# Battery energy storage technology for aviation - An overview

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Abstract: The article presents progress in last years of aviation rechargeable Li-ion batteries. Improvements in recent years have led to increase in energy and power density. Remaining challenges and future research directions are summarized. Emphasis is placed on the safety of aviation Li-ion batteries.

Keywords: *aviation, rechargeable batteries, Lithium-ion batteries*

## 1. Introduction

Rechargeable batteries are devices in which electricity is converted into chemicals and vice versa, which distinguishes them from other batteries. Initially, under the action of an external source of direct current, charging reactions are performed, chemical energy accumulates. This is the reaction of charging the battery. In the second stage, of the operation of the battery, the chemical energy is converted into electricity.

Rechargeable batteries are widely used in aircrafts as emergency and auxiliary sources of electricity, representing several series connected and installed in a common battery housing. On-board rechargeable batteries are designed for:

- power supply of electric starters and other equipment for autonomous starting of aircraft engines;
- supply of vital consumers in case of failure of the electrical generators during the flight;
- covering the peak loads when switching on powerful consumers;
- inspection of the operation of low-power equipment on the ground in the absence of airport sources of electricity.

There is a focus right now of converting everything that we use to run on electricity. Currently, new developments of future aircraft focus on the electric and electric – hybrid aircraft, while features, as the specific energy and thermal instability of the available rechargeable battery technology cause serious problems [1], [2], [3]. Li-ion batteries could offer higher energy density, which have gained enormous attention to researchers [4]. Therefore, it will be made research on the recent advances of the of Li-ion batteries. Sodium-ion batteries are considered as the best candidate power sources in transportation because sodium is widely available (the fourth most abundant element on earth) and exhibits similar chemistry to that of lithium-ion batteries, but their specific energy density is lower than Li-ion batteries [5]. In comparison with terrestrial rechargeable batteries, safe and high specific energy rather than cost is the major constraint for aviation. Other rechargeable batteries as lead-acid and nickel-cadmium batteries are currently being replacing in aviation by lithium-ion technology, because it can offer greater capacity for less weight. It should be made clear difference between power density – W/kg, and energy density – Wh/kg. The storage devices with the highest power density are the supercapacitors while with the highest energy density – lithium-ion batteries.

## 2. Improving Lithium Batteries

Lithium-ion batteries are nowadays technology with application in many fields. The significant improvement of the lithium-ion battery technology was made when lithium metal as an anode active material was changed by carbonaceous compounds, mostly graphite. According to the electrolyte lithium-ion batteries are divided into three groups: with liquid electrolytes [6],[7]; with polymer electrolytes[8], [9], and with solid-state inorganic electrolytes [10], [11], [12].

Nowadays, the most widely used lithium-ion batteries in aviation are lithium-polymer. They are so called because the electrolyte is a thin polymer film. Possibility to replace liquid organic electrolyte to polymer, which should reduce the likelihood of its leaks and increase the safety of the lithium-ion battery, has been studied since the beginning of the commercialization of these current sources. The idea of a lithium polymer battery (Li-pol) is based on the phenomenon of the transition of some polymers into semiconductor state as a result of the introduction of electrolyte ions into them. In this case, the conductivity of polymers increases by more than an order of magnitude. The efforts of researchers have been directed to the search for polymer electrolytes for both lithium-ion batteries and batteries with metallic lithium, the theoretically possible energy density of which is several times higher than that of lithium-ion batteries. Its electric voltage is 3,6 V. Lithium-polymer aviation batteries consist of eight cells located in a common metal housing, giving 28,8 V in total with energy density 260 Wh/kg. Generally, lithium-ion aircraft batteries applications have an underestimated full charge voltage at cell compared to household batteries, respectively lower electrical capacitance, but due to this – more service life.

New concept with using Si nanoparticles with carbon nanotubes was developed in Taiwan for Li-ion batteries [13]. This solved the long-standing rate capability problem of ionic liquid electrolyte. Tests show that this battery retains its capacity after a cycle of 300 charge-discharge [13].

Solid-state Li-ion batteries are thought to be potential next-generation energy storage devices for future aircrafts. In all solid-state Li-ion batteries electrolytes is solid. This is novel concept replacing electrolyte with solid instead of liquid or polymer to obtain higher energy density and to reduce the risk of fire. New research shows that can be achieved voltage 5 V for single cell battery with charge-discharge current density (0.5C = 200 $mA/cm^2$ ) [14]. Using cells with volgate 5 V instead of 3,6 V will reduce its number in aviation rechargable batteries from 8 to 6, and thus reducing the imbalance between individual cells. The biggest problem with solid-state Li-ion batteries is production itself. At current state of art its production cost is much higher than Li-ion batteries with liquid and polymer electrolytes.

In Japan, researchers reported that with $K_2NiF_4$-type Ba-Li oxyhydride solid electrolyte, hydride ions ($H^-$) can be used in solid-state Li-ion batteries as charge carrier that facilitates fast ionic conduction in solids [15]. The significance of this discovery is that it thus increases the conductivity through the solid electrolyte. Another breakthrough from this year (2022) [16] was published by Chinese scientists who achieved to increasing 10 times the diffusion coefficient of Li ions of Li metal anode. They used metallic lithium replacing the graphite anode to increase the energy density of the rechargeable battery. But what is significant in their study is the use of lithium hydride (LiH) nanoparticles which achieved two goals: prevent growth of dendritic lithium and increase the mobility of lithium ions.

Another solution for preventing lithium dendrites was proposed by international team of scientist in March 2022 [17]. The idea is to use hierarchical porous structure on anode made by Cu, P, Co and C which significantly localizes lithium dendrite growth.

The reason why scientists and engineers around the world are actively working to mitigation the lithium dendrite growth is that when it reaches the cathode a short circuit occurs in the battery and an explosion occurs. It is needless to say why explosions are unacceptable in aviation. What distinguishes the two studies above from the others is that the efforts so far have been aimed at creating a barrier between the two cathodes, while the new methods are based on preventing the formation of lithium dendrites.

To date (March 2022) rechargeable batteries known to science with highest energy density are Li-$O_2$ batteries, due to the highest energy density (11,700 Wh/kg based on Li-metal mass) in theory compared with any other rechargeable batteries [18]. The biggest problems for Li-air batteries are $H_2O$ and $CO_2$ that exist in ambient air, which can not only form byproducts with discharge products ($Li_2O_2$), but also react with the electrolyte and the Li anode [19]. Theoretically, the model of Li-air batteries with liquid electrolyte has been developed in 1976 by E. L. Littauer and K. C. Tsai of the Lockheed Missiles & Space Company (USA), and in 1996 K. M. Abraham and Z. Jiang created a lithium-oxygen battery with solid electrolyte. The lithium-oxygen rechargeable battery (Li-$O_2$) consists of a lithium anode, an electrolyte, a separator and an oxygen cathode. In theory, this type of rechargeable battery has energy comparable to the energy of organic fuels used in aviation.

Another technology currently being actively developed is using silicon for anode [20]. In [21] is provided a general overview of recent progress and the current problems and prospects, and is summarized the future research of silicon anode lithium batteries.

An important aspect of aviation batteries is the correct measurement of the charge level. Using Thevenin model and Kalman filter new method for charge estimation of lithium batteries was developed in China, published in December 2021, with error in less than 0,8 % [22]. Till now it is one of the most accurate methods for charge estimation of lithium batteries found in scientific literature.

**3. A safety of a Li-ion battery**

When considering and analyzing of a given technology and its application and development in aviation, one of the main aspects is its level of safety. The external short circuit, overcharge and overheat are the main events that can lead to the destruction of Li-ion batteries and in the worst cases to explosion. One of the significant factors concerning safety of Li-ion batteries is cell imbalance which varies each cell voltage in the battery pack overtime. To solve that problem in the battery pack the battery cells should be leveled to keeps up the difference in charged levels of the cells in the battery as small as possible. There are different techniques of cell balancing classified in two groups: passive and active cell balancing methods [23], [24]. Passive cell balancing method equalizes the charge level of individual cells by dissipation of energy from the most charged, while active cell balancing method transfers energy from higher charged cells to lower charged ones [25]. Battery cell balancing not only increases the safety level of the Li-ion battery but also extends its service life.

Another important topic concerning safety of Li-ion batteries is thermal management. To improve the safety and reliability of Li-ion aviation batteries is of great importance correct prediction of temperature fields inside cells. A very dangerous condition occurs when a self-induced temperature rise occurs, called thermal runaway, which results in battery explosion [26], [27], [28]. Several fires had occurred in commercial aircrafts due to thermal runaway of lithium-ion batteries [29]. The prevention of thermal runaway in lithium-ion aviation batteries is vital as in FMEA analysis it is one of the factors for high value of RPN (risk priority number). Methods for battery thermal management are air cooling, liquid cooling, heat pipe cooling and phase change cooling and in case of lower temperature battery warming. Passive systems for heat removal using phase change process are better options compared to forced air and liquid cooling methods. The uses of passive cooling systems eliminate the costs associated with the installation, maintenance and operation of active cooling systems that require fans and pumps with electric power supplies. When using passive cooling of lithium-ion batteries there are no external power sources or forces, no moving mechanical parts, and no moving working fluid. Another motivation for the use of passive cooling systems for aviation lithium-ion batteries is the potential for enhanced safety through increased safety system reliability – safety is vital for aviation.

Air-cooling system is simple with low cost. In case for aviation what differs from convention lithium-ion batteries is that pressure decrease with increase of the altitude of the aircraft. A novel air-cooling structure design has been proposed by Chinese scientist with profiling the mass flow through the cells [30]. Unfortunately till now for current air-cooling system, the cooling efficiency is still not enough for the large aviation batteries due to lower pressure in higher altitude [30].

The liquid cooling is more efficient cooling method compared with air cooling, but the liquid cooling system is more sophisticated than air-cooling and there is risk of occurring loss of coolant accident due to leakage of liquid working fluid and last but not least with more weight. Researches in this field are focused on finding the most efficient working fluid. Italian scientists [31] made experiments for investigating the cooling capabilities of different cooling fluids. The experimental results show that the perfluorinated polyether fluid has the best performance [31].

Cooling with phase change materials shows in last years to be very efficient for lithium-ion battery thermal management. Phase change cooling systems are two types: solid-liquid phase change [32] and gas-liquid phase change [33]. Solid-liquid phase change materials are used in passive cooling systems, and the gas-liquid phase change materials are used in active cooling systems. Phase-change cooling involves the use of the heat of vaporization of the coolant or heat of transition from solid to liquid (and vice versa). A team of scientists from Hefei Energy Research Institute, China proposed in 2019 a flexible form stable composite phase change material for battery cooling [34]. Experiments have shown 20ºC lower battery temperatures using novel flexible form stable composite phase change materials. Another breakthrough was made in 2020 by scientists from Chinese Academy of Sciences using innovative phase change material consisting of paraffin, expanded graphite and epoxy resin [35].

## 4. Conclusions

In the last years, aviation batteries have developed significantly, but the new designs still are not widely used in commercial manned aviation. In unmanned aerial vehicles lithium-ion batteries are the most used technology. Supercapacitors, although not very large in capacity, can provide a high power density. Thus the supercapacitor and the rechargeable battery can operate in tandem. In the long run, lithium-oxygen (Li-O2) batteries are likely to be used. They are currently in the final stages of laboratory research. The main areas of research for lithium-ion rechargeable aviation batteries are reducing the mass and dimensions, increasing the service life, reducing the charging time, greater safety in their operation.

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