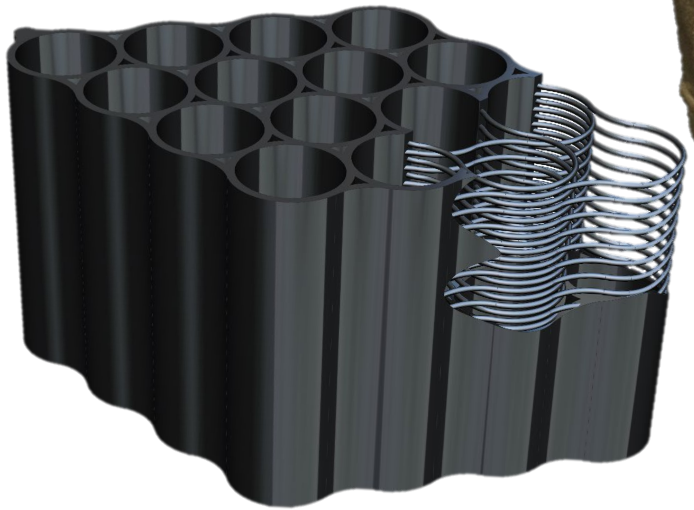

An Additively Manufactured Li-ion battery case with embedded Oscillating Heat Pipes. The cutaway image (left) shows the internal channels. The image on the right shows a test article.

Virtual Research Presentation Conference

An Additively Manufactured Li-ion Battery Case that Prevents Thermal Runaway

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Program: Topic

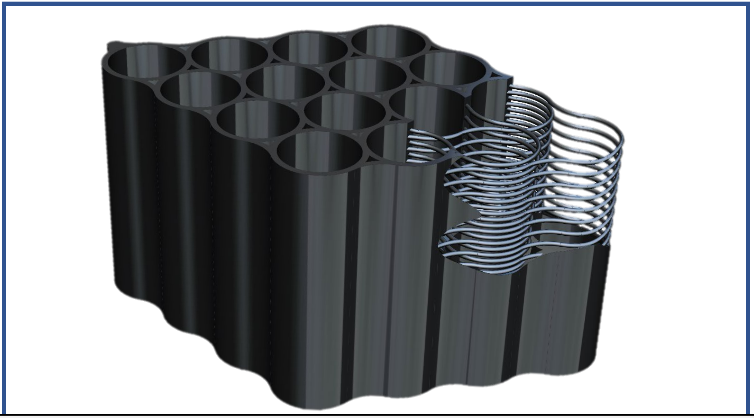
Jet Propulsion Laboratory
California Institute of Technology

Assigned Presentation #: RPC-174

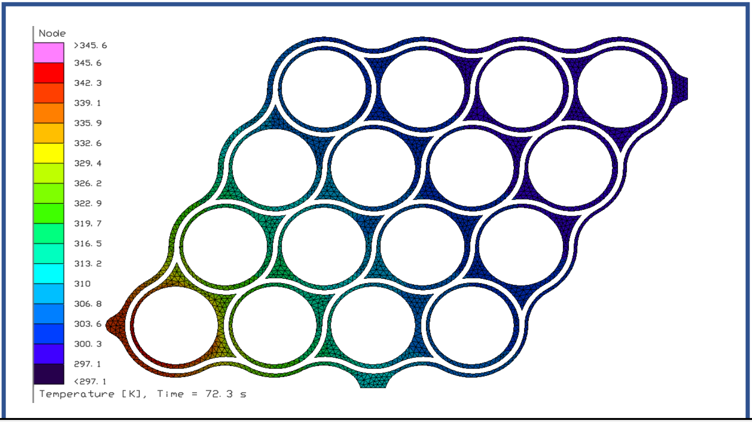
Tutorial Introduction

Abstract

A novel Li-ion battery case was developed that can prevent the propagation of thermal runaway while simultaneously enabling rapid charge and discharge rates required by high power applications. These goals were achieved in a mass efficient package that boasts 20% higher energy densities than current state of the practice Li-ion batteries. The high performance battery case utilizes Additive Manufacturing to embed 15 meters of conformal Oscillating Heat Pipes (OHP) into a monolithic aluminum battery case. OHPs are passive two-phase thermal control systems that are capable of transporting heat 100x more effectively than copper.



An Additively Manufactured Li-ion battery case with embedded Oscillating Heat Pipes. The partial cutaway shows the heat pipe path.



Simulation of thermal runaway in the corner cell of the AM OHP Case. The adjacent cells remain below 50 C during the peak heat release

Problem Description

Context (Why this problem and why now)

Li-ion Batteries (LIB) are the premier energy storage solution for spaceborne missions. The high energy density of the cells coupled with their stable cycling performance makes them attractive for a wide variety missions. However there are two outstanding issues with current LIB: (1) They are susceptible to catastrophic failure due to thermal runaway, and (2) they are typically limited to low power applications due to an inability to handle the heat loads generated by the cells.

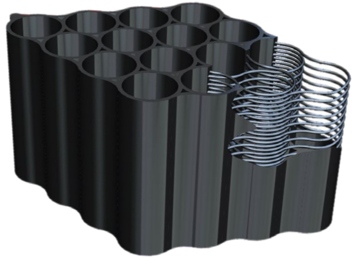
Comparison with current state-of-the-art LIBs

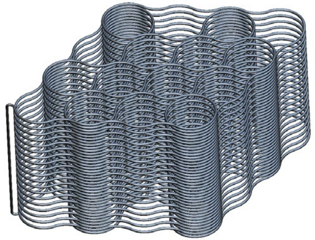
Current state of the art LIBs used at JPL are limited to low power operation (<0.5 C discharge rate) to minimize cell warm-up. In addition they are susceptible to the propagation of thermal runaway and have maximum energy densities of 120 to 160 Wh/kg, whith energy density at the cell level near 250 Wh/kg. In comparison, the AM LIB with embedded OHPs developed here is capable of high power operation (3C discharge rate), has the capability to prevent the propagation of thermal runaway, and achieves energy densities of 190 to 210 Wh/kg.

Relevance to NASA and JPL (Impact on current or future programs)

The AM battery case with embedded OHPs addresses two outstanding issues with current LIBs: high power operation and thermal runaway protection. This battery case has the potential to enable new classes of high power missions such as rotorcraft and brings another level of robustness and reliability to future Li-ion battery systems.

Methodology


The AM Battery Case with embedded OHPs (partial cutaway)


The OHP channel network within the AM Battery Case

Concept Overview

The AM Li-ion Battery Case with embedded Oscillating Heat Pipes simultaneously enables high power operation and prevents the propagation of thermal runaway. It achieves these capabilities through the integration of OHPs which result in the case having exceptional thermal transport capabilities. OHPs can transport orders of magnitude more heat than solid conductors for a given temperature differential.

Prevention of Thermal Runaway Propagation

In a thermal runaway event, a single cell undergoes a failure which results in a runaway exothermic reaction. Up to 50kJ of heat can be released over a period of minutes. In a typical battery case, this heat builds up around the failed cell, and heats up the neighboring cells which triggers a chain reaction of thermal runaway events. In the AM OHP Battery Case developed here, the heat evolved during a thermal runaway event is rapidly distributed throughout the entire case by the OHP network, and the local build up of heat is prevented. Instead the heat is absorbed uniformly across the entire LIB, which consequently undergoes a modest temperature rise.

High Power Operation

During high power operation, Li-ion cells release significant levels of heat (e.g 5 W at a 3 C-rate). In a typical LIB, the heat transport capability is insufficient to sustainably regulate the temperature of the cells during this type of operation; as a consequence the cells heat up to unacceptable levels. The AM OHP Battery Case can effectively remove heat from the operating cells at these levels and transport it to a heat sink using the embedded OHP channels.

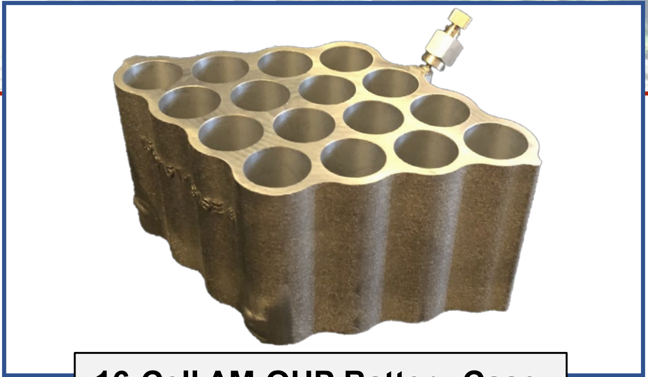
Results

In order to demonstrate the feasibility of this concept, an AM Battery Case with embedded Oscillating Heat Pipes (OHP) was designed, fabricated and tested. The unit was designed to accommodate 16 cells.

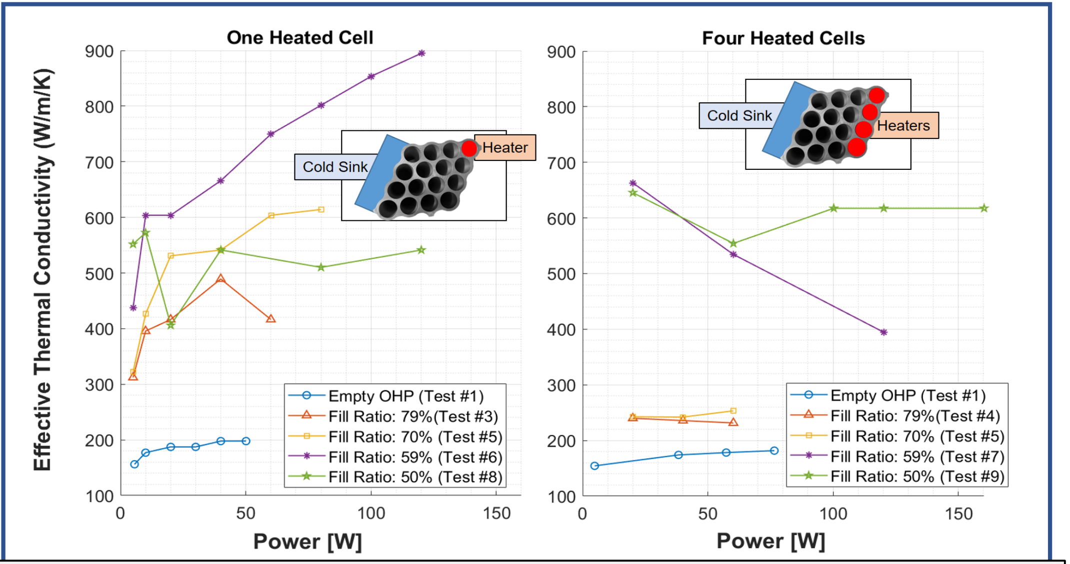
The thermal transport capability of the battery case was verified through a series of tests where the thermal conductance of the case was measured for two different heating configurations and four different OHP fill ratios.

<u>A maximum effective thermal conductivity of 900 W/m/K was measured</u>. This is over 2x larger than copper. With further optimization, the effective thermal conductivity of the case could be increased by an additional 10x.

Prevention of thermal runaway and the ability to accommodate high power operation was verified using simulation. Due to COVID restrictions, test-based demonstrations were not possible.



16-Cell AM OHP Battery Case



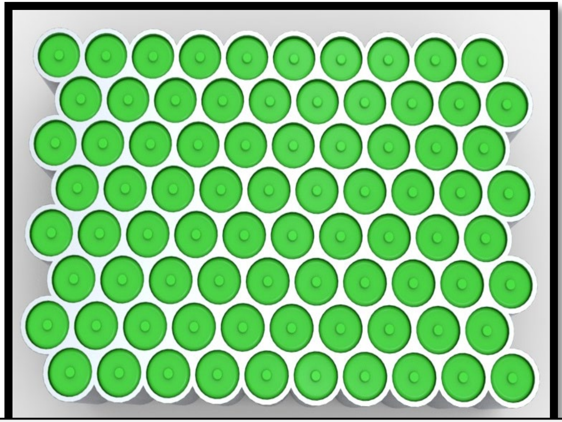
Thermal Conductance Data from the 16-Cell AM OHP Battery Case

Publications and References

1. Sunada, E.T., Roberts, S.N., Furst, B.I. and Bugga, R.V., California Institute of Technology, 2019. *Thermal Management Systems for Battery Cells and Methods of Their Manufacture*. U.S. Patent Application 16/447,824.

2. Furst, B., Bugga, R. and Roberts, S., 2020, July. *A Concept Demonstrator for an Additively Manufactured Li-ion Battery Case with Embedded Heat Pipes*. 49th International Conference on Environmental Systems.

Concept for Light-Weight AM OHP Battery Case



Concept for 80-Cell AM OHP Battery Case