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Backgrounder

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Batteries, Powered Flight and the Boeing 787

Two terracotta jars, copper sheeting and an iron rod found by archeologists working at a site near Baghdad suggest that battery technology, in varying forms, has existed for nearly 2,000 years. The team found that the artifacts could be assembled into a functional battery.

But it was the work of U.S. patriot and inventor Benjamin Franklin — who coined the term "battery" and demonstrated electricity could be stored — that inspired further scientific exploration. Like many technologies, present-day batteries are the result of steady experimentation, incremental advancements and increased understanding.

Electricity has been required for powered flight since the pioneering days of aviation. Orville and Wilbur Wright used an electrical spark to ignite the gas-air mixture in the internal-combustion engine that powered the Wright Flyer off the ground and into the history books.

Since then, airplanes have become increasingly complex, with demanding performance requirements and operational features that require more advanced electrical systems, of which batteries are an integral component.

A brief tutorial

Appreciating the role batteries play in the 787's electrical system first requires an understanding of how they work. Batteries provide electrical power, pure and simple. And the two primary batteries on board the 787 each must store a significant amount of energy — 65 ampere-hours (amp-hours) at 32.2 volts, or more than 2,000 watt-hours of energy.

To put this into perspective, consider an electric car battery. If it delivers 80 amp-hours, it means that if the electrical system needs only one amp to operate, the car can run off battery power for 80 hours. Or, if the car needs 80 amps to operate, it can run for one hour. Similarly, every combination of amps required and time can be met as long as the product equals no more than 80. Amp-hours is an approximation; the voltage and the amount of current do not instantly drop off at a certain point but rather decline over time.

One advantage of today's advanced batteries is that they better match voltage and current, making power output more sustainable. The amount of energy a battery must deliver from its internal chemical reactions is determined by how much power is required for the system to function. Determining how much power an airplane's electrical system requires is a critical design factor for engineers.

In their simplest form, batteries have three components: positive and negative electrodes (referred to as terminals when outside the battery) and an electrolyte. When the terminals are connected to an external load, a chemical reaction delivers electrons — an electrical current.

The factors that determine how much current is produced include system loads and the type of battery. One way to think about it is in the context of a residential water system: The reservoir stores the water (energy in the battery), the force that pushes it out of the faucet is pressure (voltage), and the size of the pipe determines how much water is delivered (current).

Primary batteries

The 787 has two primary rechargeable batteries — the auxiliary power unit (APU) battery and the main battery. While identical part numbers, they serve separate purposes.

The main function of the APU battery is to supply power to start the APU, a small turbine engine in the airplane's tail. When the APU is running, it can supply power for ground operations and to start the four generators, two on each engine, which are in turn used to start the engines. Together, the APU and its battery also serve as part of the multiple layers of redundancy that would ensure power in the rare possibility of a loss of primary sources of power. The APU battery is located just behind the wings on the right side, in the aft EE bay under the main cabin floor.

On the ground, the main battery "powers up" airplane systems, bringing the airplane to life before the engines have been started, and to support ground operations such as refueling. Once the engines are started, however, electrical energy for the airplane comes from the four engine generators, not the battery. In flight, the main battery is available to provide standby power when transitioning between power sources and to provide backup power for critical systems in the extremely unlikely event of a power failure. It is located in the forward electronics equipment (EE) bay, which is under the main cabin floor at the front of the airplane.

Making the right choice

The 787's game-changing operational and passenger features depend on its robust and reliable electrical system. To that end, Boeing engineering teams completed a thorough and rigorous evaluation of battery options to select the one that meets performance requirements and the stringent safety and reliability standards set by the company and by regulatory authorities. The following chart lists some of the battery options available today.

Battery Type	Composition	Common Use
Alkaline	Zinc and magnesium dioxide electrodes; potassium hydroxide electrolyte	Low-cost consumer applications such as toys and flashlights
Lithium-Ion (Li-ion)	Graphite and lithium oxide electrodes; lithium salts suspended in an organic carbonate electrolyte	Cell phones, computers and advanced aerospace applications such as aircraft and space systems
Nickel Cadmium (NiCd)	Nickel oxide and metallic cadmium electrodes; potassium hydroxide electrolyte	Consumer products, commercial airplanes
Nickel Metal Hydride (NiMH)	Nickel oxide and hydrogen-absorbing metal-alloy electrodes; potassium hydroxide electrolyte	Consumer products, hybrid automobiles
Nickel Hydrogen (NiH_2)	Nickel-oxide and gaseous hydrogen electrodes; potassium hydroxide electrolyte (requires a pressure vessel to contain the gas)	Space applications

Earlier commercial airplane models, such as the 777, 747 and MD-11, use nickel cadmium (NiCd) batteries, which are heavy, large and less powerful. Boeing ultimately determined that lithium-ion batteries would have the right chemistry and functionality to support the high-power tasks performed by the 787's main and APU batteries, such as powering certain systems while on the ground and starting the APU.

Li-Ion batteries have several advantages:

- Higher voltage and higher current production.
- The functionality of NiCd batteries while weighing 30 percent less.
- Compact — about the size of the average car battery.
- Ability to recharge more quickly.
- Will continue to charge to full capacity, and more quickly.
- Improved power quality.

Boeing has been using lithium-ion batteries for several years in other applications. For instance, the batteries have been used successfully in the satellite industry, in vehicles such as the 702 commercial communications satellite, which relies on the technology to power the entire payload. Closer to home, lithium-ion batteries are used in many common applications to power personal computing devices, some household power tools and more.

Boeing design philosophy

Boeing engineers design airplanes with two things in mind: Design to prevent failures and design in protections in the rare event a failure occurs. Above all, the goal is to ensure that no single failure will prevent safe operations and put the airplane at risk.

The safety systems that are part of and support the batteries on board the 787 are designed to address a number of fault scenarios, including overcharging, deep discharge, improper manufacturing, battery cell unbalance and extreme cold weather. Of these, overcharging is potentially the most serious and therefore is addressed with four independent protections to ensure it does not occur. Additional layers of protection for the airplane include the containment case around the battery and the strategic location of equipment in the electronics bay such that anything near the battery is either redundant or not required for flight.

787 meets FAA certification requirements

The 787 completed the most rigorous certification and flight test program in the history of commercial aviation, racking up more than 5,000 flight hours and an equal number of test hours on the ground with a fleet of six test airplanes.

The airplane meets U.S. Federal Aviation Administration requirements for airplanes using lithium-ion batteries. Battery system certification criteria ensure multiple levels of protections, design features that ensure safe battery operation, designed-in crew monitoring and warning systems, and procedures that promote safe operation and maintenance.

Proven lithium-ion performance

The 787 main and APU batteries, each with eight cells, have logged more than 2.2 million cell-hours on the ground and in the air, including more than 50,000 flight hours. No battery-related incidents occurred before January 2013, when the airplane experienced two such incidents. Investigation into these incidents is in progress.

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