National Aeronautics and Space Administration

High-Energy and High-Power Lithium-ion Battery Design using Additive Manufacturing

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Program: FY21 R&TD Innovative Spontaneous Concepts

Objectives:

- Design, fabricate, model, and test an additively manufactured (AM) Li-ion battery assembly that incorporates conformal oscillating heat pipes (OHP) directly into the primary battery case.
  - Incorporate high energy Li-ion cells in a compact case using flight-like 8s2p configuration for high energy module design.
- Demonstrate the AM-OHP Li-ion battery can operate at high power, where conventional battery designs cannot contend with heat generated from the battery.

Approach:

- The battery case was additively manufactured using a powder bed fusion system incorporating an AlSi10Mg alloy (Fig. 1).
  - Contained approximately 20 m of embedded OHP tubing.
  - Populated with LG Chem MJ1 18650 cells in a 8s2p arrangement.
- A thermal model of the OHP battery case was developed using SolidWorks and correlated to the thermal test data.
  - A model of a solid Al battery case was also developed for comparison.
- Battery module was operated at four discharge rates ranging from C/3 to 3C (Fig 2).

Results:

- Exceptionally high effective thermal conductivity of the OHP case was demonstrated: approximately 2000 W/m/K compared to 170 W/m/K for the empty case.
- Optimal fill ratio was quantified and fixed at 40% for all tests.
- OHP case maintains much lower temperature than either bare Al or an empty OHP case during thermal testing (Fig. 3).
  - Reduced temperature rise by 12 °C compared to the empty OHP battery case.
- OHP case affords for higher degree of isothermality across the battery (Fig 3). and reduced temperature rise by 12 °C compared to the empty OHP battery case (Fig. 4).
- At high discharge rate (cell manufacturer's limit of 20A), the OHP battery case maintains safe operational temperature over entire discharge.
  - In contrast, bare call without OHP case discharged at the same current reaches maximum allowable temperature and is shut down prematurely.
- Test results clearly demonstrate the ability of the OHP case to yield high power operation in a high energy configuration using flight-like 8s2p Li-ion cells.

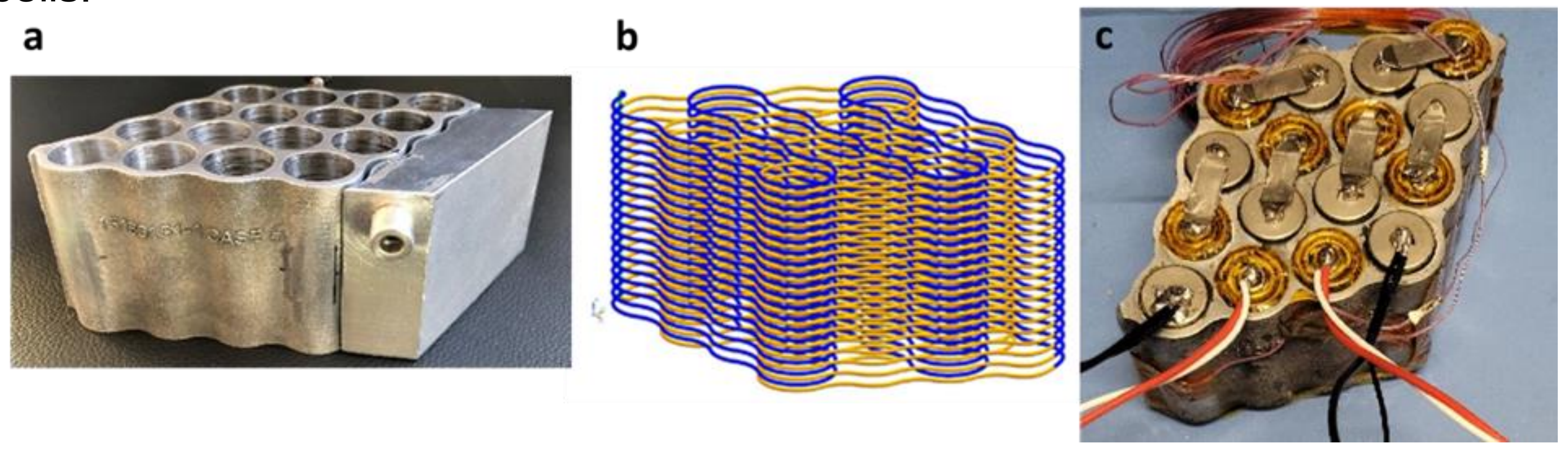

Figure 1. a) OHP battery case with cold block; b) Schematic of OHP heat pipes; c) OHP battery assembly populated with 18650 cells, connected into a flight-like 8s2p configuration..

Background:

- Key shortcoming of Li-ion batteries is their poor tolerance to any electrical, mechanical or thermal abuse or any internal shorting resulting from manufacturing defects or operational errors.
- Due to use of flammable organic liquid electrolytes, they are susceptible to serious safety issues, including thermal runaway.
- In battery packs, there are limitations in the maximum allowable current due to the inability of the battery cells to effectively dissipate heat.
- A simple, low-cost, low-mass solution to address heat dissipation issues would be highly beneficial to future spacecraft.

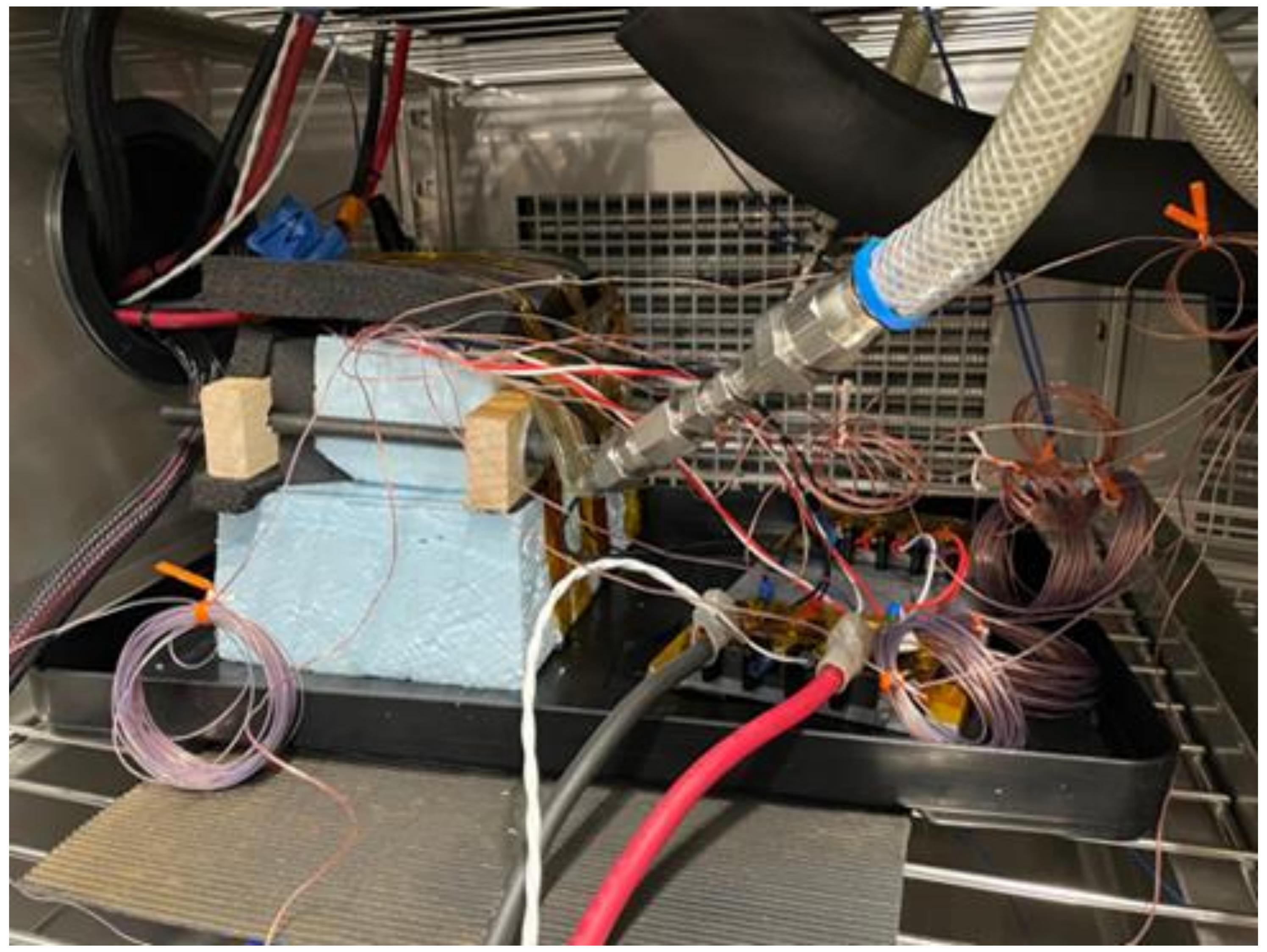

Figure 2. OHP 8s2p battery module test configuration. The battery module is surrounded by insulation and tested within an environmental test chamber. Electrical, thermocouple, and cold plate circulation interfaces shown.

Significance/Benefits to JPL and NASA:

- Results represent an important advancement in thermal management of high power spacecraft batteries which has several critical benefits relative to state-of-practice lithium ion batteries:
  - Allows for high charge/discharge rate to afford high power battery designs
  - Increases cell-to-cell isothermality to reduce cell-level impedance mismatch and concomitant premature cell failure
  - May also offer the means to mitigate significant risk associated with thermal runaway and thermal propagation events.

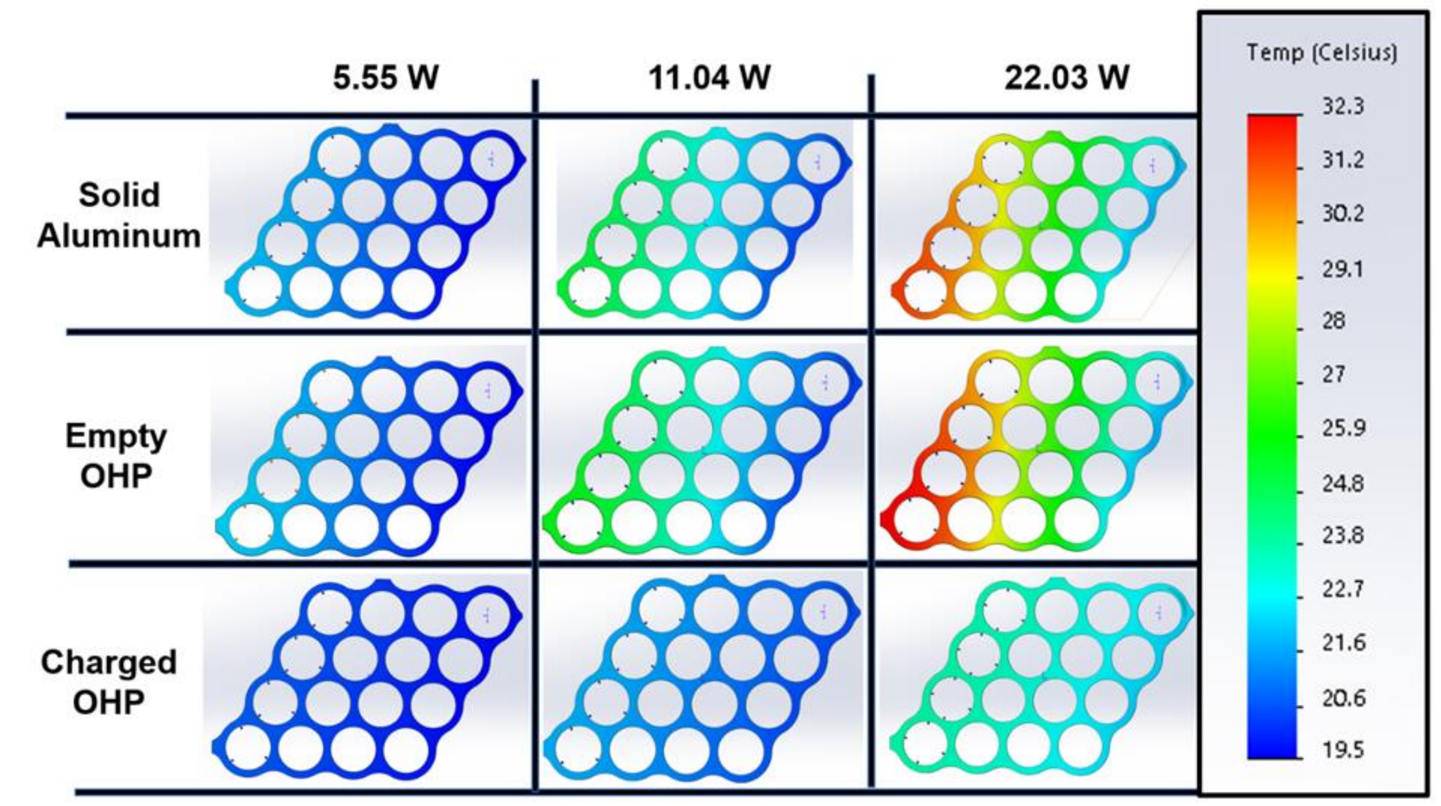

Figure 3. Illustration of the efficacy of the AM OHP battery case (bottom row) compared to a solid Al battery case (top row) and an OHP battery case with an empty OHP (middle row). The different columns correspond to different power levels. The color scale for all figures is identical (right). The OHP battery case is able to maintain lower temperatures and a higher degree of isothermality.

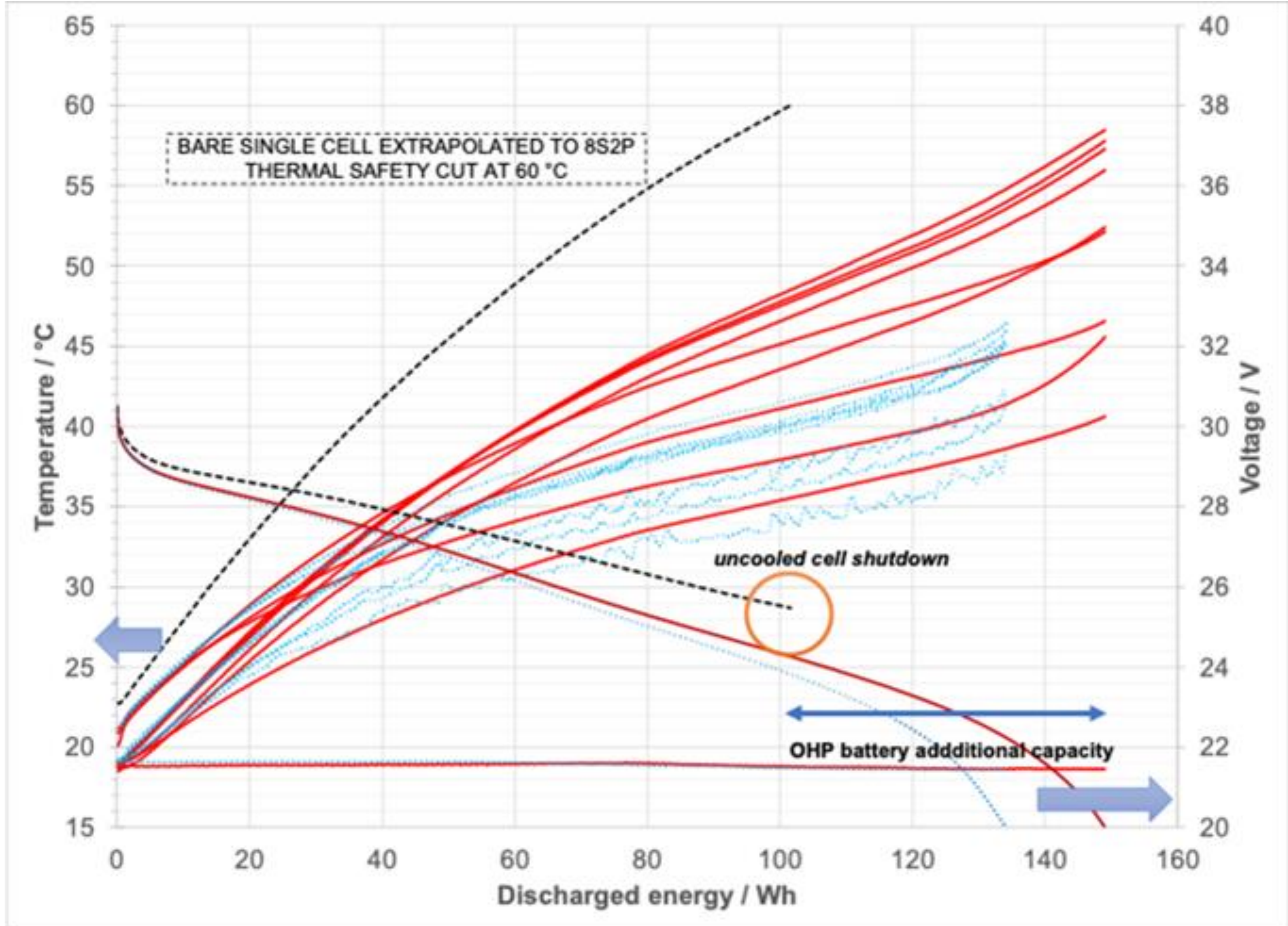

Figure 4. Discharge voltage curves and surface temperature measurements for 8s2p module at max allowable discharge rate 2.95C (20 A). Dotted lines: OHP charged with fluid. Solid lines: OHP empty. Dashed lines: bare single cell discharge extrapolated to 8s2p performance. The oval indicates shutdown of the uncooled single cell due to overheating, and the arrow indicates the additional capacity of the OHP battery module achieved relative to the overheated single cell after shutdown.

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