Saft's Xcelion 6T® 28V Lithium Ion Battery for Military Vehicles

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ABSTRACT

Saft has developed a competitively-priced lithium-ion replacement for the traditional lead-acid batteries for use in the next generation of military vehicles. Saft's 24 volt Xcelion 6T® delivers power at high rate that surpasses the delivered capacity of two lead-acid batteries. The battery design is tailored to support high rates, even at extreme cold temperatures, to support the mission needs for silent watch and starting for military vehicles. The product is now industrialized and commercially available for integration in the next generation of vehicles.

INTRODUCTION

Most heavy-duty vehicles designed for industrial and military use were originally fitted with batteries that supplied little more power than what was needed for engine starts and ancillary equipment operation. The lead-acid battery has served that purpose extremely well for many years for basic vehicle operations. Historical vehicle electronic systems were designed to handle low-level starting, lighting and ignition (SLI) loads. However, today's modern military assets are equipped with sophisticated electronics and digital packages which often feature an array of mission-critical sensors, jammers, communication and control systems that strain traditional lead-acid batteries. Advanced lithium ion batteries offer the improved performance and life required to meet today's needs for the vehicle.

As a design-compatible, drop-in alternative to traditional NATO 6T lead-acid batteries, the Xcelion 6T® provides increased energy density, measurable life cycle cost benefits and on-board diagnostics that monitor and manage output, performance and protections. The Xcelion 6T® weighs less than its lead-acid counterparts, delivers more power with greater reliability and requires no structural or interface design adaptation. The integral battery management system (BMS) is used for automated balancing and protection, offering CAN communication for advanced vehicles or operation as a standard battery for legacy vehicles. Advanced features of the BMS include real-time battery data monitoring with two-way communication between system and user, reserve protection to support starting at the end of a silent watch, and battle override to allow deep cycles and aggressive use beyond reserve levels.

The advanced Li-ion chemistry in the Xcelion 6T® not only provides more power, but reduces life-cycle cost and the total cost of ownership. The battery sustains significantly more deep-discharge cycles compared to legacy lead-acid, as much as 14 times more for shallow cycling and 25 times more for full depth of discharge. Longer battery life means fewer batteries to buy, replace, ship, store, and dispose and recycle and eliminates need for excess inventory. Reduced weight means one-person lifting and easier maintenance and replacement. Longer life and lighter weight reduces total spare inventory quantity and cost, shipping costs and other logistics burdens. The physical dimensions and connections of the Xcelion 6T® are identical to those of traditional NATO 6T batteries allowing for a direct drop in for today's applications.

As today's systems demand greater power capacity that supersede the capabilities of legacy battery technology, advances in Li-ion technology and the development of new power solutions are beginning to push beyond outdated technology and chemistry. With greater power density, energy efficiency and enhanced performance, plus a reduction of the logistical burdens to store, transport and distribute replacement batteries, the Xcelion 6T® holds the potential to transform industry standards and market dynamics. These advantages generate life cycle cost benefits, translating to reduced total cost of ownership.

ADVANTAGES OVER LEAD-ACID

Batteries that incorporate lithium-ion (Li-ion) chemistries have demonstrated their ability to provide more power and to operate for significantly more deep discharge cycles. These advantages translate to a lower life-cycle cost compared to lead-acid batteries. The Xcelion 6T® is a Li-ion drop-in replacement for 28V systems that provides the power equivalent of two (2) series lead-acid batteries. Physical dimensions and connections are identical to the standard NATO 6T lead batteries.

Lithium-ion batteries have a built-in battery management system (BMS) that communicates real-time diagnostic information about the battery's SOC to users. This provides the operator with confidence in knowing that after an extended silent watch sufficient power remains to start the engine. The battery system's Li-ion chemistry enhances the capabilities of today's military vehicles during silent watch operations and for supporting a multitude of power-hungry technologies vital to today's advanced vehicle operations and unit safety / survival.

The system provides power for SLI as well as devices critical to safety during silent watch missions. Li-ion technology safely powers electronics, communications, night sight and other silent watch devices while the vehicle is turned off. Additionally, the 24V, 60Ah design provides greater power density and energy efficiency with long-lasting performance that reduces logistical burdens to store, transport and distribute replacement batteries. It also features available CANBus communications that relay vital information, including SOC (%), battery and cell voltages, temperatures, and battery diagnostics.

One key advantage of the Xcelion 6T® is the ability to delivery capacity and energy at higher rates. Normally, a 120Ah battery label indicates that the battery could provide: 1A for 120 hours; 120A for 1 hour; or 20A for 6 hours – whatever combination of that gives 120Ah output. This is not the case with lead-acid batteries, normally rated at a 20 hour (C/20) discharge rate. Faster discharging reduces the available capacity of the lead-acid battery drastically. Peukert's law shows that the available capacity of a typical lead-acid battery against discharge time is stated for 20 hours at 100% capacity and that eh delivered capacity will diminish at higher than C/20 rates. In comparison, Saft's Xcelion 6T capacities vary only 4% of nameplate capacity at higher rate. Consistent capacity over various discharge rates results in a realized increase in energy density for lithium-ion batteries when compared to legacy lead-acid. For example, the High Mobility Multi-Wheeled Vehicle (HMMWV) is outfitted with two Lead-acid 6T batteries that weigh 88lbs each. The sticker label energy indicates the two batteries equate to a 2.88 kWh energy source. However, if the HMMWV is equipped with surveillance and reconnaissance mission equipment, it may require the batteries to provide up to a 120A (1C) discharge rate during silent watch. Therefore, the actual capacity would be 59% of the sticker label, or 71Ahs, resulting in actual energy of 1.7kWh.

Figure 1 shows the energy delivered from a single 6T battery at various rates and temperatures. The lead acid battery delivers its capacity at 12V and the Xcelion 6T® delivers at 24V in a single 6T format package. The Xcelion 6T® delivers far more energy at these higher rates and is less sensitive to rate of discharge.

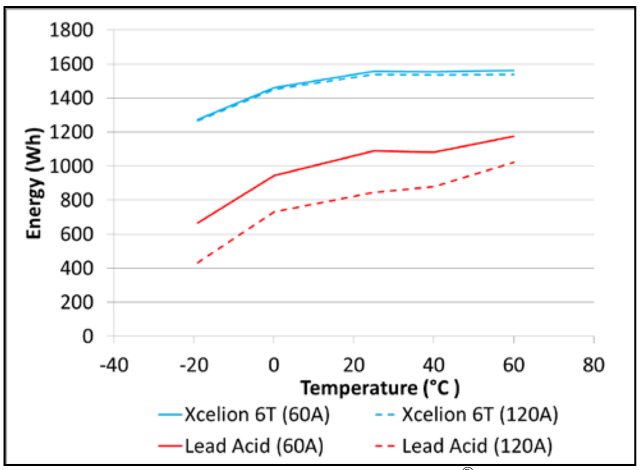

Figure 1: Delivered Energy of Xcelion 6T® vs. lead-acid

Saft's Xcelion 6T® is a 24V 6T lithium-ion equivalent that weighs 46lbs and provides 1.6 kWh of energy at C-rate discharge. Using the Xcelion 6T® rather than the lead-acid 6T option results in a 74% decrease in weight and a two-for-one replacement in volume per system (or 50% reduction.

The Xcelion 6T® delivers more capacity and Energy in comparison to the standard lead-acid AGM 6T battery. The available capacity of traditional lead-acid batteries is dramatically affected by faster charge and discharge rates and limited temperature ranges. By comparison, the increased usable energy density of Li-ion batteries provides consistent capability over various discharge rates and temperatures. Figure 2 shows the excellent rate capability of the Xcelion 6T® battery. Designed for high rate discharges, there is minimal effect on delivered capacity and energy when discharging at high rates. Even at a 240A discharge rate (4C) the Xcelion 6T® is able to deliver essentially all of its capacity. The low impedance of the battery also means less voltage drop under high loads, offering better stability for the 28V bus and a proven ability to dampen the effects of rapid load changes on the vehicle.

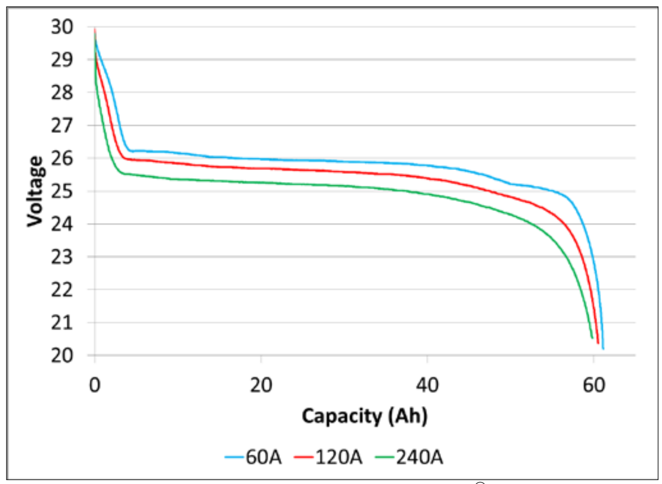

Figure 2: Rate Capability of Xcelion 6T® at Room Temperature

Additionally, use of the more the powerful Xcelion 6T® Li-ion batteries reduces the overall weight of the vehicles while amply meeting the power needs longer than the lifetime expectancy of the lead-acid units replaced. At 40kg per 12V battery, the lead-acid batteries create a high mass burden on the vehicle. The Xcelion 6T® battery is superior for delivery specific energy. Table I shows the specific energy of the Xcelion 6T® in comparison to its lead-acid counterpart. The table shows the energy delivered per unit mass at a 60A discharge rate.

Temperature (°C)	Lead Acid Energy (Wh/kg)	Xcelion 6T Energy (Wh/kg)
-19	17	61
0	24	71
25	27	75
40	27	75
60	29	76

Table I: Specific Energy of the Xcelion 6T® compared to lead-acid

The Xcelion 6T® can substantially reduce the mass burden of the batteries with each battery weighing less and the superior rate capability resulting in the need for fewer batteries to support normal vehicle loads. The weight savings allows for additional resources or capabilities to be outfitted on a vehicle.

OPTIMIZED FOR POWER

In addition to energy density, it is also important to compare power density between the two electro-chemistries. The lead-acid 6T battery is required to provide 1,100 amps for 30 seconds at -18°C, and 400 amps for 30 seconds at -40°C. Saft's Xcelion 6T® is the only 24V lithium-ion 6T equivalent that delivers this power capability. The Xcelion 6T® includes Saft's proprietary Superphosphate® technology that offers excellent rate capability and power stability across state of charge.

Figure 3 shows the load response of the Xcelion 6T® across state of charge (SOC). An aged battery was tested under a 400A load for 30 seconds at each pulse. The battery was stabilized at 25°C between pulses. The data shows that the battery provides a reliable capability in delivering power for starting loads even at deep depths of discharge. This allows for the user to run a longer silent watch, discharging more energy from the battery, and still having enough power capability from the battery to start the engine. It has been demonstrated in real vehicle testing that a single battery at 20% SOC still provides the necessary power for an engine start.

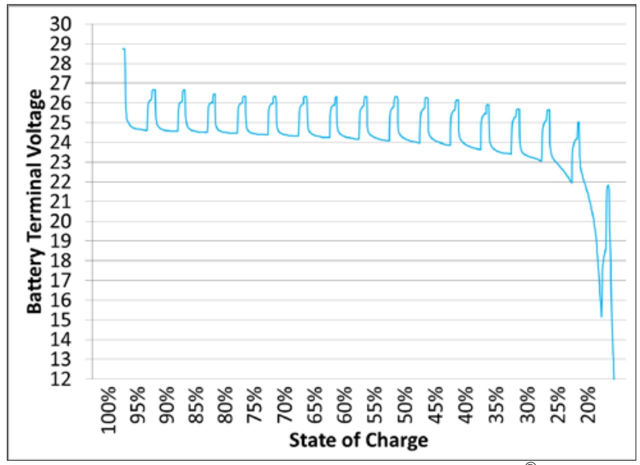

Figure 3: Pulse power capability of Xcelion 6T® across State of Charge

OPTIMIZED FOR COLD TEMPERATURE

A key advantage of the Xcelion 6T® is the performance in arctic environments. The lead-acid 6T battery is required to provide 1,100 amps for 30 seconds at -18˚C, and 400 amps for 30 seconds at -40˚C. Other systems require preheating with a heating kit before starting below -40˚C. The Xcelion 6T® can support a cold start at -40°C upon demand without any preheating delays. Saft's Xcelion 6T® is the only 24V Li-ion equivalent that delivers this capability at this extreme low temperature. Additionally, the Xcelion 6T® automatically engages built-in heaters for optimum charging in extreme cold conditions.

Saft Lithium Ion chemistries offer superior performance at cold temperature compared to lead-acid and other lithium ion providers. The cells in the Xcelion 6T® battery are specifically designed and optimized for the application. While the battery includes heaters that are used to allow for cold temperature charging, the heater are not engaged and are not necessary to support cold temperature starting.

Figure 4 shows the performance of the Xcelion 6T® battery under cold temperature cranking loads of 400A at -40°C. Without any preheating, the battery is capable of meeting minimum voltage requirements under load during the 30 second pulse. The voltage actually rises during the pulse due to self-heating of the cells from their internal resistance. The self-heating during cranking improves the performance further with subsequent pulse loads. The ability to provide this power capability at cold temperature on-demand allows for immediate availability of the vehicle to the user without the delay of a preheating operation or the complication of running a secondary battery heater from an external power source to keep the batteries at 'start ready' temperatures.

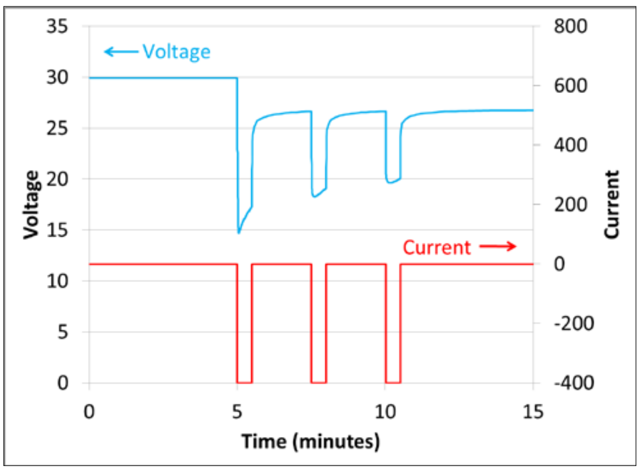

Figure 4: Xcelion 6T® performance under 400A/s30sec load at -40°C without preheating

The performance at -40° for supporting vehicle starting is superior to lead-acid battery performance. Figure 5 shows the comparison of loaded battery voltage for a single Xcelion 6T® battery compared to two (2) AGM lead-acid batteries in series. The single Xcelion 6T® battery is able to exceed the cold temperature capability of the baseline lead 6T batteries, at ¼ of the total battery weight and ½ the volume. The ability of a single battery to support cold temperature starting allows for fewer batteries to be installed in the vehicle, providing a weight and volume savings and higher reliability.

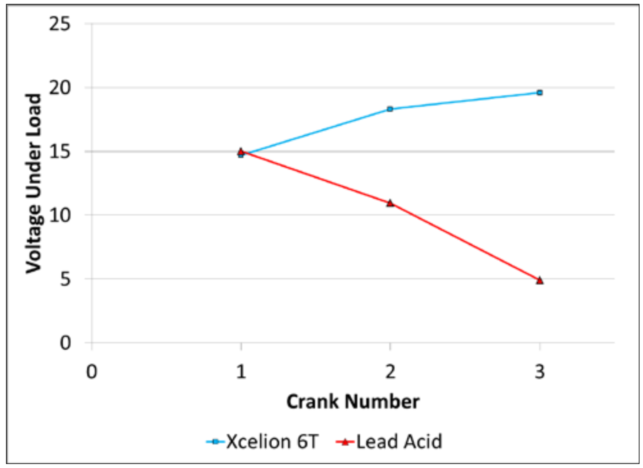

Figure 5: 400A/30sec pulse capability at -40°C

DESIGNED FOR LONG LIFE

The Superphosphate® cell chemistry used in the Xcelion 6T® battery has been optimized for life at high depth of discharge. Figure 6 shows the cycle life to 80% capacity loss for the Saft battery in comparison to lead acid and commercial 18650 lithium ion cells.

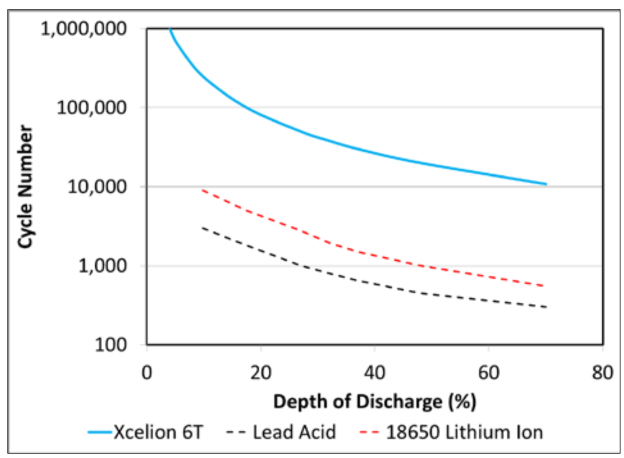

Figure 6: Cycle life comparison of battery technologies

The Saft Xcelion 6T® battery is able to support an order of magnitude more cycles than traditional batteries and is designed for the high depth of discharge demands required for effective silent watch.

In addition to cycle, life, the calendar life of the battery becomes important for long life batteries. Calendar life is the normal ageing that occurs while the battery is in use or in storage. As with all battery chemistries, it is affected by temperature and batteries will tend to age more quickly at elevated temperatures. Figure 7 shows the calendar life of the Xcelion 6T battery as a function of temperature.

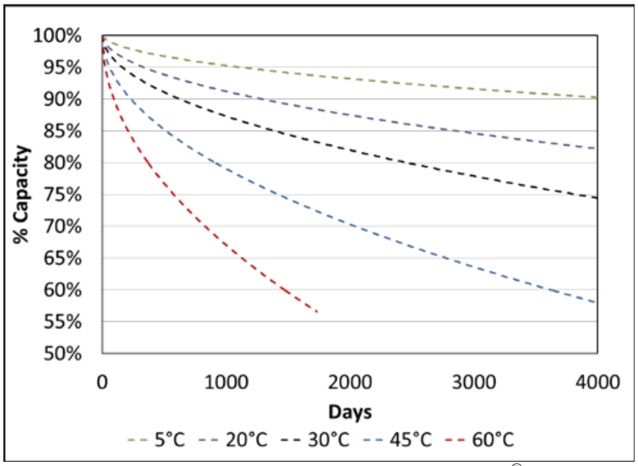

Figure 7: Calendar Life of Xcelion 6T®

The Xcelion 6T® is capable of many years of operation with little loss in capacity. For example, for an average temperature of 30°C, the battery will show 20% capacity loss in about 7 years. Plus, the battery will still remain useable beyond this time if the amount stored capacity is still useful to the user for silent watch loads.

Besides capacity loss as a function of calendar life, it is also important to understand impedance growth over the life of the battery. The impedance growth will affect the ability of the battery to support loads. Figure 8 shows the impedance growth of the Xcelion 6T® electrochemistry compared to normal 18650 lithium ion chemistry. The Superphosphate® chemistry used in the Xcelion 6T® batteries provides excellent impedance stability over the life of the battery. This means that it will still be able to support starting loads over the life of the vehicle. The ageing that occurs with typical batteries will mean that the loss in ability for the battery to support starting loads will likely be an end of life factor for that battery, even if it still has available capacity.

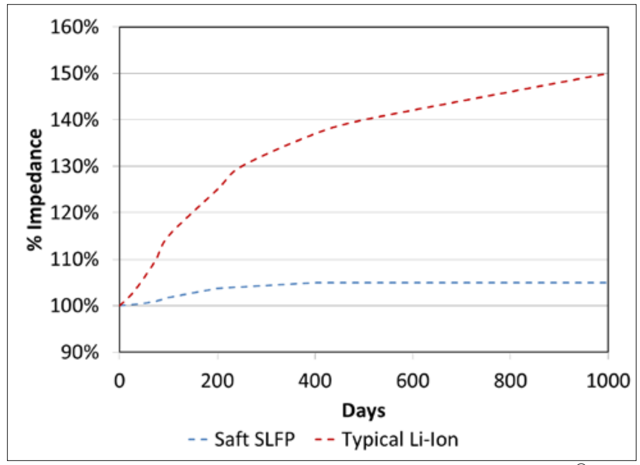

Figure 8: Impedance growth of Saft Superphosphate® in comparison to typical 18650 Li-Ion

The Xcelion 6T® battery offers its long life through excellent behavior for cycle life and impedance stability. The long cycle life and capacity retention means that it can still support silent watch missions even with years of battery use and the low impedance growth means that it will support vehicle starting with years of battery use and ageing.

SMART BATTERY FEATURES

The Xcelion 6T® can be utilized as a drop in replacement for lead-acid batteries without the need to utilize the external communications. In legacy mode, the integral BMS will still properly manage the battery states, cell balancing, and safety without the need to communicate with the battery. Modern vehicles will take advantage of the smart features offered by the BMS with active communication with the battery. Advanced features include real-time battery data monitoring with two-way communication between system and user, reserve protection to support starting at the end of a silent watch, generator control for optimal battery charging to extend battery life, and battle override to allow deep cycles and aggressive use beyond reserve levels.

Normal battery monitoring and control offers a large array of data about the battery that is easily communicated to the user through SAE J1939 compliant CANbus. In integral information on the battery is much more effective than an add-on BMS that can be used with traditional lead acid batteries. The BMS is integral to the function of lithium ion batteries and the resulted data provides valuable information for the user to more effectively manage a mission.

CONCLUSIONS

The Xcelion 6T® is the result of several generations of battery design for military vehicles. The design has been industrialized with a substantial value engineering effort to reduce the total part count, the number of assembly steps, and the unit cost of the component parts. The resulting design is competitive with existing lead-acid battery pricing over the life of the vehicle. The cell design is tailored specifically for the application to guarantee performance for power, life, and overall performance. While the cells are customized for the application, they are produced in high volume at Saft's industrial cell manufacturing facilities. This allows for low cost cell manufacturing that is competitive with the commercial lithium ion market while also maintaining design control and guaranteed source of cells from the United States and Europe.

Lead-acid batteries have served as the energy storage backbone of military fleets for decades. However, as the power and energy demands on these vehicles continue to increase in response to dynamic global mission needs, advanced-chemistry batteries, particularly cost-effective, ruggedized options such as Saft's Xcelion 6T® emerge as reliable power system options that weigh less than their lead-acid counterparts, do not require vehicle / interface design rework, yet extend the system life cycle.