Comparative Testing of Commercially Available and Novel Lithium Cell Technologies for Unmanned Aircraft Systems Applications

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Abstract

Unmanned Aircraft Systems (UAS) encompass a variety of air vehicles with different sizes, shapes, propulsion systems, launch methods, and power systems depending on the application. Certain UAS require batteries that can provide both high power for launch and high energy for endurance. In this work, commercially available rechargeable lithium ion cells used in air vehicles were evaluated for electrochemical performance and compared to novel rechargeable lithium ion technologies to assess the state of commercial technology and provide recommendations for improved power and energy capabilities for UAS.

Commercial-off-the-shelf (COTS) cylindrical 18650 cells and pouch cells from two vendors were obtained and were evaluated according to respective specification sheets. Novel lithium ion technologies from three vendors were also evaluated for comparison. Additional testing of high discharge currents and low operating temperatures was performed to push the technologies to their boundaries for assessment of applicability in consideration of more extreme military conditions. Most cells were able to meet power requirements of current UAS, however, the novel technologies were able to provide more well-rounded performance: one vendor's cells provided increased energy density in addition to high power capability whereas another vendor's cells provided improved performance at low temperature in addition to high power capability. A third vendor was able to demonstrate increased flight time. Anonymized comparative data plots will be presented.

This work establishes a baseline of performance evaluation of commercially available lithium ion cells for UAS applications and assesses the performance advantages offered by more novel cell technologies. For all applications, cell electrochemical performance advantages and non-technical considerations, such as cost, must be balanced between COTS and novel developmental cells.

Keywords

Unmanned aircraft systems; UAS; lithium ion; batteries.

Introduction

Development of high power density and high energy density lithium ion cells have enabled UAS with increased range, electronic loads, and weight. As UAS technology advances, the power loads required from the propulsion and electronic units increases, requiring batteries with improved capabilities. High power density is required for the elevated power load that occurs during takeoff, landing, and electronic pulses, and high energy density is required for extended range and loitering capabilities. Additionally, cold temperature resilience is a key characteristic of these batteries because of altitude at which UAS can operate. Therefore, focus on chemistry design that maintains high energy density capability at low temperatures is paramount for effectiveness. Safety can be addressed through battery management systems and cell architecture. These priorities are essential to UAS development and to increasing overall UAS capabilities.

Results

Cylindrical Cell Comparison: Commercially available cylindrical 18650 rechargeable lithium ion cells from Vendor 1 were evaluated for comparison against novel cylindrical 18650 rechargeable lithium ion cells from Vendor 2. Vendor 1 cells are known for use in commercial drone applications. Technology from Vendor 2 contained anode with >25% silicon and advanced electrolyte materials to improve accessible voltage range, energy density, as well as safety.

Vendor 1 cells were tested in accordance with manufacturer's specifications. The cells displayed relatively high rate capabilities, achieving approximately 65% nominal capacity at approximately 6.5C rate, though this capacity retention was lower than reported by the manufacturer. As depicted in manufacturer's specifications, the cell skin temperature at these high rates did increase to above 80°C.

Vendor 2 cells yielded energy densities almost 50% higher than Vendor 1 cells at low (<C/5) discharge rates, but comparable at 1C discharge rates. Vendor 1 cells demonstrated better rate capabilities, see Figure 1.

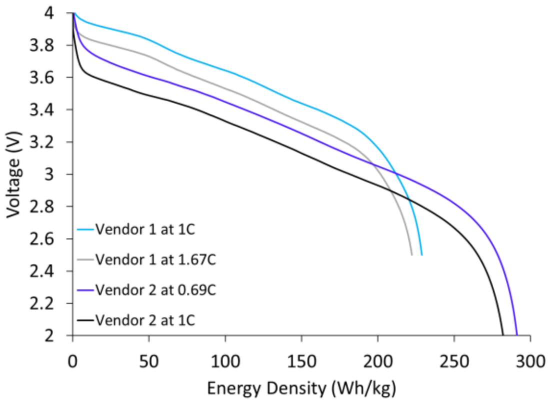

Figure 1. Vendor 1 cells demonstrated better rate capability but Vendor 2 cells achieved higher energy densities.

Temperature testing of Vendor 2 cells revealed greater than 80% capacity retention at -20°C and greater than 60% capacity retention at -40°C, whereas Vendor 1 cells were only rated for discharge down to -20°C, see Figure 2.

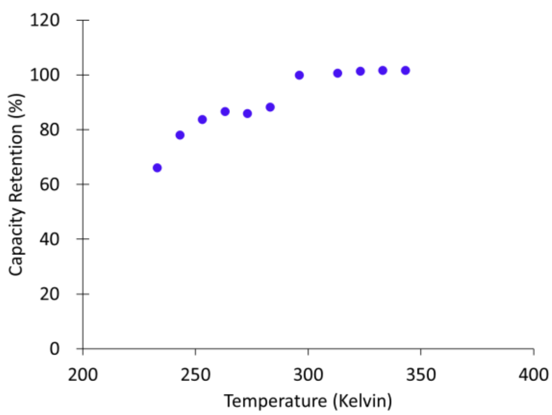

Figure 2. Vendor 2 cells retained surprising capacity retention across wide temperature ranges. Capacity retention in percent relative to nominal capacity.

Vendor 2 cells were only tested to 50 cycles due to the low manufacturing readiness level of the Vendor 2 cells compared to commercially available Vendor 1 cells.

Pouch Cell Comparison: Commercially available rechargeable lithium ion pouch cells from Vendor 3, known for use in commercial drone applications, were tested and evaluated to verify manufacturer's listed specifications. Pouch cells of similar capacity containing advanced lithium metal anode and enabling electrolyte formulations from Vendor 4 were evaluated for high power and high energy capabilities. Commercially available lithium polymer (LiPo) pouch cells of similar capacity were also tested to provide comparison.

Vendor 3 cells were able to achieve relatively high discharge current rates (tested up to 20C) with no impact on capacity, see Figure 3.

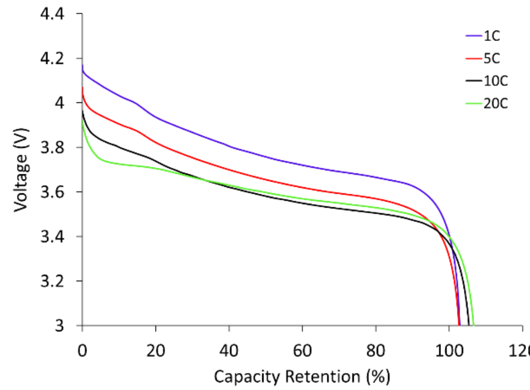

Figure 3. Rate capability of Vendor 3 cells at 1C, 5C, 10C, 20C rate. Capacity retention in percent relative to nominal capacity.

As shown in the Ragone plot in Figure 4, though Vendor 4 cells were marketed as a high power variant, Vendor 3 cells had better power capabilities. Vendor 4 cells, with advanced anode material, displayed improved energy densities compared to Vendor 3 and Vendor 5 cells.

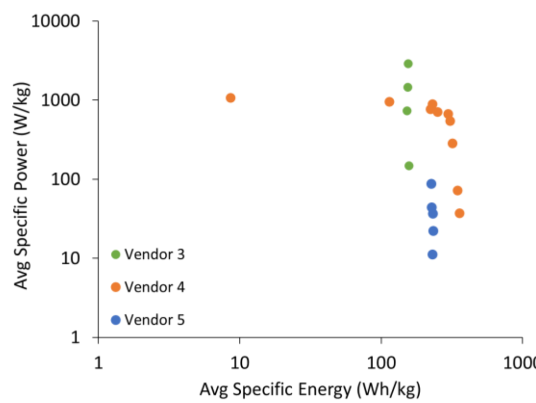

Figure 4. Ragone plot of pouch cells of similar capacity. Plot of Vendor 3 cell data is not complete due to limitations in testing capabilities at the time of testing. Plot of Vendor 5 cell data is not complete due to resource limitations. However, the tradeoff and comparison of energy and power densities are evident.

Additional Pouch Cell Testing: An alternative Vendor 6 was selected to improve the performance of an existing carried UAS system. Cells were manufactured according to the volume and weight requirements using advanced anode technology in order to increase capacity. Cells were subjected to testing across a wide temperature range to ensure suitability.

As seen in Figure 5, Vendor 6 cell discharge curves demonstrated cold temperature limitations due to cutoff voltage. A wider voltage range would have accommodated the cold temperature voltage drop with more capacity remaining within the cells at cutoff. Importantly, the capacity of cells at room temperature was twice as high as the incumbent cell (data not shown) in the same volume making the extreme temperature limitations less impactful given the extension under normal conditions.

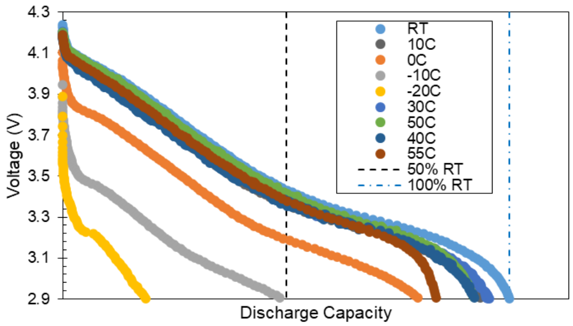

Figure 5. Performance of Vendor 6 cells over a wide temperature range. X axis shows discharge capacity retention relative to nominal capacity.

Conclusions

Commercial off the shelf (COTS) rechargeable lithium ion cells used in air vehicles were evaluated for electrochemical performance and compared to novel rechargeable lithium ion technologies.

Novel lithium cells touted for high power UAS applications provided expanded energy densities, and in some cases, temperature capabilities compared to COTS solutions. However, these novel chemistries still require improvements in power density and rate capability to offer an energy-power combination technology alternative for UAS.

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