow directly into the reservoir and nickel electrode creating a continuous water balance in the cell.

If the oxygen were allowed to recombine at the hydrogen electrode, the water produced could get trapped in the gas screen or flood the hydrogen electrode. In either event the performance of the cell would be impaired. Using asbestos as the separator and having the separator touch the cell frame at all four edges gaskets oxygen from getting to the hydrogen electrode.

INITIAL DESIGN AND PERFORMANCE GOALS

To meet the design capacity objective of 75Ah it is necessary for the nickel electrode area to be 192 in² (1239 cm²), based on a 0.083 in (2.11mm) thick electrode chosen for the initial design. This area can be accommodated in almost any combination of electrode length and width but the configuration chosen for the initial design will be three (3) 4.0 inch wide by 16.0 inch long (10.2cm x 40.6cm) modules, each contained in a cell frame mounted on a single bipolar conduction plate. This configuration was established by the thermal design of the battery and manufacturing constraints on the cell frames.

The cell stack will consist of a bipolar conduction plate, electrolyte reservoir/recombination site plate, nickel electrode, separator, integrated-hydrogen electrode, and gas screen. The nickel electrode within each cell frame will be split in two equal parts. The split electrode will be adequately spaced and the gap will be filled with a wick made of separator material. The wick serve two purposes: (1) to provide a space for area expansion of the electrode, and (2) to provide a direct return path for water from the reservoir to the separator. A wick will also be placed at each end of the nickel electrode.

The bipolar conduction plate thickness for the initial design will be 0.040 inches (1.02mm). This thickness was based on an operating depth of discharge of 80% and a nickel electrode width of 4.0 inches (10.2cm). Selection of this nickel electrode width and bipolar plate thickness is discussed in Reference 5.

The hydrogen electrode is an integrated structure. The application of this new development by Yardney came about when the negative electrode originally considered for design experienced flooding during operation.

The separator and electrolyte wicks are beater treated asbestos (BTA) fabricated using similar techniques which NASA-LeRC has been successfully using. The reservoir material will be nickel foam metal. Two types of gas screen will be used. One is a fine mesh in direct contact with the negative electrode to provide good electrical conductivity; the second is a larger mesh for gas access.

A cross-section of the cell is shown in Figure 2. The thicknesses of the various components are summarized in Table 1.

Each cell module is contained within a plastic cell frame. The cell frame provides the necessary gas access, isolates the cell components from the cooling channels, seals the cell from electrolyte leakage which would result in cell bridging, and provides an internal oxygen seal which won't allow oxygen to recombine at the negative electrode. The cell frame is slightly thinner than the sum of the cell component thicknesses so that when the stack is compressed each cell is uniformly compressed providing a good electrical contact with the bipolar conduction plate between cells and uniform interelectrode spacing.

Stack compression is maintained by end plates and tie rods. The tie rods pass through the cell frames and bipolar conduction plates and are insulated with a teflon sleeve. The tie rods cannot pass outside the cell frames because they would interfere with the cooling panels.

The cooling panels are assembled onto the long sides of the stack. 'L' fins bonded onto the cell frame provide the necessary heat transfer surface for the heat path between the bipolar conduction plate and the cooling panels. Since the bipolar conduction plate is in direct contact with the cell it is insulated from the cooling plate as previously discussed.

The performance goals shown on Table 2 have been established for the initial design battery stack.

SUMMARY

Ford Aerospace and Yardney have established the initial design for the NASA-Lewis advanced nickel-hydrogen battery. Fabrication of two 10-cell boilerplate battery stacks will soon begin. The test batteries will undergo characterization testing and low earth orbit life cycling.

The design effectively deals with waste heat generated in the cell stack. Stack temperatures and temperature gradients are maintained to acceptable limits by utilizing the bipolar conduction plate as a heat path to the active cooling fluid panel external to the edge of the cell stack.

The thermal design and mechanical design of the battery stack together maintain a materials balance within the cell. An electrolyte seal on each cell frame prohibits electrolyte bridging. An oxygen recombination site and electrolyte reservoir/separator design does not allow oxygen to leave the cell in which it was generated.

REFERENCES

1. "Bipolar Nickel-Hydrogen Batteries for Aerospace Applications", C. W. Koehler, G. van Ommering, N.H. Puester, and V.J. Puglisi, 1983 Goddard Space Flight Center Battery Workshop, p.495.
2. "Bipolar Nickel-Hydrogen Battery System Design", G. van Ommering and C. W. Koehler, Proceedings of the 19th Intersociety Energy Conversion Engineering Conference, Volume I, p. 625.
3. "Nickel-Hydrogen Bipolar Battery Electrode Design", V.J. Puglisi, 1984 Goddard Space Flight Center Battery Workshop (to be published).
4. "Thermal and Geometrical Considerations in a Bipolar Nickel-Hydrogen Battery Design", C.W. Koehler and G. van Ommering, 31st Power Sources Symposium Proceedings, (to be published).
5. "System Considerations for a Bipolar Nickel Hydrogen Battery", G. van Ommering and C. W. Koehler, 1984 Goddard Space Flight Center Battery Workshop (to be published).

BIPOLAR CONDUCTION PLATE THICKNESS
VS
NICKEL ELECTRODE WIDTH

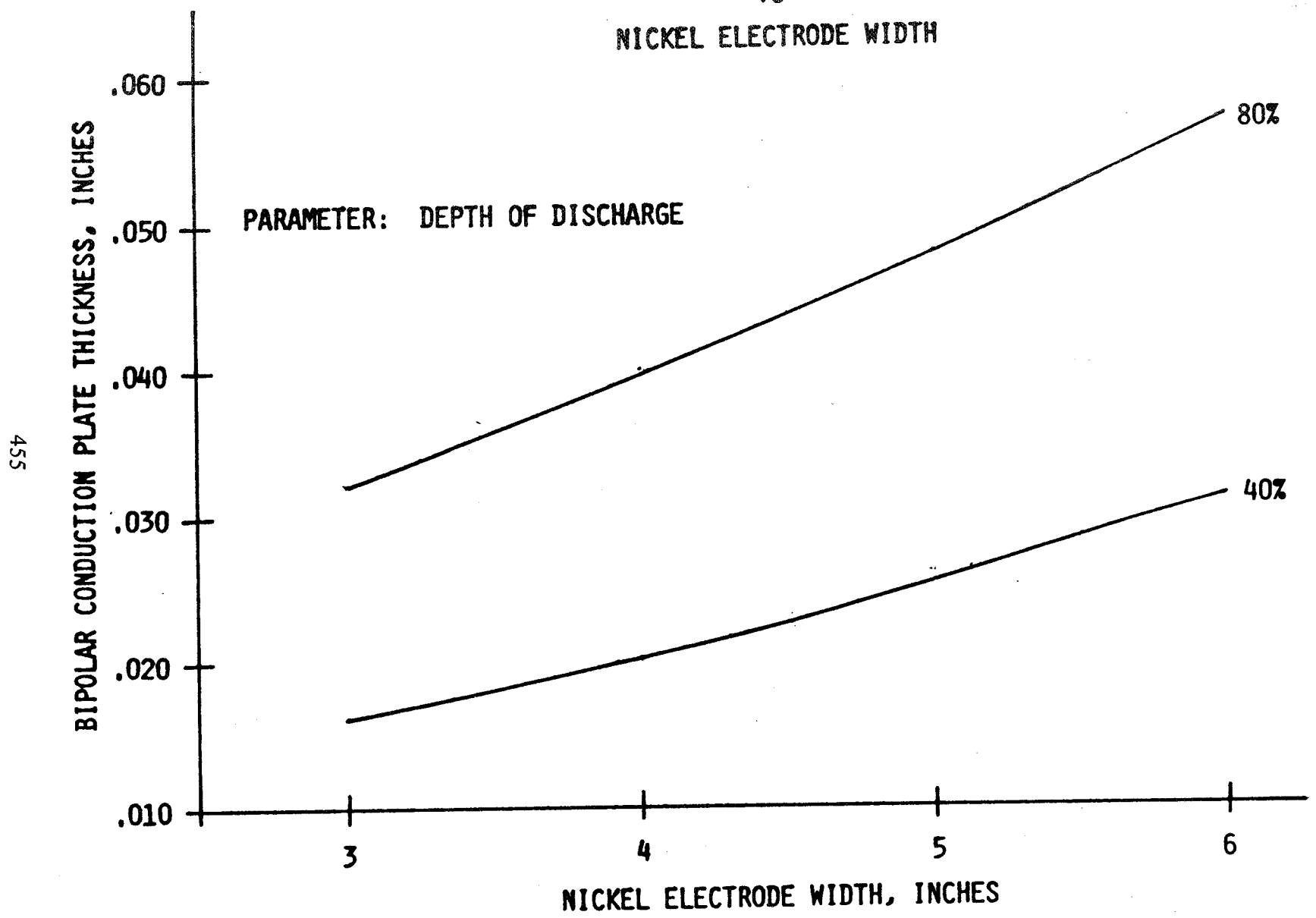


Figure 1. Bipolar Conduction Plate Thickness vs Nickel Electrode Width

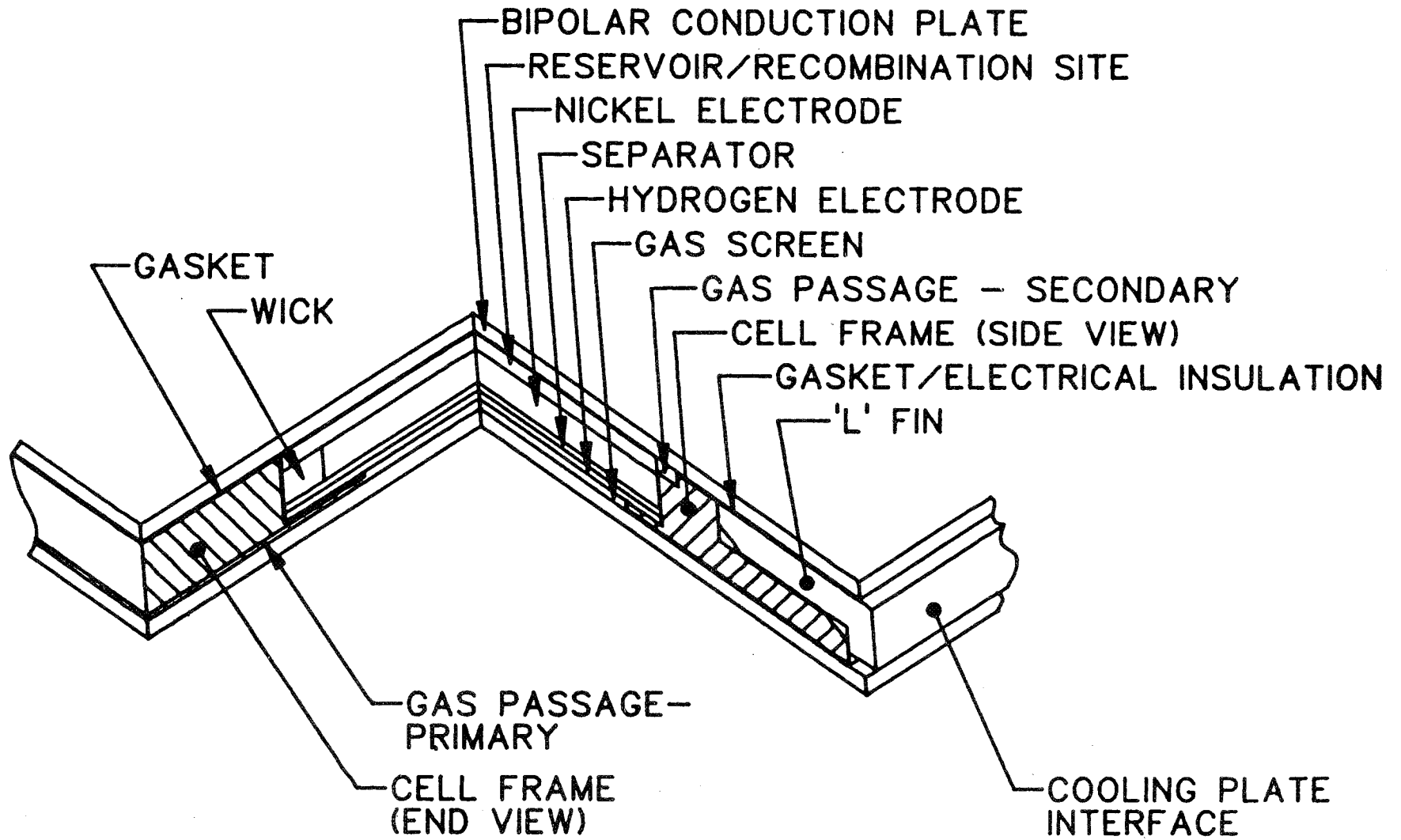


Figure 2. Bipolar Nickel-Hydrogen Cell

Table 1. CELL COMPONENT THICKNESSES

Component	Thickness	
1. Bipolar Conduction Plate	0.040 inch	1.02 mm
2. Electrolyte Reservoir	0.038	0.97
3. Nickel Electrode	0.083	2.11
4. Separator	0.015	0.38
5. Integrated Negative Electrode	0.015	0.38
6. Nickel Gas Screen (Total)	0.023	0.58

Table 2. BATTERY PERFORMANCE GOALS

Characteristic	Performance Goal
Electrical Performance:	
Charge Current	72 A (.96C)
Recharge Fraction	1.10
Charge Voltage (Maximum)	1.58V/cell (10°C)
Discharge Current	103A (1.37C)
Discharge Capacity (Minimum)	75 Ah (to 1.0V/cell)
Discharge Voltage (Minimum)	1.20V/cell average to 80% DOD
Pulse Load	30C for 5 seconds
Minimum Voltage	1.00V/cell
Specific Energy	50 wh/kg (22.7 wh/lb)
Energy Density	0.06 wh/cm ³ (0.98 wh/in ³)
Cycle Life	30,000 cycle at 80% DOD
Thermal Performance:	
Cooling	Active, pumped fluid cooling
Operating Temperature	0°-25°C during 90 minute orbit
Qualification Temperature	-10° to +35°C
Temperature Gradients	5°C within single cell; 1°C from cell-to-cell