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Military Qualification of a High-Reliability, Light-Weight 24V/30Ah Aircraft Battery

XV. The Fifteenth Annual Battery Conference on Applications and Advances

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ABSTRACT

The United States Navy has flown Valve Regulated Lead-Acid Batteries (VRLA) for approximately 18 years. The first VRLA aircraft batteries were cylindrical cell design and evolved to a prismatic design to save weight, volume, and to increase rate capability. This paper discusses the next generation of the VRLA aircraft battery. The HORIZON composite grid VRLA design reduces weight, increases high rate performance, and is expected to increases service life. This Commercial Operations and Support Cost Savings Initiative (COSSI) is being jointly funded by Electrosource, Defense Advanced Research Projects Agency (DARPA) - Joint Dual Use Program Office, and Naval Air Systems Command. This paper discusses the weight reduction over the present 30 Ah prismatic VRLA aircraft battery design; improvements in high rate engine start performance, and present status of the development effort. Finally, the paper discusses the applications for the 30 Ah composite grid VRLA aircraft battery, and shows the future application opportunities for light weight VRLA both in the military and commercially.

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 1970's various new advances in battery technology were emerging. The development of valve regulated 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 VRLA battery used in uninterruptable power source applications (cell size available at that time was limited to 5 ampere-hour). This type of battery required no scheduled maintenance, no special charger, and operates 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 Ampere-hour (Ah) battery on the AV-8B "Harrier II" aircraft in 1981. Based on the success of the

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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 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. 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 ampere-hour VRLA battery. With the more efficient packaging, there was a reduction in weight from 57.3 pounds to 47.4 pounds (9.9 pound reduction) realized with the monobloc design. The physical envelope was reduced in height by 1.5 inches. 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 kept constant.

Based on the success of the 7.5 Ah and 15 Ah monobloc developments a decision was made to convert present vented lead-acid batteries, produced to MIL-B-83769, on several Navy aircraft and ground support equipment to VRLA technology. This change resulted in maintenance cost savings, reduced corrosion, and improved reliability.

In 1997 ELECTROSOURCE, DARPA, and The Naval Air Systems Command jointly initiated the development of the next generation of VRLA for aircraft application. With cost saving and weight reduction being the technology drivers, the development of a 30 Ah composite grid VRLA aircraft battery based on the HORIZON technology began during FY98.

DISCUSSION

The COSSI initiative was to tak existing HORIZON commercial 24V/3 battery under flight evaluation in Turbo-Thrush and under initial stage Federal Aviation Authority certific and Qualify it to MIL-B-8565 require followed by government mandated f evaluation. The initiative was just on a 20:1 cost benefit and should ac a payback period of 4.2 years. goals were to be achieved by: extension of service life of the exi battery from the then 2 years to 3 resulting in decreased annual ba procurement costs and reduced mainte manpower costs and (2) reduced consumption and fatigue costs due projected 25% weight reduction.

Batteries are typically on aircraft to provide emergency powe flight and engine start capability. batteries used for engine applications require high output curr The new prismatic VRLA battery de provide high rate current outputs rivals those of vented nickel-ca batteries of the same application. Figures 1 and 2 present the 14 discharge curves at 75 and -15 de Fahrenheit from present 30 Ah pris VRLA and 30 Ah nickel-cadmium batt used by the fleet.

The 14 volt discharge curves o first batteries delivered by Electros under the COSSI effort deli substantially lower output than required D8565/5-1 specification output and present 30 Ah prismatic ba curves shown in Figures 1 and 2. F 3 shows the original output of Electrosource 30 Ah VRLA aircraft ba at -15 degrees Fahrenheit. The worked with Electrosource to renego milestones and suggested that they into using cold temperature expander change electrolyte concentration improve 14-volt discharge performa This effort ended with output perfor at 75 and -15 degrees Fahre increasing to values shown in figures 4 and 5 respectfully.

Presently, Electrosource is working on finalizing the design that will pass the vibration of specification sheet D8565/5-1. Problems in this area have been with keeping the plates from moving during vibration and failure of the grids due to corrosion. Part of the problem could be attributed to having too many plate pairs for the Electrosource design as shown by the extremely high 14 volt output.

The present 30 Ah Electrosource battery is only exhibiting a 12 % weight reduction due to using a metal case. Plans are to use a plastic battery case once production quantities can justify the high investment price of a plastic case mold.

Plans are to complete Qualification testing by April FY00. Following the Laboratory Qualification testing being conducted by Naval Surface Warfare Center, Crane Division a 1-year flight evaluation will occur on the P-3, C-130, and T-37 aircraft. Plans are to introduce the technology via preferred spare by reducing the D8565/5-1 weight by 15 to 20 percent.

Extensive commercial applications for the 24V/30Ah aircraft battery are in a variety of business jets and other aircraft and accounts for 25,000 unit sales on a world-wide basis per year. A partial list of aircraft and helicopters using this battery is shown in Table I.

A list of current qualified military aircraft batteries with application is provided in Table II. The US Navy plans to convert the applications shown to this third generation design beginning with the D8565/7-2 battery used in the V-22, VH-60, and AV-8B aircraft.

Make	Model
Aerospatiale	AB204, ATR72, Other
Agusta	AB204, AB205, AB212
BAE	31 Jetstream
Beech King Air	200, 300, Other
Bell Helicopter	204
Boeing Vertol	107, 114
Cessna	Caravan, Conquest, Other
Dehavilland	DHC6 Twin Otter
Embraer	Bandeireante, Brazilia, Other
Falcon	20, 200, 2000, Other
Fokker	900, F27
Gates Lear	24, 25, 55
Gulfstream	GI, GII, GIII
Lockheed	Jetstar I, L100 Hercules, Other
Mitsubishi	10, 25, 26, 36, Other
Rockwell	Turbocommander, Others
Rockwell/Gulfstream	Command, Other
Short Bros.	320, 360, Other
Sikorsky Helicopter	S76, SH58, SH55, Other

Table I. Commercial Aircraft for Use with the Horizon 24V/30Ah Battery

Battery Military P/N	Rated Capacity	Maximum Weight (Kg)	Aircraft
D8565/4-1	7.5	11.8	F/A-18, H-46, F-117
D8565/5-1	30.0	36.4	C-130, P-3 GSE, T-37, H-58
D8565/6-1	1.5	2.9	V-22, H-47, S-3, E-2C, C-2
D8565/7-2	24.0	29.0	V-22, VH-60, A/V-8B
D8565/9-1	24.0	28.6	T-34 & GSE
D8565/11-1	9.5	15.9	F-4, H-60, C-141
D8565/14-1	15.0	20.5	F/A-18 E & F
D8565/15-1	35.0	40.7	KC-135, C-130J

Table II. Present Military Battery Applications

CONCLUSIONS

The use of VRLA batteries in aircraft applications over the past 18 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 has been improved.

The chemistry continues to improve its' market share in both the military and commercial aircraft markets world wide. Other chemistries are under development and being introduced which will slow this market penetration; however, this important investment by DARPA in solving VRLA battery weight and service life limitations could continue the present trend.

ACKNOWLEDGMENTS

The Naval Air Systems Command would like to thank Commercial Operations and Support Cost Savings Initiative (COSSI) Program of Defense Advanced Research Projects Agency (DARPA) - Joint Dual Use Program Office (JDUPO), and JDUPO Navy Representatives Daniel Hoffman & Cathy Nodgaard for their continued support of this effort. This project will allow the US Navy aircraft to be the most relia cost effective, and available aircraf the world.

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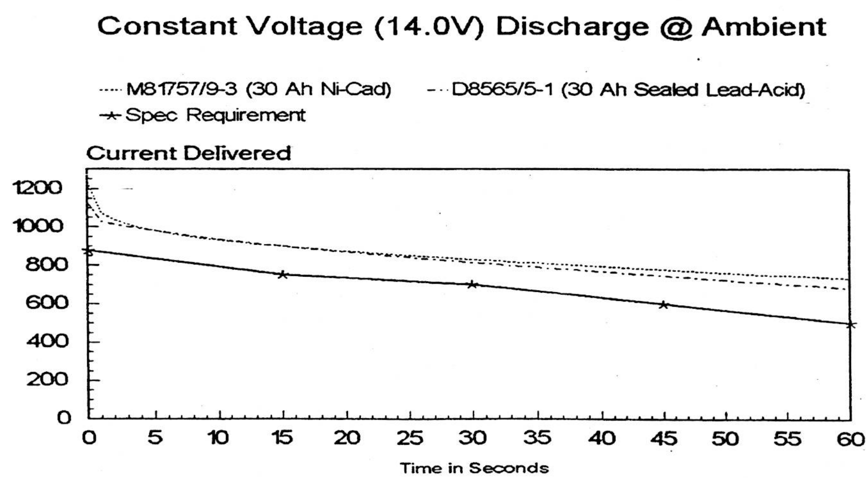

Figure 1

Constant Voltage (14.0V) Discharge @ -15 F

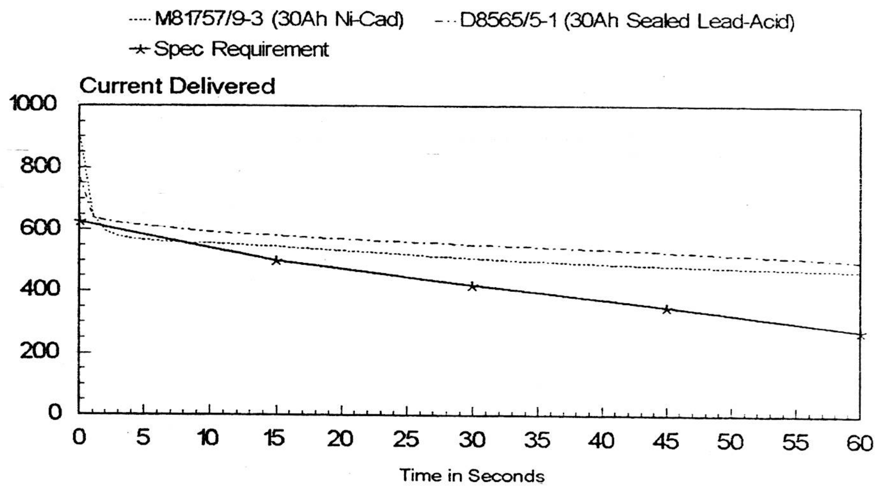

Figure 2

Initial Constant Voltage (14.0V) Discharge @ -15 F

Electrosource Battery

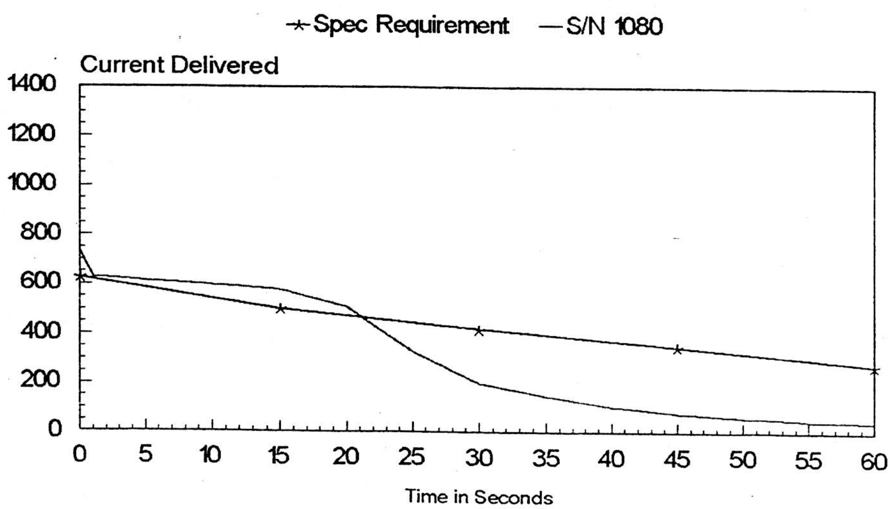

Figure 3

Constant Voltage (14.0V) Discharge @ -15 F

Electrosource Battery

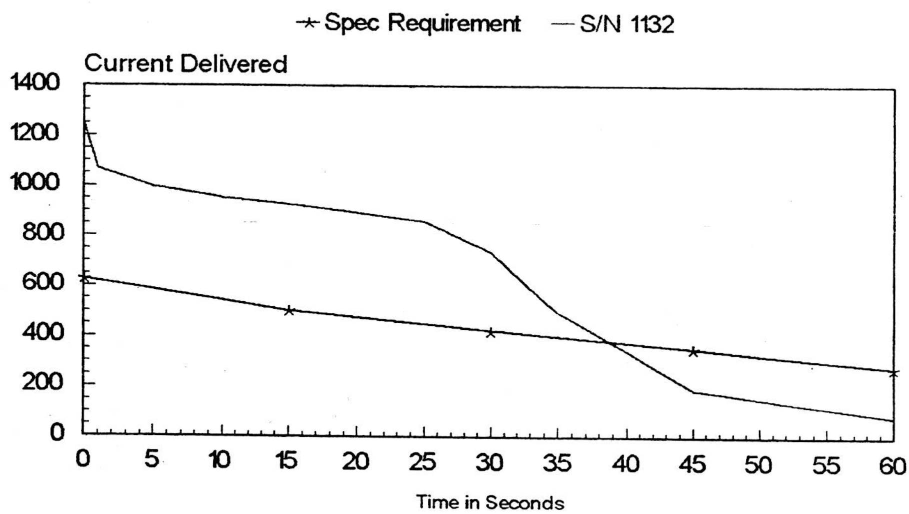

Figure 4

Constant Voltage (14.0V) Discharge @ Ambient

Electrosource Battery Redesigned

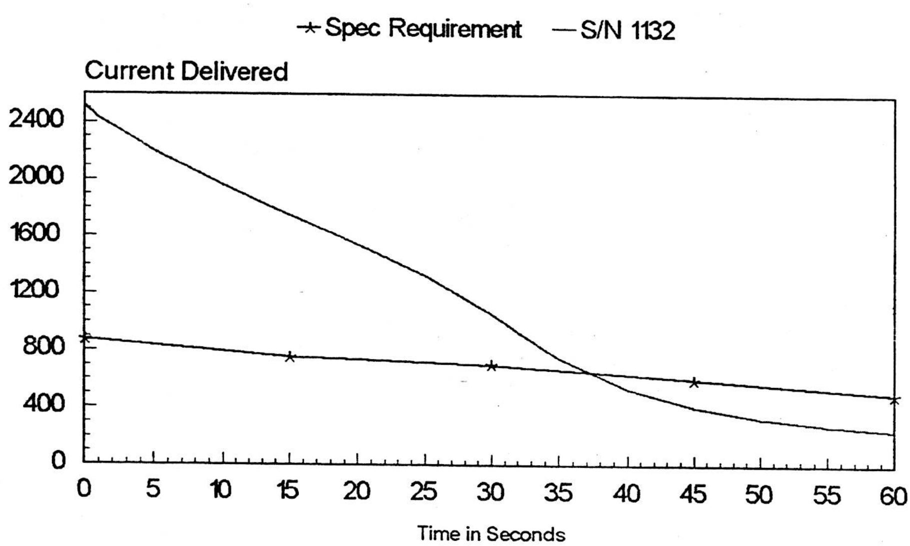

Figure 5

High Pulse Power Batteries for Air Deployable Navy Applications

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The Navy needs a high power battery for an advanced sonobuoy. Several chemistries and designs have been examined and reported on (*1-4*). The main focus at this point is on thermal batteries and lithium/sulfur dioxide (Li/SO_2) batteries. Other chemistries have been evaluated (e.g. lithium/manganese dioxide and lithium/thionyl chloride), however only lithium/sulfur dioxide and thermals have the combination of high power, energy, and low cost (producibility) that is required.

Thermal batteries, which are primary reserve molten-salt electrolyte systems, have demonstrated the ability to provide high power (*5*). However, they have difficulties with long life duration due to parasitic discharge and thermal management. Specialized, long-life designs are also typically expensive. Ambient electrolyte lithium/sulfur dioxide batteries are able to operate for long durations and at a lower cost, but suffer from voltage loss and overheating, due to excessive polarization, during sustained high power pulses (*6*).

The battery goals for the advanced sonobuoy are listed in Table 1 (*4*).

Table I. Sonobuoy Battery Goals

Power:	5,500 watts
Pulse Time:	140 seconds
Pulse Width:	.5 to 10 seconds
Duty Cycle:	Up to 30%
Mission Life:	6 hours
Storage Temperature:	-20 to +55 °C
Operating Temperature:	0 to +35 °C
Power Supply Cavity:	4.7"d x 12"l
Cost (in production):	$400
Voltage:	65-150 volts
Weight:	19 pounds maximum

Thermal Batteries

Thermal batteries have a history of providing high power for short periods of time. They are also exceptionally safe (*7*) and have an extremely long shelf life, usually 10 to 20 years. However, they are conventionally limited in duration from several seconds to approximately 2 hours, well under the 6 hour goal for the advanced sonobuoy. Since they are not available commercially and are "purpose" built, they are relatively expensive, potentially costing more than the desired total for the sonobuoy. Two contractors, ENSER and InvenTek, are looking into resolving these problems (8,9). A small business innovative research (SBIR) effort is in place with InvenTek.

ENSER has developed and demonstrated a 3-1/4 hour battery life. InvenTek has demonstrated the capability to meet six-hour mission-lives in thermal mock-ups and smaller batteries. Efforts are underway to improve the design optimization and thermal management of the cell stack to demonstrate this performance in full-up prototypes and active batteries.

Table II. Thermal Battery Status

Operational Life:	3.25 hours
Power:	5,500 watts
Operating Temperature:	Ambient

Lithium/Sulfur Dioxide Batteries

A focused lithium/sulfur dioxide cell chemistry development effort has demonstrated increased pulse power capability. NSWC Carderock has tested several of the Li/SO_2 cells and battery modules. A test equipment suite capable of measuring individual cell voltages and temperatures continuously, during the application of pulse loads, has been assembled. The battery packs have demonstrated the ability to provide the high power required, however, there are continuing concerns about initial depassivation, voltage reversal, and thermal management.

The standard pulse profile for all tests consists of a 10-second load followed by a 90-second rest period, representing a 10% duty-cycle. Specialized testing and pulse needs include duty-cycles up to 30%. Actual usage may include combinations of high duty-cycle pulses followed by long periods of inactivity. Standard temperatures for these tests are 0 and 35°C. Pre-conditioning at -20°C with pulse discharge testing at 0°C has been demonstrated. Tests with a 55°C precondition which were then discharged at 35°C have shown the ability

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