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Value Proposition of Lithium Ion versus Pb-Acid for Military Vehicles

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ABSTRACT

This paper will focus on understanding the value proposition associated with utilizing advanced lithium-ion 6T solutions versus legacy Pb-acid 6Ts for military ground vehicles. The value proposition will include an analysis of the benefits associated with lithium-ion 6T batteries and reduction in life cycle cost (LCC). The analysis of benefits will include comparative discharge curves at various rates and temperatures, discuss enhancements features such as an integrated battery management system that provides real-time battery diagnostics via CANBus J1939 protocol, increased power/energy density, reduced charge time and increased cycle life. The LCC analysis will investigate acquisition cost comparison, replacement rates, and reduced installation & transportation costs. The LCC analysis concludes with a detailed review of how the lithium-ion 6T solution can drastically reduce the operation and maintenance (O&M) cost of the Joint Light Tactical Vehicle (JLTV) over its 20 year life.

INTRODUCTION

In the past, military support vehicles have had relatively modest power requirements with onboard electric loads seldom exceeding that required to support radio systems. Not so long ago, vehicle electronic systems could be operated for short periods of time without starting the vehicle's engine.

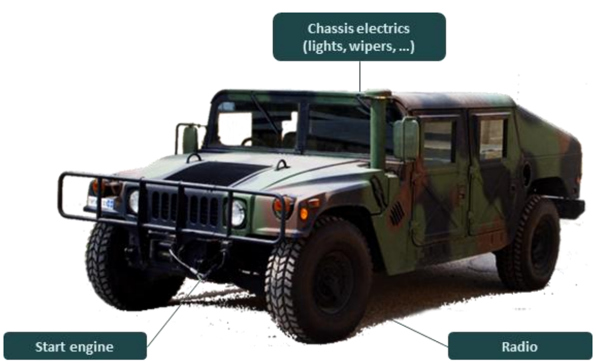

Figure 1. Sample of Electronic Loads on base HMMWV

As modern military operations have shifted away from historical modes of conflict where force-on-force combat occurred on a "front line," the distinction between combat and logistical vehicles has become blurred. In today's threat environment, logistics and other noncombat vehicles commonly encounter the same range of threats as combat vehicles. As a result, the ability to generate significant amounts of electrical power has become increasingly critical for the full spectrum of military vehicles. Non-combat vehicles are increasingly designed to accommodate combat-grade vehicle electronic systems, or what the military calls "vectronics," including sensors, jammers, communication and control equipment. The ability to support the electric power needed to operate these systems has become a critical issue.

The need to power the plethora of emerging sensors and communication systems installed in military vehicles is putting a significant strain on current vehicle power systems, specifically legacy Pb-acid 6T batteries.

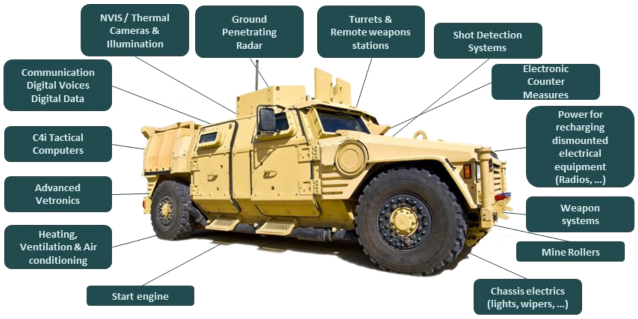

Figure 2. Sample of Electronic Loads on JLTV

The strain placed on legacy Pb-acid 6T batteries, in turn causes issues such as premature failure by excessive discharge, improper charging and extreme internal temperatures. The consequence for these actions are frequent replacements, which requires high levels of spare stock, and limited trust by Warfighters for use in deep-cycle applications. Another shortfall of legacy Pb-acid 6T batteries is that State of Charge (SOC) / State of Health (SOH) is difficult to detect, whichcould cause unexpected loss of power. This unexpected loss of power can lead to engine start failures, and inability to complete missions, and has the potential to put the Warfighter in harm's way.

PERFORMANCE COMPARISON

The performance comparison section of this paper will focus on effects of discharge rates, energy/power densities, benefits of an integrated battery management system and cycle life.

All Capacities are not equal, normally a "120Ah" Pb-acid battery gives an implication that, it could give 1A for 120 hours, or 120 A for 1 hour, or 20A for 6 hours or whatever combination of that which gives 120AH as the multiplication output.

In reality this is not the case. Faster discharging reduces the available capacity of the battery drastically. Available capacity of a battery could be computed using an empirical

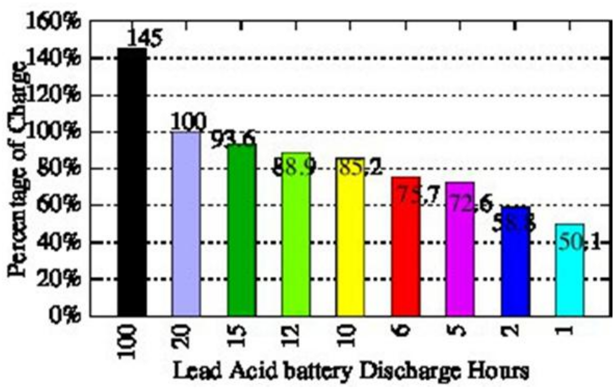

Figure 3. Pb-acid available capacity as a function of discharge time

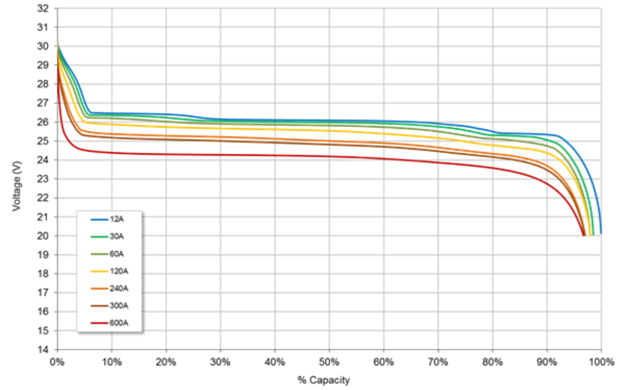

Figure 4. Saft Li-ion 6T available capacity as a function of discharge time

law named "Peukert's law." Figure 3 displays the available capacity of a typical lead-acid battery against discharge time. 100% capacity is stated for 20 hours.

In comparison, the peukert effect is not as severe for lithium-on batteries. Figure 4, is a graphical representation of Saft's Super-Phosphate™ 6T lithium-ion battery discharged at various rates. The rate of discharge shown varies between C/5 to 10 C-rate, and the resulting capacities vary only 4% of sticker label capacity.

Consistent capacity over various discharge rates is related to increases in energy density of lithium-ion batteries when compared to legacy Pb-acid. Take the HMMWV as an example; today the vehicle is outfitted with two (2) Pb-acid 6T batteries that weigh 88lbs each. Purely looking at sticker label energy, the two (2) batteries equate to a 2.88 kWh. However, if the HMMWV is equipped with surveillance and reconnaissance mission equipment, it may require the batteries to provide up to 120 amp discharge rate (or 1C-rate) during silent watch. Due to the peukert effect, the actual capacity would be 50% of the sticker label, or 60 AHs, resulting in actual energy of 1.44 kWh. Today, lithium-ion battery manufacturers have developed 24V 6T lithium-ion equivalents that weigh 50lbs each and contain at minimum 1.44 kWh of energy at C-rate discharge. This results in a 72% decrease in weight and a "two-for-one" replacement in volume per system (or 50% reduction).

In addition to energy density, it is also important to compare power density between the two electro-chemistries. The Pb-acid 6T battery is required to provide 1,100 amps for 30 seconds at -18C^{o}, and 400 amps for 30 seconds at -40 C^{o}. Lithium-ion battery manufacturers have developed 24V 6T lithium-ion equivalents that deliver the same power capability. Figure 5, displays Saft's lithium-ion 6T voltage profile while delivering 1,100 amps for 30 seconds at -18C.

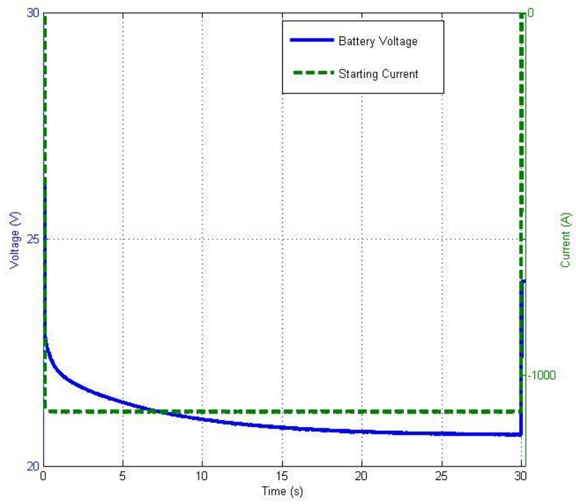

Figure 5. Saft Li-ion 6T 1,100 amp discharge pulse at -18C

All lithium-ion batteries are required to have some form of battery management system. For lithium-ion batteries to operate safely and provide a long lifetime, they must be constrained to an operational envelope that prevents over current, over temperature, low temperature charging, and most significantly, overcharge and over discharge of each individual cell, and cell balancing.

Initially, you may consider it a burden to have a battery management system within lithium-ion batteries as it increases the amount of electronics and cost. However, when analyzing failure modes of Pb-acid batteries in military operation, the number one failure mode was improper charging of the battery. BMS's within lithium-ion batteries often prevent improper charging, therefore removing or drastically reducing this failure mode for the Warfighter.

The inclusion of a BMS in a lithium-ion battery provides the opportunity for the battery to communicate information externally to logisticians, Warfighter, OEMs and other vehicle systems. This provides the user(s) with real-time diagnostic information on the battery; e.g. battery voltage, cell string voltages, State of Charge (SOC), State of Health (SOH) and diagnostics/maintenance messages. These battery management systems provide the warfighter with accurate information about the battery state of charge in real time so it can be used with confidence, and ensure there is enough power remaining for an engine crank at the end of a silent watch mission.

LIFE CYCLE COST COMPARISON

The life cycle cost section of this paper will focus on cycle life comparisons of Pb-acid versus lithium-ion batteries, and the cost savings associated with transportation and installation as a result of increased cycle life.

The Pb-acid batteries are qualified today to provide (at a minimum) a cycle life of 360 shallow cycles (40% depth of discharge) and 120 deep cycles (70% depth of discharge) per MIL-PRF-21143B. As discussed earlier, military vehicle batteries nowadays are called upon to provide higher power loads and be cycled at up to 80% depth-of-discharge. This change in use of legacy Pb-acid batteries has led to shortened operational life, resulting in increased numbers of spares and field replacements required.

Lithium-ion batteries typically provide a longer cycle life than lead-acid batteries, meaning that each battery can be used for more silent watch and/or engine cranking when using this chemistry. This longer battery life provides a life cycle cost advantage and reduces required maintenance. Lithium-ion industry standards, at a minimum, require 1,000 100% depth-of-discharge cycle life. Saft's Super-Phosphate™ VL30PFe cell has proven cycle life of 3,000 cycles, at 100 % full depth-of-discharge, and 5,000 cycles at 40% depth-of-discharge at 25°C. In comparing Saft's cycle life versus the Pb-acid, you can potentially achieve a 25X increase in full depth-of-discharge and a 14X increase in shallow discharge capability. This translates to less battery replacements, which in-turn results in reduced shipments and volumes of stored batteries. Based on the study conducted by US Army Materiel Systems Analysis Activity in May of 2011, it costs the Government $125 to transport and $105 to install one (1) 6T Pb-acid battery. Historically, averaged over the past 10 years, the US Army Department Logistics Agency (DLA) has purchased about 500,000 6T Pb-acid batteries per year, with a maximum of 700,000 per year during this timeframe. Taking into consideration the average, this translates into a $115M dollars of transportation and installation cost per year, excluding acquisition cost. If you evaluate the number of military vehicles, and corresponding numbers of 6T Pb-acid batteries per vehicle, at any one time the service is utilizing 700,000 batteries. Based on this information the government is getting an average of 1-1.4 year service life from the Pb-acid 6T battery.

Currently, the DLA purchases Pb-acid 6Ts at about $.40 per watt-hour versus li-ion 6Ts targeting $1.25 per watt-hour. The $.40 per watt-hour figure is comprised of two (2) 12V Pb-acid in series to power a military vehicles 28V electrical buss. Cost to manufacture lithium-ion cells is reducing, but it will be sometime before the acquisition costs of the batteries are equivalent.

It is becoming increasingly important on new vehicle programs for the government to conduct a LCC analysis of systems during the procurement phase. In order to reduce the vehicles' LCC, it is imperative to have subsystems that can meet a high Mean Miles between Failure (MMBF) and Mean Miles between Hardware Mission Failure (MMBHMF). Beyond just cell cycle life testing as discussed earlier, Saft has conducted analysis of projected lithium-ion battery life based upon the actual missions, roles, and environments over the life of the JLTV vehicle. Results of this analysis determined, at minimum, Saft's lithium-ion 6T battery would last 7 years. Figure 5, shows the resulting comparison when analyzing acquisition cost in $/Wh and the expected replacement rates of the two electro-chemistry systems over the 20 year life of the JLTV program.

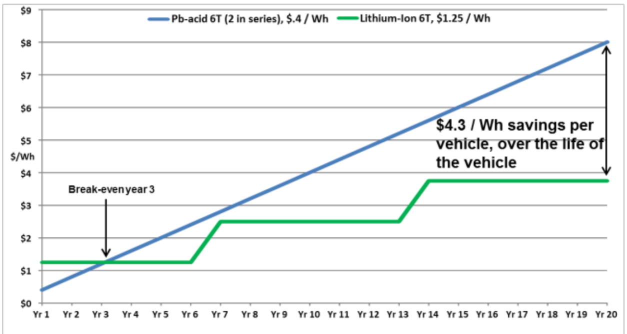

Figure 6. LCC Comparison of Pb-acid and lithium-ion

The breakeven point for the increased acquisition cost of the lithium-ion 6T is reached at year 3. The $4.3/Wh savings per vehicle, translates to a savings of $9,936 per vehicle. Similar to reduced transportation and installation costs discussed earlier, when you multiply the $9,936 per vehicle savings, by the expected JLTV fleet size of 20,000 vehicles, you experience a $200 million life cycle cost savings for the program!

SUMMARY

Lead acid batteries have been the energy storage backbone of the US military's fleet for a number of years. As DoD varies their operational tempo and fighting style, so does the way they use energy in peacetime and during deployments. Lead acid batteries will always have their place on today's battlefield for legacy systems and for applications where very high power and energy density are not critical. However, as the power and energy demands on vehicles increase, so does the need for advanced chemistry batteries, such as lithium ion.

With the leadership of TARDEC's Energy Storage Team the realization of lithium-ion 6T as a drop-in replacement to legacy PB-acid batteries is not far away. Additionally, vehicle acquisition programs, for example the Joint Light Tactical Vehicle (JLTV) have expressed interest in lithium-ion 6T batteries as a way to help meet the weight target and reduce the vehicle's lifecycle cost. Saft has already delivered lithium-ion 6T batteries to the JLTV Engineering Manufacturing Development (EMD) phase of the program, and is currently installed in vehicles under government test. This battery has also been evaluated in other vehicle platforms such as the High Mobility Mulit-Purpose Wheeled Vehicle (HMMWV) and a Mine Resistant Ambush Protected vehicle (MRAP).

Due to the dependence on the batteries for soldier protection and because lead acid battery cycle life and weight are a significant logistics burden, a new, improved battery (i.e lithium -on battery) that fulfills this need is required to fight on today's battlefield. There are many benefits of using Li-ion batteries over Pb-acid for most military vehicles. These advantages include longer cycle and calendar life, consistent power over batteries' State of Charge (SOC), re-charge at higher C rates, and the ability to perform full depth of discharge without degrading life or performance of the battery. As today's battlefield changes…so does the way we transport and use energy.

ACKNOWLEDGEMENTS

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REFERENCES

1. MIL-PRF-32143B 6T Lead acid Specification
2. US Army Materiel Systems Analysis Activity (AMSAA) Field Studies Branch Hawker Batteries, May 2011
3. Challenges with Specification Development of Lead Acid Replacement Batteries, GVSETS, A123 Systems, Livonia, MI August 2012
4. Hawker Data Sheet Supplement, 12V, 120Ah C20, ABSORBED GLASS MAT (AGM)

ABOUT THE COMPANY

Saft (Euronext: Saft) is a world leading designer and manufacturer of advanced technology batteries for industry. The Group is the world's leading manufacturer of nickel batteries and primary lithium batteries for the industrial infrastructure and processes, transportation, civil and military electronics' markets. Saft is the world leader in space and defense batteries with its Li-ion technologies which are also deployed in the energy storage, transportation and telecommunication network markets. More than 3,800 employees in 18 countries, 14 manufacturing sites and an extensive sales network all contribute to accelerating the Group's growth for the future.

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