Tech focus

This month's focus is on some of the research being done to improve the performance of batteries for aerospace applications.

Aircraft battery for better ultra-low-temperature performance

The **Air Force Research Laboratory** (AFRL), Electrochemistry and Thermal Sciences Branch, has evaluated numerous aircraft battery designs and chemistries since the 1960s. Designs have emphasized low weight, small volume, and maximum performance at minimal costs over a temperature range of -40 to +60°C. Since the mid-1990s, the temperature range has increased on new aircraft.

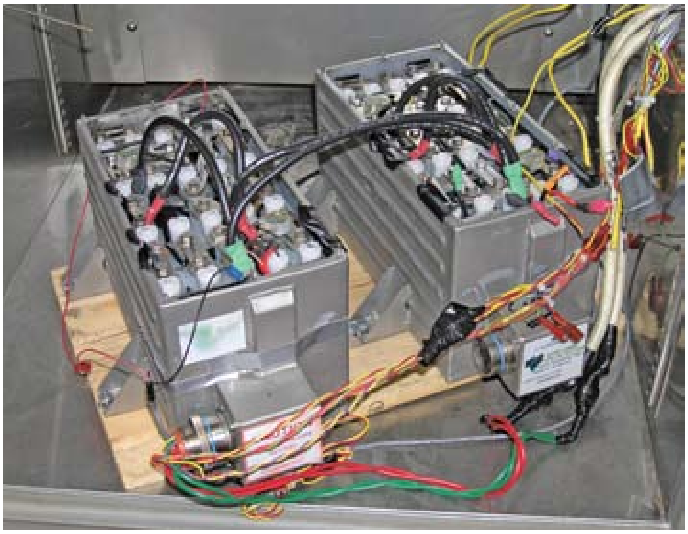
But research work at the AFRL is showing promise.

Based on weight, volume, performance, and temperature criteria, battery design typically employs serial cell connections with a minimum number of cells and connectors for good reliability, robustness, and low cost. However, if the desired performance at ultra-low temperature is not met, design changes are necessary. These design changes typically reduce the overall capacity of the cell and result in what is referred to as a high-power design. Such a design typically has a higher price than a regular battery due to use of special materials, designs, and packaging.

Some of the design changes include using higher-capacity cells, thinner cell plates (increasing the surface area for the chemical reaction) within the cells, square vs. rectangular cells (for shorter current path), and specially designed electrolytes for low-temperature operation (higher conductivity). All of these result in a nonstandard cell or battery that increases costs. In most cases, these measures have the desired effect and enable the battery to meet the performance requirements.

One concept that appears to have been overlooked in designing a battery for low-temperature performance uses lower-capacity cell packs in a parallel-series configuration, which significantly reduces battery resistance and should also improve ultra-low-temperature performance. Based on the equation $1/R_t = 1/R_1 + 1/R_2 + \ldots + 1/R_n$ (where R_t is the total resistance and R_1 is the resistance of the first cell pack, R_2 the second, *etc.*), the resistance of a battery will decrease as the number of cell packs increases. For ultra-low-temperature performance, the best design is one in which the internal resistance of the battery is as low as possible consistent with minimizing the number of cells to comply with weight and volume restrictions of the design.

The Electrochemistry and Thermal Sciences Branch of the AFRL has experimented with parallel cell designs to evaluate the concept and to help solve low-temperature performance problems. Preliminary results using available assets showed a marked improvement in ultra-low-temperature performance using two strings of cells in parallel; however, further experiments are needed to eliminate an increased capacity effect and quantify the improvements.



Results are pending for the two-battery parallel test configuration.

Other areas for which more information is being sought include chemistry dependence of the concept and the optimum number of cell packs in parallel to maximize the effect consistent with application volume and weight restrictions. Questions that need to be answered include:

- Is the concept valid across all battery chemistries?
- Does the effect vary depending on which chemistry one is using to design the battery?
- Does the overall battery weight and volume increase offset low-temperature performance gains?
- How many cell packs in parallel maximizes low-temperature performance?
- What safety issues are associated with using a parallel-series configuration vs. a series configuration, especially for Li-ion cells?

In designing an expanded test program, the AFRL researchers are addressing all of these factors. But because Li-ion chemistry is the hot chemistry for new aircraft batteries and the most expensive compared to legacy battery systems, they elected to perform further experiments on Li-ion cells and use existing commercial production cells as the test specimens.

The researchers elected to use 14-V half batteries for the test program to minimize costs and assembly.

Results will be reported soon.

Information for this article was provided by **John K. Erbacher**, **Gary J. Loeber**, and **Sarah M. Owens** of the Air Force Research Laboratory, Wright-Patterson AFB; and **Cameron A. Riepenhoff**, University of Dayton Research Institute - Metals and Ceramics.

Li-ion technology examined for aerospace applications

Sony introduced Li-ion electrochemistry in the 1990s, and since then it has become the premier high-energy system for portable electronics devices. Li-ion cells are found today in every laptop computer and almost every mobile phone and handheld communication device sold across the world.

More recently, companies such as **Saft** have been exploring potential aerospace applications for Li-ion technology. In early 2002, for example, the company made progress in the area of very-high-power (VHP) Li-ion technology—specifically, pulse power applications. The work was initiated under a **DARPA** (Defense Advanced Research Projects Agency, **U.S. Department of Defense**) contract and the effort continued subsequently under funding from the **U.S. Air Force**. Saft is currently working on further improvement of VHP technology for use in aircraft and Directed Energy Weapon applications.

VHP technology found its first practical application as the system of choice for the 270-V battery in an advanced fighter aircraft. Now under qualification at Saft is a battery consisting of VL4V cells in series. These cells represent the industrially mature version of the VHP state-of-the art production technology. The VL4V's excellent low-temperature performance enables the operation of a battery meeting the demanding requirements of the aircraft application. The technology is capable of delivering high power pulses at very low temperature (-40°C) over the lifetime of the cell even after excursions to high temperature (72°C).

Saft has three different cell sizes available with the VHP technology. The VL4V is the smallest cell, and although it was developed for aircraft use, it also serves as the test vehicle for general innovations in the technology. There are VL12V and VL8V sizes as well, both using the same electrochemistry as the VL4V.

In general, the technology is capable of 8 kW/kg in 2-s pulses, as well as 12 kW/kg in millisecond-long pulses. This power performance is superior to the performance of supercapacitors and is provided at fairly high energy content. The specific energy of the VHP cells is around 65 W·h/kg. About 70% of this energy is available at the very-high-power level.

Under the Air Force program, Saft focused its development efforts on improvement of mechanical bussing and further optimization of the electrochemistry. The goals encompass maximizing specific power, increasing cycle life under heavy load conditions, and minimizing heat generation. These goals are not mutually exclusive and often improvements in one benefit the others.

It has been experimentally determined that the main source of heat generation in Saft cylindrical cells is not electrochemical. The bussing of both the positive and negative terminals is predominantly responsible for I^2R heating. Results of the testing strongly indicate that most of the heat is generated in the positive terminal bussing of the cell. By using a new mechanical feed, the ac impedance of the VL4V cell, measured through the 1000-Hz method, was reduced by about 35%.

The smallest in Saft's family of three Very High Power (VHP) cells was developed specifically for aircraft applications, and it serves as the company's vehicle for VHP innovation.

Design optimization of the VL4V cell to further reduce I^2R heating and increase manufacturability is ongoing. Saft is also working on redesign of the negative terminal to optimize high-rate charging.

Information for this article was provided by **Kamen Nechev**, **Bridget Deveney**, and **Teymur Guseynov** of Saft America; and **John Erbacher** and **Stephen Vukson** of the Air Force Research Laboratory, Wright-Patterson AFB.