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Journal of Power Sources 136 (2004) 372–375
JOURNAL OF POWER SOURCES
www.elsevier.com/locate/jpowsour

The sealed lead–acid battery: performance and present aircraft applications

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This paper is dedicated to the memory of Mr. David Rice who was a great friend to all who wrote this paper. May he rest in peace and as he always said: this is "great stuff"

Abstract

The United States Navy has flown valve-regulated lead–acid batteries (VRLA) for approximately 22 years. The first VRLA aircraft batteries were of a cylindrical cell design and these evolved to a prismatic design to save weight, volume, and to increase rate capability. This paper discusses the evolution of the VRLA aircraft battery designs, present VRLA battery performance, and battery size availability along with their aircraft applications (both military and commercial). The paper provides some of the reliability data from present applications. Finally, the paper discusses what future evolution of the VRLA technology is required to improve performance and to remain the technology of choice over other sealed aircraft battery designs.
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Keywords: Applications/aircraft; Valve-regulated lead–acid batteries

1. Introduction

Aircraft batteries have historically represented one of the most troublesome aircraft systems. Major problem areas have been corrosion, thermal-run-away, and labor intensive battery maintenance. Vented lead–acid and nickel/cadmium batteries were primarily used in the past for main aircraft batteries. These batteries had high failure rates and required expensive maintenance.

During the middle 1970s, various new advances in battery technology were emerging. The development of sealed lead–acid (VRLA) technology was one of the most important technological advances in batteries in the last 30 years. The first VRLA introduced was the Gates Energy Products commercial cylindrical cell, a VRLA battery used in uninterruptable power source applications (cell size available at that time was limited to 5 Ah). This type of battery required no scheduled maintenance, no special charger, and operated in any orientation. Naval Air Systems Command and Naval Surface Warfare Center, Crane Division decided to evaluate VRLA technology for use in high performance aircraft to reduce battery maintenance, aircraft battery life cycle costs, and the need for a dedicated aircraft battery charger. In 1978, the Navy began the development of large VRLA technology cells capable of meeting the requirements of AV-8B main aircraft battery applications.

The VRLA technology was first introduced in a 15 Ah battery on the AV-8B "Harrier II" aircraft in 1981. Based on the success of the technology on the AV-8B, the Navy decided to use VRLA in all of its vented lead–acid and vented nickel–cadmium aircraft battery applications where the technology was compatible.

The VRLA technology continued its penetration into the military main aircraft battery market through Air Force Tiger Team and High Reliability Maintenance Free Battery initiatives in the middle to late 1980s.

In the commercial world, the technology is being introduced in new aircraft designs and as a replacement to improve reliability, reduce aircraft maintenance cost, and increase aircraft availability. The military has also looked at this technology to be a suitable replacement for flooded batteries used on shipboard systems such as backup and stationary systems and machine guns like the MK38. The Army has recently decided to introduce the technology in its continuing production of the H-60 Blackhawk. The Air Force

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0378-7753/$ – see front matter © 2004 Published by Elsevier B.V.
doi:10.1016/j.jpowsour.2004.03.045

has come on board with the recent approval of a VRLA battery for the F-16 Fighting Falcon and the B-52 Bomber.

This paper discusses the evolution of the VRLA aircraft battery designs, present VRLA battery performance, and battery size availability along with their aircraft applications [1–4].

2. Discussion

2.1. US military applications

Based on the success of the technology on the AV-8B, the Navy decided to use a VRLA 7.5 Ah battery on the F/A-18 “Hornet”. The VRLA technology was retrofitted into F/A-18 production aircraft in 1983. This retrofit occurred because reliability of the sealed nickel/cadmium and integral battery charger on the first 36 aircraft was 30 Mean Flight Hours Before Failure (MFHBF). MFHBF of the cylindrical VRLA batteries on the AV-8B and F/A-18 ranged from a low of 500 h to a high of 1500 h during 15 years of use. Maintenance manhours went from over 700 per 1000 flight hours to 50. This resulted in a savings of over $125 million (shown in Fig. 1) in maintenance and replacement costs. The 7.5 Ah battery was also retrofitted into the H-46 helicopter resulting in greatly improved reliability. This battery was also applied to the F-117 aircraft during its production.

In 1985, the Navy awarded a development contract for a monobloc design (car battery configuration) VRLA battery to replace the cylindrical 15 Ah VRLA battery. With the more efficient packaging, there was a reduction in weight from 57.3 to 47.4 lb (9.9 lb reduction) realized with the monobloc design (i.e., from 26 to 21.5 kg). The physical envelope was reduced in height by 1.5 in. (38 mm). The high rate (engine start) performance was also increased in the monobloc (flat plate) design. The cylindrical VRLA 7.5 Ah battery was converted to the monobloc design with physical envelope and weight was kept constant.

Based on the success of the 7.5 and 15 Ah monobloc developments, a decision was made to convert present vented lead–acid batteries, produced to MIL-B-83769, and used on several Navy aircraft and ground support equipment, to VRLA technology. This change resulted in maintenance cost savings, reduced corrosion, and improved reliability. The US Air Force also converted several of its aircraft because of the Navy’s success. After 4 years of successful operation in the US Air Force UH-60, the US Army has been introducing in their new production H-60’s the D8565/11-1. A list of current military aircraft batteries with Ah sizes, weights, military part numbers, and aircraft of application is provided in Table 1. Other US Air Force activity, not listed in Table 1,was the prototype Battelle/Hawker system on F-16 which flew in excess of 4 years. Since the first delivery of the F-16 in 1978, the Air Force and Lockheed Martin has had an interest in improving the reliability and maintenance costs associated with Ni/Cd batteries but due to limitations in funding, struggled to introduce the effective VRLA system. As the F-16 was dubbed as the electric aircraft using fly-by-wire technology, the battery was a critical component for that required system needed wide interchangeability with 19 Air Forces in 18 countries. In 2001, the F-16 was converted to a VRLA design and is now the prominent battery on all production aircraft. Also, the A-7 Corsairs were being retrofitted with the 32/40 Ah battery.

2.2. European military applications

The European military activity may also be of interest. The main aircraft batteries for the Royal Air Force are the lead–acid 18 and 25 Ah batteries (the same as US 15 and 25 Ah batteries—US batteries are rated at end of life). These batteries are fitted into 22 RAF aircraft including the Lightnings, Hawks (Red Arrows Display team), Buccaneers, Bulldogs (Prince Charles was trained in it), Jet Provosts, Chipmunks, Scout (helicopter), HS125 (Domini), Jetstream 31, and VC10 (long range and tanker). All of those (now flying) have been retrofitted with the VRLA since 1986/7. New aircraft with VRLA include “Merlin”; the Westland/Augusta EH 101 helicopter now being manufactured for the Royal Navy; the Tucano trainer to replace the Ni/Cd; and the auxiliary battery on the French Dassault Rafale.

Batteries are typically used on aircraft to provide emergency power for flight and engine start capability. The bat-

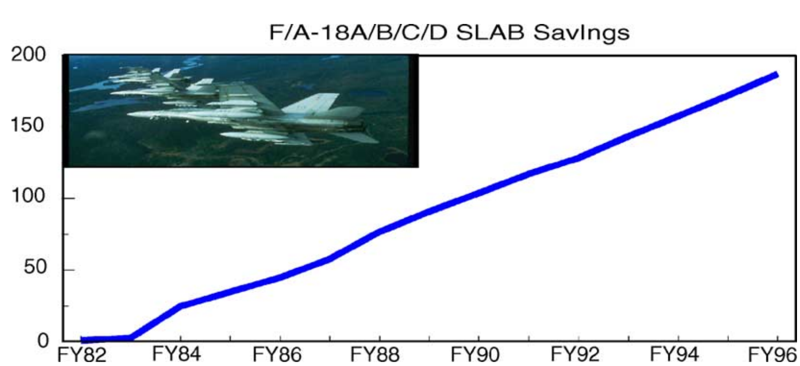

Fig. 1. Cost savings with use of VRLA battery on F/A 18 aircraft.

Table 1
Aircraft and their battery fits

Battery P/N	Rated capacity (Ah)	Maximum weight (kg)	Supercedes	Aircraft
D8565/3-3	15.0	21.5	D8565/3-2	V-22 AV-8B
D8565/4-1	7.5	11.8	CFE sealed Ni–Cd and charger	F/A-18, H-46, F-117, UCAV
D8565/5-1 and 5-2	30.0	36.4	M83769/1,5,6	C-130, P-3, T-37, H-58
D8565/6-1	1.5	2.9	New	V-22, H-47, S-3, C-2 E-2C
D8565/7-2	24.0	29.0	D8565/7-1	VH-60, AV-8B, V-22
D8565/9-1	24.0	28.6	M83769/2 and 4	T-34 and GSE
D8565/11-1	9.5	15.9	M83769/3	F-4, T-38, H-60, UH-60, C-141
D8565/13-1	10.0	14.1	LTN-72 CAROU-SEL IV	P-3, C-5
D8565/14-1	15.0	20.5	New	F/A-18 E&F, UCAV
D8565/15-1	35.0	40.7	New	KC-135 C-130J
D8565/16-1	5.0		New	UH-60
	1.5 and Chg.		MS 17334	H-53, E/A-6B

teries used for engine start applications require high output currents. The new prismatic VRLA battery designs provide high rate current outputs that rivals those of vented nickel–cadmium batteries of the same application. Figs. 2 and 3 present a couple of 14 V discharge curves at +24 and −26 °C.

One problem with VRLA technology that had existed since its initial application was the inability to recover the battery from an over-discharge. This often results from a switch being left on by aircraft maintenance personnel. Initially, high voltage pulse methods were used to break down the non-conductive lead sulfate layer that hindered recharge of the lead active material. Next, sodium sulfate was added to the electrolyte to improve the recharge from a deep discharge state. This additive now permits batteries to be charged using normal charging methods. New generation VRLA designs incorporate advanced alloy grids and paste composition which allow the battery to recover from deep discharged state with on board charging equipments.

2.3. *Commercial applications*

The US military development programs for high reliability maintenance free aircraft batteries have allowed the aircraft battery manufacturers to obtain FAA certification for several derivatives of military aircraft VRLA batteries for both commercial and military aircraft.

VRLA batteries are now original equipment on the Raytheon Beechjet (T-1A Jayhawk), the new JPATS, Premier X, Cessna Citation, Bravo, Caravan, and new Learjet models. Besides their widespread use in corporate jets and turbo prop applications, the light general aviation fixed and rotary wing manufacturers such as Robinson, Enstrom, American Champion, and others have replaced their original maintenance intensive, vented lead acid batteries with VRLA. After extensive type trials, Airborne, Federal Express, Emery, Petroleum Helicopters, Columbia Helicopters, Air Logistics, and several commuter airlines have converted their fleets from nickel–cadmium to VRLA batteries.

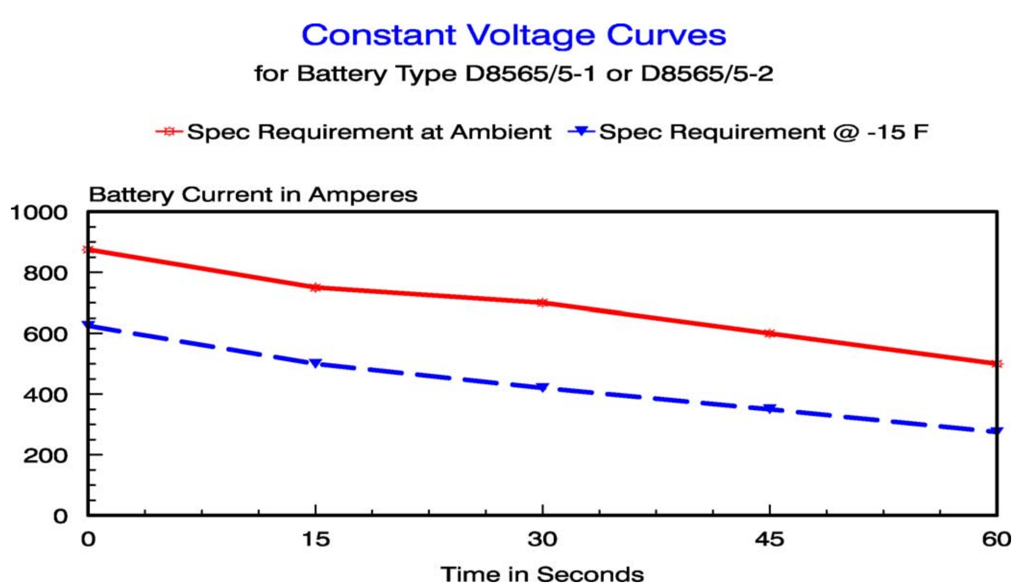

Fig. 2. Specified requirements at ambient temperature and −15 °F (−26 °C).

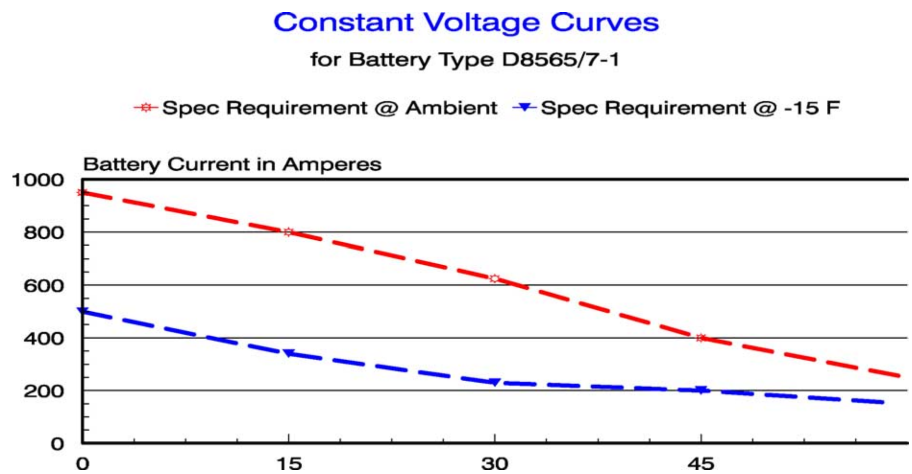

Fig. 3.

Commercial activities in Europe started with the Rolls Royce BAC 111 and the BAE 146 (four engine commuter aircraft). The 146 was the first to fly the 25 Ah in the US with Air Wisconsin and is also the British Queens's aircraft. The flight control battery on the Boeing 777 is a 5-year no maintenance VRLA.

3. Future improvements

Introduction of sealed nickel–cadmium, low maintenance nickel–cadmium, nickel metal hydride, and lithium ion that have been developed or are under development will start a trend away from VRLA batteries. The reasons for this trend will be weight reduction (in both the battery and the need for vibration isolation in some applications) and shelf life limitations of the chemistry. Possible solutions to the weight problems are light weight composite grids or co-extrusion over light weight materials. The Navy presently has a Phase II Small Business Innovative Research Project with a goal to reduce the weight by 15%. This weight reduction will look at composite grids plus additives to increase active material utilization. Both of these would solve the weight problem as well as the vibration resistance problem requiring the additional weight of isolation in some aircraft applications. Re-engineering the electrochemistry may further contribute to weight reduction while maintaining the cyclic capability and high current performance. Manufactured with high purity internals components, VRLA batteries have demonstrated long shelf life of up to 2 years at 20 °C. The shelf life problem requires continued work on additives to reduce self-discharge.

4. Conclusion

The use of VRLA batteries in aircraft battery applications over the past 22 years has reduced airframe corrosion, battery thermal-run-away, and labor intensive battery maintenance resulting in the savings of millions of dollars. Both reliability and availability of aircraft have been improved.

The chemistry continues to improve its market share in both the military and commercial aircraft markets worldwide. Other chemistries are under development and being introduced which will slow this market penetration; however, investment in solving SLA battery weight and shelf life limitations could continue the present trend.

Acknowledgements

The US Navy would like to thank the technical and engineering talent at Hawker Energy Products, Concorde Battery Corporation, and Naval Weapons Support Center, Crane Division for their development, qualification, and assurance of quality of SLA batteries delivered to the fleet. This has allowed the US Navy aircraft to be the most reliable and available aircraft in the world.

References

[1] K.L. Senderak, A.W. Goodman, in: Proceedings of the 16th International Energy Conversion Engineering Conference, vol. I, 1981, pp. 117–122.

[2] K. Senderak, K. Beard, in: Proceedings of the 30th Power Sources Symposium, The Electrochemical Society Inc., 1983, pp. 87–89.

[3] D.G. Vutetakis (Battelle), W.R. Johnson (Naval Surface Warfare Center, Crane Division), A maintenance free lead–acid battery for inertial navigation systems in aircraft, in: Proceedings of the IEEE Aerospace Electronic Systems Magazine, May 1995.

[4] D. Rice, M. Dunckley, Applications of the sealed lead–acid battery on the Boeing 777, in: Proceedings of the 10th Annual Long Beach Conference, January 1995.