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Li ion batteries for aerospace applications

R.A. Marsh[a,*], S. Vukson[a], S. Surampudi[b], B.V. Ratnakumar[b], M.C. Smart[b], M. Manzo[c], P.J. Dalton[c]

[a]*US Air Force Research Laboratory, PR PB, 1950 5th Street, Building 18, Wright Patterson AFB, OH, USA*
[b]*Jet Propulsion Laboratory, California Institute of Technology, Pasadena, CA 91109, USA*
[c]*NASA Glen Research Center, Cleveland, OH, USA*

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Abstract

Rechargeable Li ion batteries are perceived as likely substitutes for conventional nickel systems in an effort to minimize the mass and volume of the power subsystems in aerospace applications. The on-going consortium of NASA and DoD, after 2 years of existence, has propelled the advancement of aerospace Li ion technology in the US. Prototype cells of different sizes have been built by domestic manufacturers and are being evaluated both by NASA and Air Force. The early versions of these prototypes catered to needs of imminent NASA missions, i.e. Mars landers and rovers. Developmental efforts are underway to further improve the technology to meet the demands of long calendar life, as in the geosynchronous earth orbit (GEO) and the outer planets missions, and long cycle life as in the low earth orbit (LEO) missions. In this paper, we will briefly describe the objective and progress of this joint effort. © 2001 Published by Elsevier Science B.V.

Keywords: Geosynchronous earth orbit; Li ion batteries; Low earth orbit

1. NASA–Air Force missions

Rechargeable Li ion batteries offer significant advantages over the state of art nickel systems for future space missions, including reduced weight and volume of the energy storage system, improved reliability and lower power system life cycle costs. Both NASA and Air Force have begun to realize the benefits of these systems in their aerospace applications. Specifically, NASA plans to utilize Li ion batteries in several future applications as planetary landers, planetary rovers, planetary orbiters, earth orbiting spacecraft (geosynchronous earth orbit (GEO) and low earth orbit (LEO)) and astronaut equipment. Some of NASA's upcoming missions, where Li ion batteries are the baseline, include Mars exploration missions, such as the 2003 Mars lander and the Mars 2003 rover, Mars microsats, Mars sats, Mars scouts, and outer planets missions, such as Europa orbiter and solar probe. Also, plans are underway to replace the existing hydraulic auxiliary propulsion unit (APU) of the shuttle with an electrically controlled system using 100–150 kWh Li ion batteries. In addition, there are several miscellaneous NASA applications that would benefit from the use of Li ion batteries, including cameras, astronaut equipment and satellite tools. Likewise, the Air Force has several applications that require light-weight and compact batteries, including unmanned aerial vehicles, military aircraft and earth orbiting spacecraft (GEO and LEO).

The battery requirements of the various missions described differ markedly from one another and may be categorized into three groups. The performance drivers as well as the cell sizes (capacities) differ considerably as listed in Table 1. The first group consists of planetary landers and rovers (especially relevant to Mars exploration), which require Li ion batteries (of 16–28 V and 6–35 Ah) that have the ability to function well over wide temperature range (-20 to $+40$°C). The second category consists of outer planets and solar probe (OP-SP) missions and GEO spacecraft, both of which require extended operating or calendar life of 10–15 years. The third group is composed of LEO spacecraft and planetary orbiters, which require very long cycle life (30,000–50,000 cycles), although at partial depths of discharge of 30–40%. Some aircraft applications require rather high voltage (28–300 V), and high capacity (30–100 Ah) batteries that can operate over a wider operating temperature range, i.e. from -40 to $+60$°C. Further, many of these batteries need to meet stringent environmental requirements such as vibration, shock, and high impact, specific to the application. Since commercial Li ion cells are

* Corresponding author.

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inadequate in many of the above requirements, the NASA–DoD joint effort is focused on making the desired improvements both in the battery performance characteristics and size. Another aspect of emphasis in this program is the safety of the large capacity cells/and batteries.

2. NASA–DoD consortium on Li ion batteries

Realizing the commonality of their requirements for Li ion batteries and the impact the technology would have on the overall mission performance, both NASA and DoD formed a consortium in 1998. The specific objectives of this program are to (1) develop high specific energy and long cycle life Li ion cells and batteries with good low temperature performance; (2) establish production sources and (3) demonstrate technology readiness for rovers and landers by 2000, GEO missions by 2001, aviation/UAVs by 2001, military terrestrial applications by 2001, and LEO missions by 2003. The technical approach involves: (a) development of advanced electrode materials and electrolytes to achieve improved low temperature performance and cycle life; (b) optimization of cell design to achieve high specific energy; (c) development of cells (6–100 Ah) and batteries (16–300 V) of various sizes required for various future missions and (d) the development of control electronics for smart battery management. The projected technology demonstration milestones have been scheduled in the order of increasing difficulty, i.e. low temperature cells by 2000, cell scale up to 50–100 Ah by 2002, long calendar life of over 10 years by 2003 and long cycle life of over 30,000 cycles by 2004.

Fig. 1. Prototypes of Li ion cells fabricated under NASA–DoD consortium.

3. Program status and technological developments

Four North American battery manufacturers, i.e. Yardney Technical Products, Eagle Picher Industries, Bluestar Battery Systems, and SAFT America Inc., were contracted for the development of prototypes for future NASA–Air Force missions. Among them, Bluestar and SAFT were involved in the development of lander and rover cells, Eagle Picher for the LEO, GEO and aircraft cells and Yardney for almost all the cells as well as for charge electronics. Accordingly, Yardney has developed prismatic cells of 5–7 and 25 Ah cells for rover and lander applications, respectively. The lander prototypes and their impressive performance led to their subsequent contract from Lockhead Martin Astronautics (LMA) for the Mars 2001 lander battery. Bluestar had developed cylindrical cells of 7 Ah for rover and 25 Ah for lander applications. SAFT America had developed rover prototypes of 4 and 9 Ah (D and DD size) in cylindrical form, whereas Eagle Picher's efforts focused on 20 and 50–100 Ah prismatic cells (Fig. 1).

In terms of technological advancement in this program, the development of Li ion cells for lander and rover applications is nearing completion. Prototype cells have shown excellent performance characteristics, that include: (1) a cycle life of over 500 cycles (with >80% of initial capacity) both at ambient and low temperatures (Fig. 2); (2) impressive

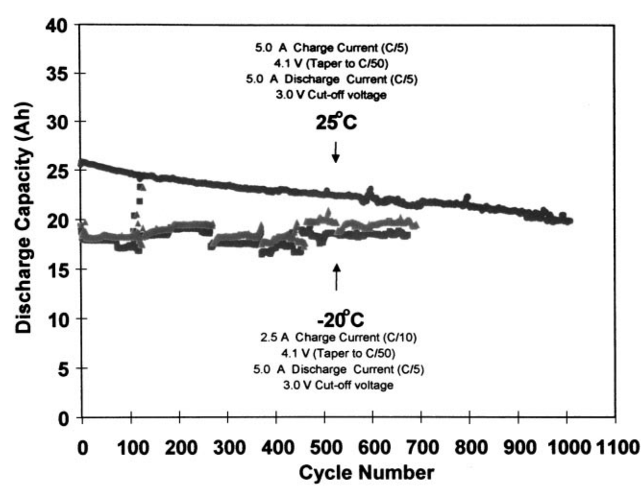

Fig. 2. Cycle life of prototypes of Li ion cells at different temperatures.

Table 1
Performance targets of Li ion cells for various NASA–Air Force missions

	Landers	Rovers	GEO orbiter	LEO/PLA > orbiter	Aircraft	UAV
Capacity (Ah)	30	8	10 20 35	10 20 35	5–20	100–200
Voltage (V)	28	28	28–100	28	28–270	28–100
Discharge rate	C/5-C	C/5-C/2	C/2	C/2-C	C	C/5-C
Cycle life	>500	>500	>2000	>30000	>1000	>1000
At the rate of DoD (%)	>60	>60	>75	>30	>50	>50
Operating temperature (°C)	−40+40	−40+40	−5+30	−5+30	−40+65	−40+65
Calendar life	3	3	>10	>5	>5	>5
Special energy (Wh/kg)[a]	>100	>100	>100	>100	>100	100
Energy density (Wh/l)[a]	120–160	120–160	120–160	120–160	120–160	120–160

[a] Based on 100% DoD at BOL.

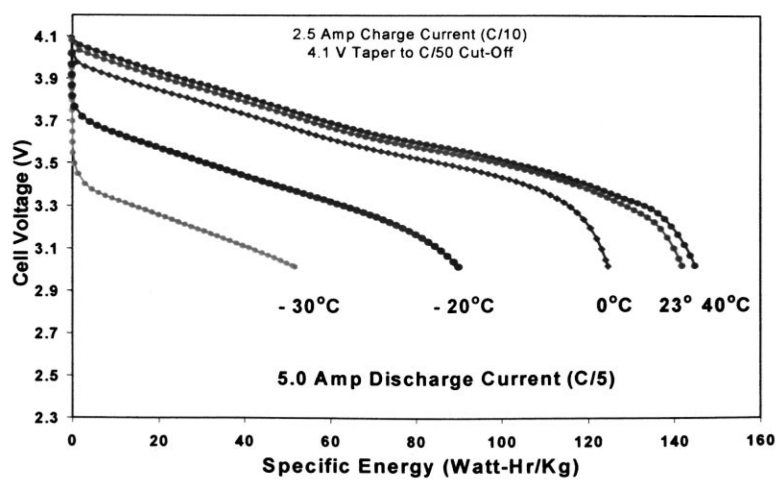

Fig. 3. Discharge curves of prototypes of Li ion cells at different temperatures.

discharge (Fig. 3) and charge characteristics at low temperature (−20°C); (3) a high current (2–3 C) pulse capability for entry descent and landing (EDL) functions; (4) good storage characteristics with over 97% capacity retained during 1.5 years of storage under favorable conditions (low temperatures and low state of charge) and (5) a long cycle life (extrapolated to exceed 9000 cycles) at 30% DoD for LEO applications. In addition, prototype cells stored under mission specified conditions (10°C and on float at voltage corresponding to 70% SOC) have performed well under mission simulation tests. In short, these studies reveal that the Li ion cells developed here meet mission needs and emphasize the mission readiness of the technology for upcoming NASA and Air Force missions.

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