Hybrid electric propulsion: the future of clean flight?

Optimizing aircraft battery performance using thermal management

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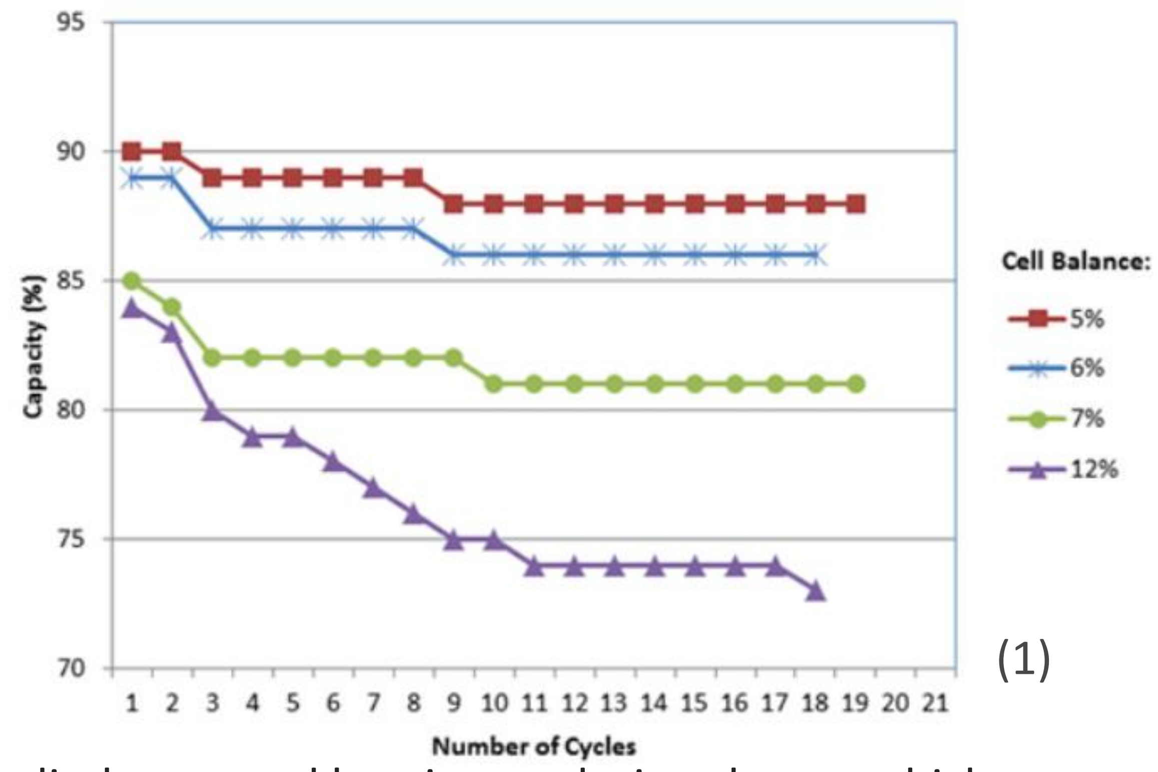
Abstract

Thermal management is one of the most important performance and safety concerns related to electric and hybrid electric aviation. High temperatures reduce internal resistance (increase power output and efficiency), but also speed up cell degradation and pose a risk of thermal runaway. Low temperatures reduce self discharge, and the formation of a solid electrolyte interface, but increase internal resistance and can cause lithium plating while charging. In an aircraft, where the power demand on a battery can vary significantly during a flight, it is important to keep a close control on temperature to ensure peak efficiency and performance while also maximizing longevity of the batteries.

Matching algorithms



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Within a battery pack, it is common that cells are connected in parallel to increase capacity. It is important that the capacity of each group is close to every other group as an imbalance can cause several dangerous affects. This includes the weaker cell being pushed into reverse polarity during discharge, and heating up during charge, which causes accelerated aging and reduces the lifetime of the pack, as demonstrated in the above graph. It is also important that cells matched in parallel have similar resistances, to avoid uneven current distribution which can contribute to unbalanced aging and unwanted temperature differences between cells. To this end, I designed an optimization algorithm that takes in a set of cells and a number of desired pairs and outputs a series of matched pairs based on keeping capacity difference below a limit and on minimizing resistance.

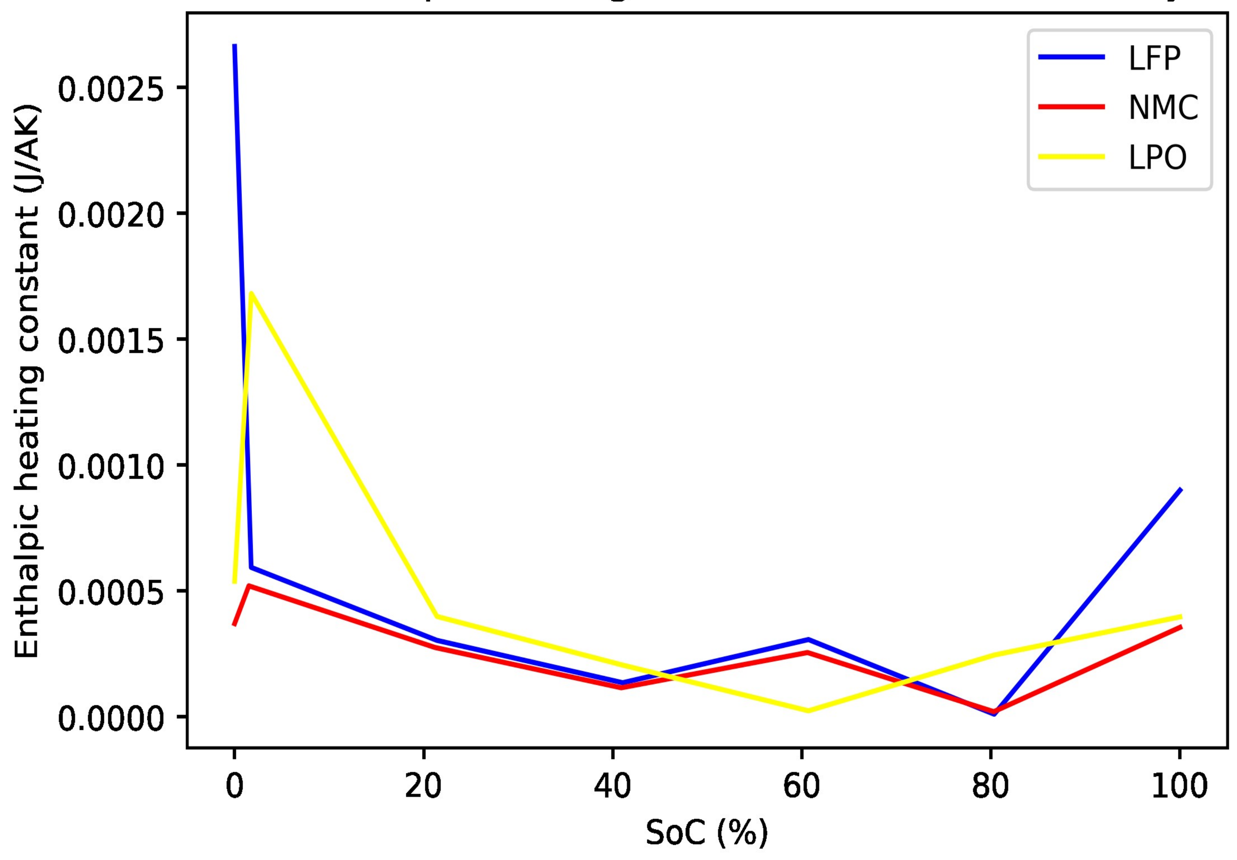
Experiment into enthalpy

Cell temperature rises during operation due to both resistive heating and the enthalpy of the reaction occurring within the cell. To analyze the heating caused by enthalpy, I conducted cycling experiments on cells of 3 different chemistries to assess the differences in enthalpic heating for each of them.

The enthalpic heating is given by this equation: $\frac{q_{ent}}{I*T} = \frac{dU_{OC}}{dT}$ (2).

The results below demonstrate how the enthalpic heating (normalized by the current and temperature) varies with state of charge, identifying the states that would lead to the most enthalpic heating during operation for each battery chemistry.

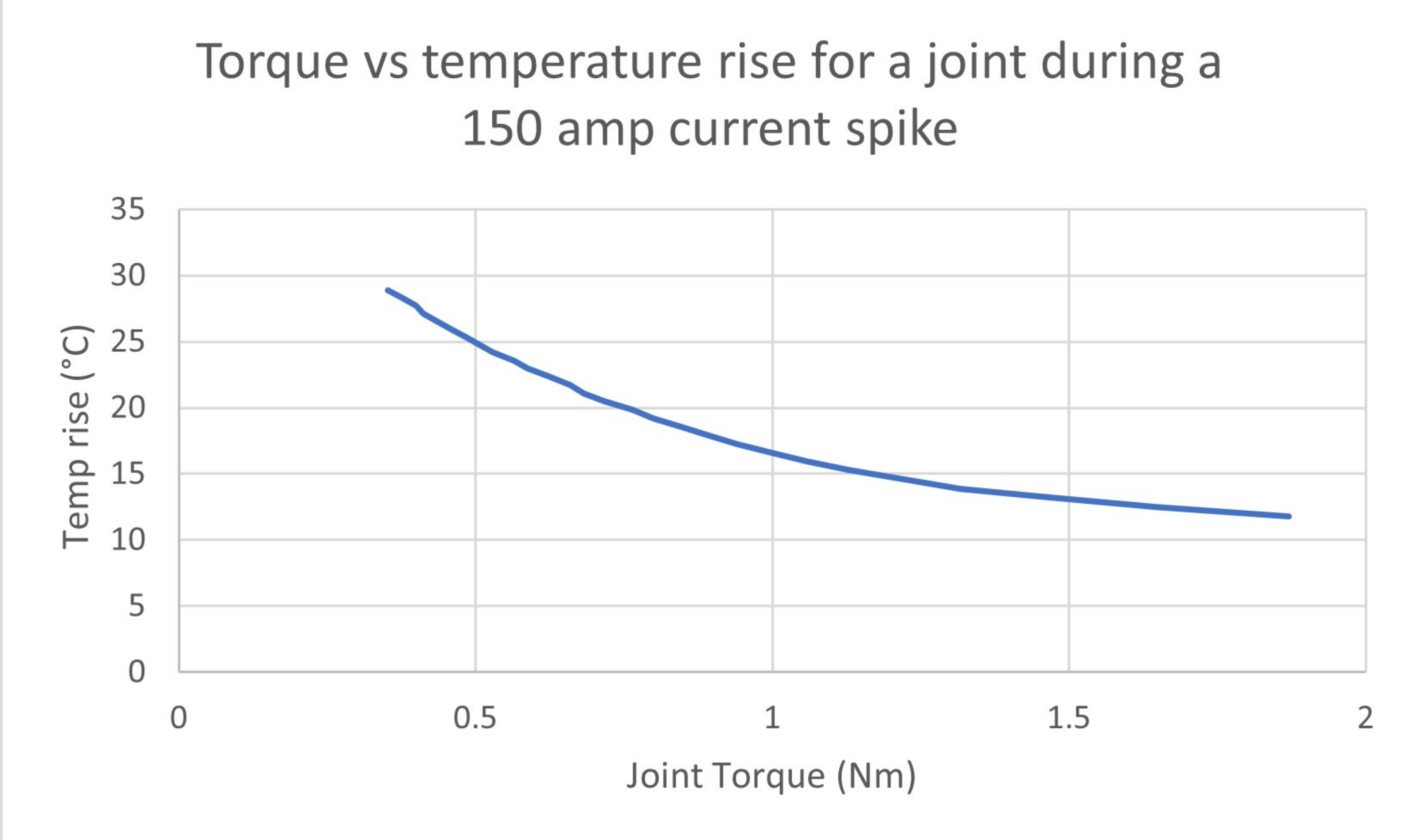
The variation of enthalpic heating with SoC for different battery chemistries



At higher currents, such as the ones batteries experience during the landing and takeoff of an aircraft, resistive heating dominates but knowledge of the heating caused by enthalpy is still useful in devising temperature management systems for a battery pack being used in an aircraft.

Localized heating

There are many potential localized heat spots in a battery pack. These are a source of danger due to the risk of any components within a pack being damaged by the heat, as well as the risk of thermal runaway. They are also a detriment to performance, as overheating a cell can damage and age cells. If some cells are hotter than others, the increase in aging will also cause mismatches in the battery pack to develop which also affects performance. To prevent this, I analyzed several potential hot spots within the pack. Current capacity analysis was done on components to assess the dimensions/material that is needed for the part to avoid large temperature increases. Joints were also analyzed by relating surface pressure to contact resistance, to calculate the nut sizes and torques needed for each joint to avoid contact resistances that would produce an unacceptable temperature rise.



Impact / Next steps

- All analysis will be considered during the building and testing of battery packs
- Battery technology will be combined with Qdot's heat exchangers and hybrid technology
- Aim is to produce an aircraft with high ranges and load carrying capability that is powered using cleaner energy sources.

References

(1): https://batteryuniversity.com/article/bu-803a-cell-matching-and-balancing

(2): DREMUS: A Data-Restricted Multi-Physics Simulation Model for Lithium-Ion Battery Storage Martin Rogall , Anup Barai , Maria Brucoli, Patrick Luk, Rohit Bhagat, David Greenwood. Journal of Energy Storage Volume 32, December 2020

Intern bio

Daniel Holmes is a fourth year undergraduate studying Engineering Science at the University of Oxford, specialized into chemical engineering. He hopes to enter the energy sector when he graduates and looks forward to being involved in the immense amounts of research and development going on, especially in the fields of renewable energy. Outside of studying, he is a keen sports player and is helping to run his college rowing club as vice captain

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