National Aeronautics and Space Administration

FY23 Strategic Initiatives Research and Technology Development (SRTD)

Advanced, Wide Operating Temperature Batteries for Venus Aerobot Missions

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Strategic Focus Area: Technologies for Venus Cloud Environments /Venus In-Situ Aerosol Measurement Technologies **| Strategic Initiative Leader:** James A Cutts

Objectives: The overall task objective was to develop a wide temperature (-30ºC to 100ºC) -capable, flight-worthy Li-ion battery module that can meet the required temperature range, cycle life, and energy requirements of a Venus Aerobot mission with the following tasks:

1) Downselect four Generation-2 electrolytes and provide these electrolytes to Saft to produce Generation-2 flight-like cells
2) After receipt of these cells, demonstrate performance improvements over the Generation-1 cells
3) Incorporate these high temperature cells into a brassboard battery module
4) Carry out random vibration and thermal vacuum tests of the battery module to establish TRL 5
5) Develop at least four Generation-3 wide temperature electrolytes for the FY24 program.

Background: JPL seeks to develop technologies to enable a mission with a Venus-deployed aerobot with a temperature range from -30ºC to 100ºC. While space-rated Li-ion cells can be tailored to meet the lower temperature limit, operating or storage temperatures higher than about 60ºC can rapidly degrade cell performance. As such, a new mission-enabling battery cell technology must be developed that can tolerate the temperature extremes of the Venus atmospheric mission.

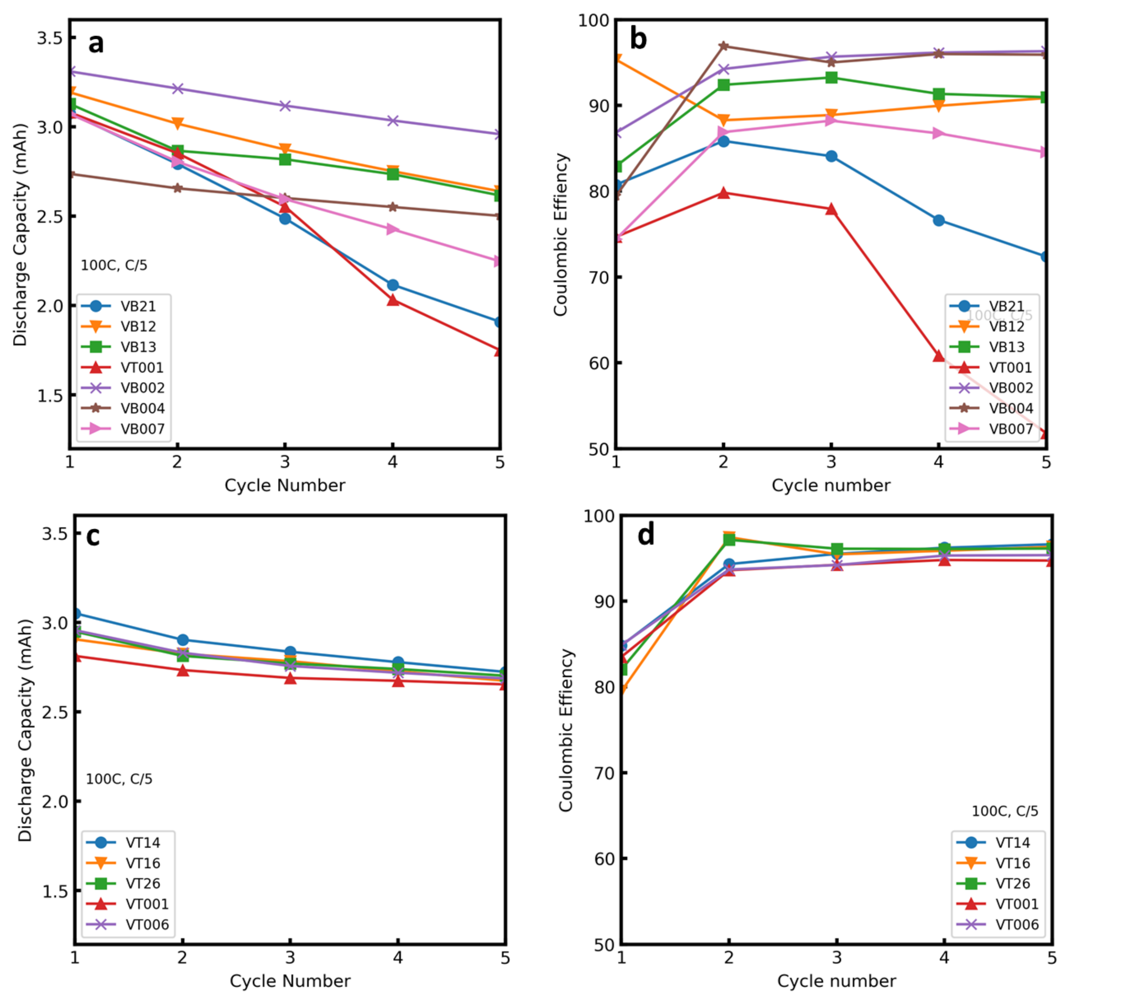

Figure 1. Comparison of Generation-1 electrolyte a) specific discharge capacity and b) Coulombic efficiency to Generation-3 electrolyte c) specific discharge capacity and d) Coulombic efficiency.

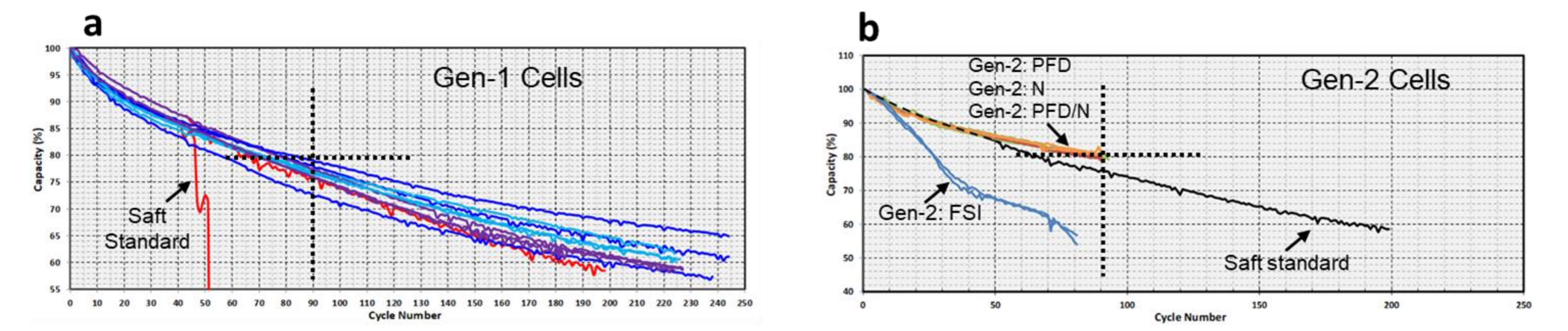

Figure 2. Comparison of Saft cell discharge capacity incorporating a) Generation-1 electrolyte and b) Generation-2 electrolyte. The dashed cross indicates 80% beginning of life capacity and 90 cycles.

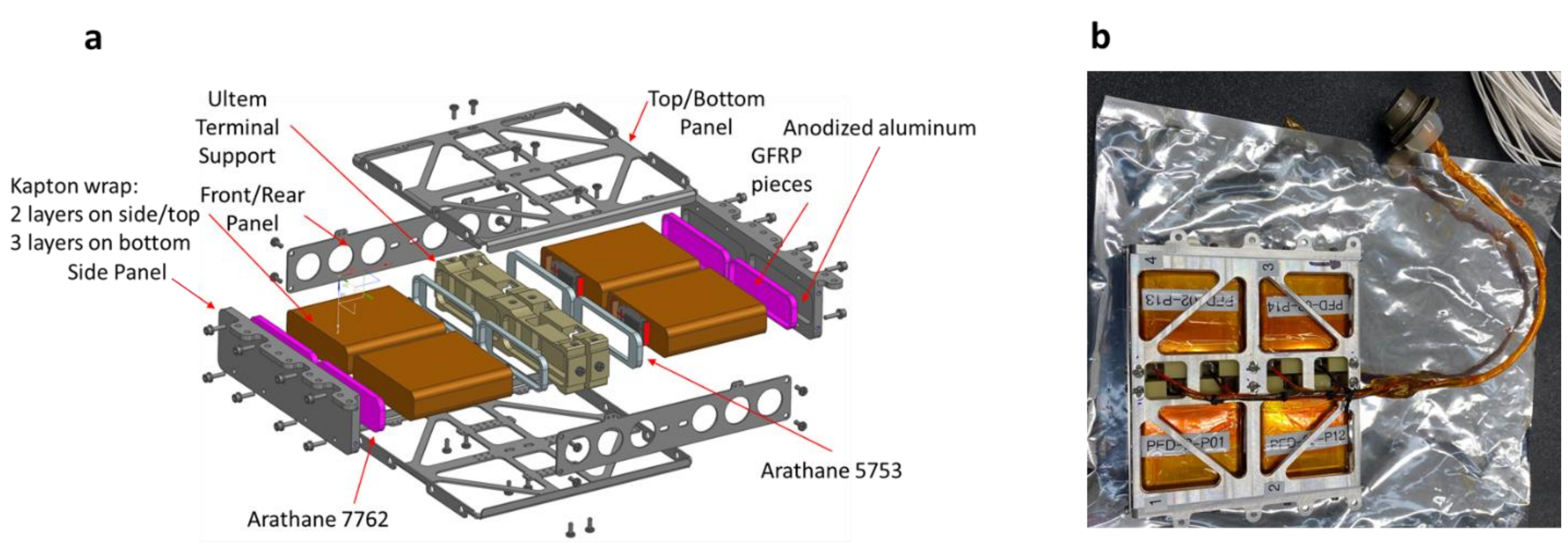

Figure 3. Venus aerobot battery assembly a) schematic and b) completed module with harness.

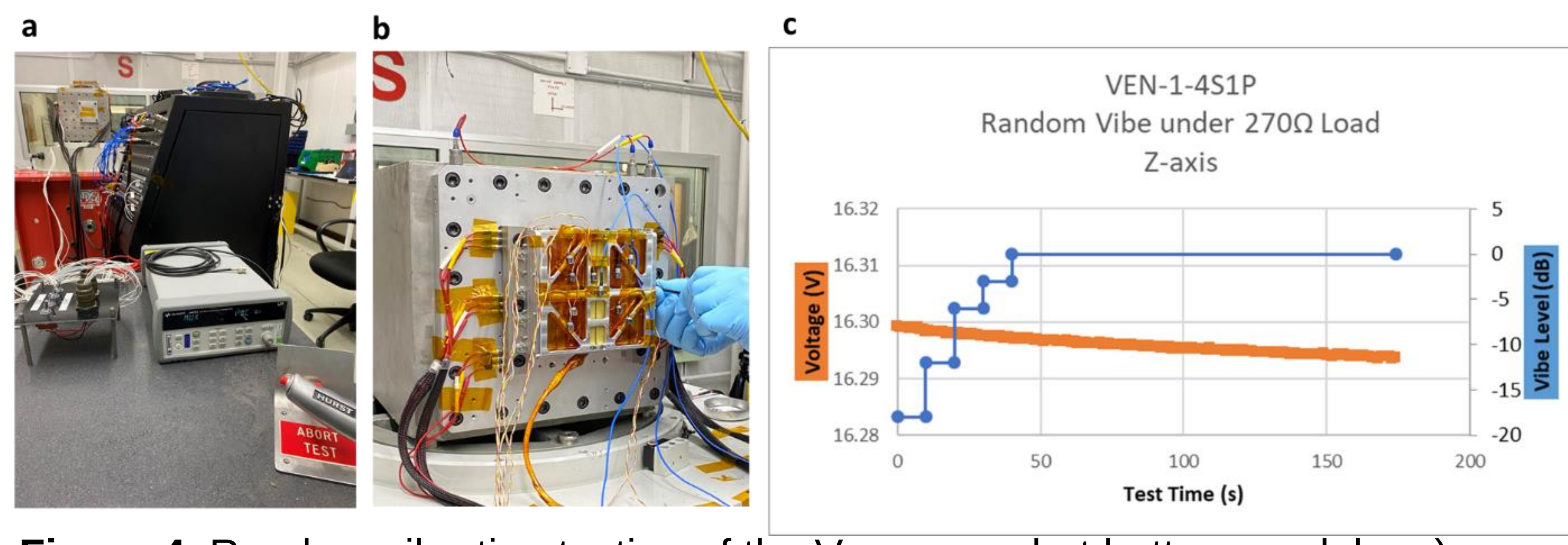

Figure 4. Random vibration testing of the Venus aerobot battery module; a) Resistive load test equipment, b) battery module mounted onto the vibration fixture, and c) discharge voltage and random vibration level demonstrating no voltage chatter during vibration testing.

Approach:

- Identify at least four Generation-2 electrolyte formulations for wide temperature operation
- Issue a subcontract to Saft to incorporate Generation-2 electrolytes into Saft MP-xtd cells
- Evaluate the electrical performance of prototype Generation-2 cells
- Perform electrochemical studies of Generation-3 electrolytes
- Assemble a brassboard multi-cell battery module with Saft Generation-2 cells
- Carry out random vibration and thermal vacuum tests on brassboard multi-cell battery module

Significance/Benefits to JPL and NASA: This year's effort resulted in the identification of numerous electrolyte formulations that enabled even greater performance of the battery technology for operation over a wide temperature range. These new electrolytes were successfully incorporated into aerospace-grade battery cells that were delivered to JPL for testing. By assembling these cells into a flight-like battery module, these cells and battery module were tested under relevant environmental conditions, thereby meeting key requirements for a planned Technology Readiness Assessment Review (TRA).

Results:

- Numerous new Generation-3 electrolytes were developed. Several formulations outperformed the Generation-1 electrolyte in terms of reproducibility, average specific capacity, and Coulombic efficiency (Figure 1).
- Three of the four Generation-2 electrolytes incorporated into Saft cells outperformed the Generation-1 electrolyte cells after 90 charge/discharge cycles at 100ºC and a voltage range of 4.1-3.3V (Figure 2).
- The top-performing Generation-2 electrolyte was identified. The PDF formulation (1M $LiPF_6$ in 50:50 vol% ethylene carbonate:ethyl methyl carbonate + 1% lithium phosphorodifluoridate (PDF)+ 2% vinylene carbonate)) outperformed all other Generation-2 electrolytes when incorporated into Saft cells.
- PDF cells were incorporated into Saft cells and then the cells were assembled into a single string, four-cell battery module (4s1p) (Figure 3).
- After completing the fabrication, assembly, and post-assembly electrical tests, the battery was subjected to the CADRE battery proto-flight random vibration test specification levels (overall 19.8 G_{rms} G^2/Hz) while actively discharging the battery using a resistive load (Figure 4).
- The battery successfully completed full level random vibration for two minutes on all three axes with no shifts in resonance peaks (Figure 4).
- No voltage chatter during discharge was observed during random vibration, demonstrating successful completion of the random vibration tests (Figure 4).

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Publications:

Brendan E. Hawkins, Harrison Asare, Brian Chen, Robert J. Messinger, William West, John-Paul Jones, "Elucidating Failure Mechanisms in Li-ion Batteries Operating at 100 °C," *J. Electrochem Soc., (accepted for publication)*.

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