By Matteo Emanuelli

How the Lithium-Ion Battery Grounded Boeing's "Dream"

First flight of Boeing 787 Dreamliner on December 15, 2009. The Li-ion batteries are located on the 787 at fore and aft. – Credits: Dave Sizer

It all began on January 7, 2013 when an electrical fire filled Japan Airlines (JAL) Boeing 787's cabin with smoke a few minutes after passengers disembarked at Logan International Airport in Boston following a flight from Tokyo. The fire was caused by the explosion of a battery used to start the jet's Auxiliary Power Unit (APU), a small turbine engine located in a compartment beneath the tail used to supply power when the engines aren't running. Only one day later, inspectors at United Airlines (UA) found a defective wire bundle connected to the APU battery of another 787 in Boston, while they were performing a check prompted by the earlier incident.

On January 16, an All Nippon Airways (ANA) 787 flying from Yamaguchi to Tokyo with 137 people aboard had to make an emergency landing at Takamatsu after smoke was reported in the cockpit. Five people were injured during the evacuation on an airport taxiway. The smoke was caused by a battery fire in the plane's forward electronics bay.

These were just the latest of a series of battery-related mishaps involving Boeing's 787 Dreamliner. A UA flight from Houston to Newark was forced to make an emergency landing in New Orleans after the failure of one of its power generators on December 4, 2012. One day later, Qatar Airways grounded one of its three Dreamliners because of the same problem and on December 17, UA reported that another 787 had developed electrical issues. Boeing reported a battery malfunction incident even earlier during a pre-delivery test flight in 2010, that had resulted in an emergency landing.

> All the mishaps reported have in common the malfunction of the plane's Li-ion batteries

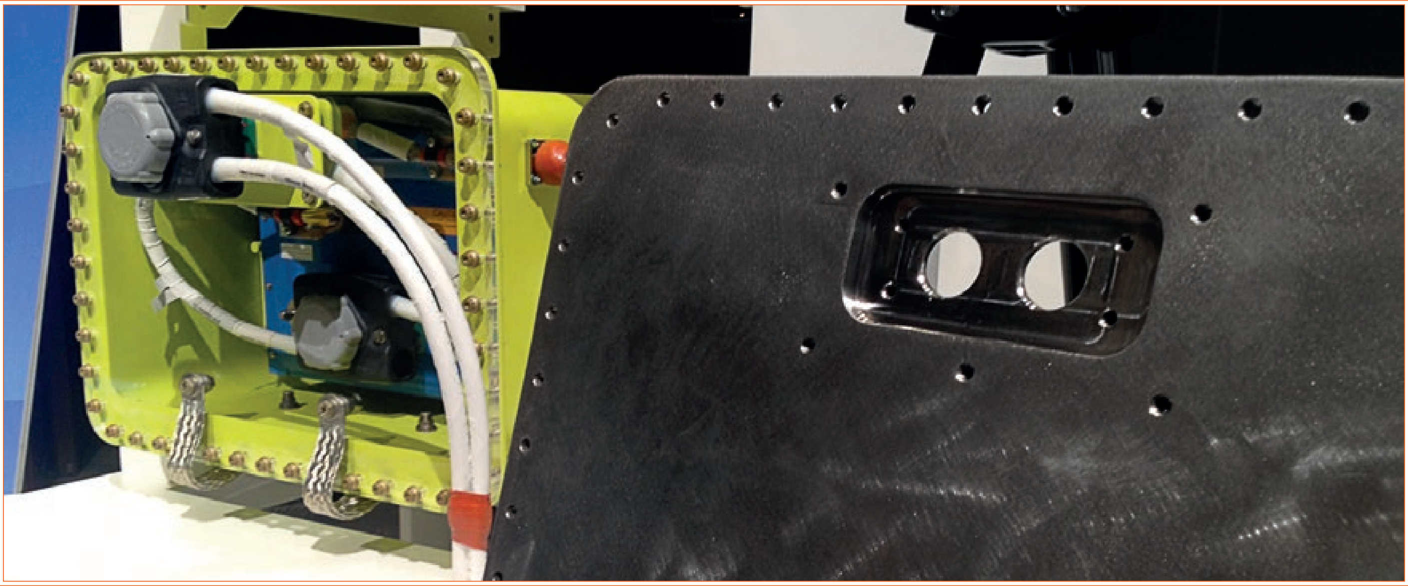
In response to these events, the US Federal Aviation Administration (FAA) announced a safety review of the 787 on January 11. Within a few days, FAA followed the decision by JAL and ANA to voluntarily ground their Dreamliners, with the order that all US registered 787s be grounded as well on January 16. In a domino effect, Poland and the rest of Europe followed the decision by decree of the European Aviation Safety Administration; they were joined a few hours later by India and Ethiopia. The gravity of the decision is underlined by the fact that this was the first time that an entire fleet of aircraft has been pulled out of service since DC-10 in 1979.

Although it is not unusual to have minor glitches in a newly introduced plane like the Boeing 787 Dreamliner, all the mishaps reported have in common the malfunction of the plane's Lithium-ion (Li-ion) batteries, found in both forward and aft underfloor electronics bays. The two Li-ion batteries aboard each craft have double the size of a typical car battery. The one in the forward electronics bay serves as flight system backup and powers pilot displays, while the one in the aft section is used to start the APU.

Advantages and Disadvantages

Boeing 787 is not the only aircraft using Li-ion batteries. Airbus A380 also uses the technology, but on the Dreamliner these batteries are used more extensively and are central to the design.

Dreamliner needs very powerful batteries because its control systems are managed entirely by electrical signals instead of hydraulic controls. Since the 787 is designed to be lighter and more efficient than previous generations of jets, the engineers at Boeing had to opt for



The comprehensive set of solutions that Boeing has proposed to the FAA is supposed to address every possible cause of the batteries' failure, according to the company. - Credits: Boeing

"We have made numerous improvements that we believe will make it a safer, more reliable battery system"

Li-ion technology. Li-ion batteries have high energy density, which means they are smaller, lighter than a traditional Nickel-Cadmium battery for a given amount of power. Moreover, Li-ion batteries have no memory effect, good charge rate capability, and the highest performance efficiency. Finally, Li-ion units can be flexibly shaped, an important characteristic on a plane, where finding space can represent a problem.

Li-ion batteries, however, are known for their safety drawbacks and they need more careful management than traditional units, as highlighted by the recent spate of incidents. These batteries tend to be very sensitive to operating conditions and easily overheat or short out when overcharged or exposed to temperatures higher or lower than their design capabilities. The high temperature environment is dangerous since it causes a breakdown of the electrodes and decomposition of electrolyte leading to a thermal runaway and fire. Very low temperatures could easily lead to an internal short during the charging process, resulting again in a fire and/or thermal runaway. When not used in its nominal condition, a Li-ion unit can also release irritating and corrosive gas from the batteries' electrolyte fluid. Moreover, 787's batteries use a lithium cobalt oxide configuration which is among the most energy-dense and flammable chemistries of Li-ion batteries on the market.

Boeing's Investigation

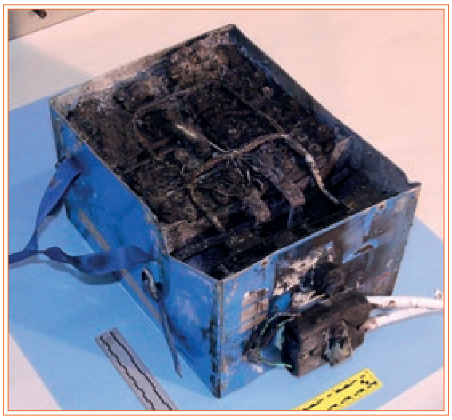
After months of investigation, it is still unclear exactly what could have caused the 787's problems. Up to now, Boeing has not been able to reproduce the issue on a flight test. However, the company has developed a comprehensive set of improvements to the 787 Li-ion batteries, hopefully covering all the possible issues. If these improvements pass the certification testing, FAA and the other international regulators will likely let operators resume 787 commercial flights. By the time this goes to publication, test flights are expected to be complete.

"We will be positioned to help our customers implement these changes and begin the process of getting their 787s back in the air," said Boeing Commercial Airplanes President and CEO Ray Conner in a 787 technical briefing in Tokyo on March 12. "Passengers can be assured that we have completed a thorough review of the battery system and made numerous improvements that we believe will make it a safer, more reliable battery system."

Improvements include enhanced production and operating processes, improved battery design features, and a new sealed battery enclosure able to contain any released flame, smoke, or gas that may result from the simultaneous failure of all eight battery cells.

An Inherently Unsafe Design?

When the 787 issue first came up, experts fingered the cell assembly or the control circuit design as the most likely culprits. SpaceX and Tesla Motors CEO Elon Musk, despite not being ▶▶



The JAL Boeing 787's APU battery involved in the Boston incident, on January 7, 2013.
Credits: National Transport Safety Board

Li-Ion batteries have been used in space over the past decade for long term satellite applications

associated with Boeing or the 787 investigation, commented publicly that the Boeing pack architecture is inherently unsafe. Instead of Boeing's architecture using a battery with a grouping of eight large cells, Musk proposed the architecture developed for Tesla cars, containing thousands of smaller cells that are independently separated to prevent fire in a single cell from harming the surrounding ones. "When thermal runaway occurs with a big cell, a proportionately larger amount of energy is released and it is very difficult to prevent that energy from then heating up the neighboring cells and causing a domino effect that results in the entire pack catching fire," said Musk in an email to Flightglobal.com.

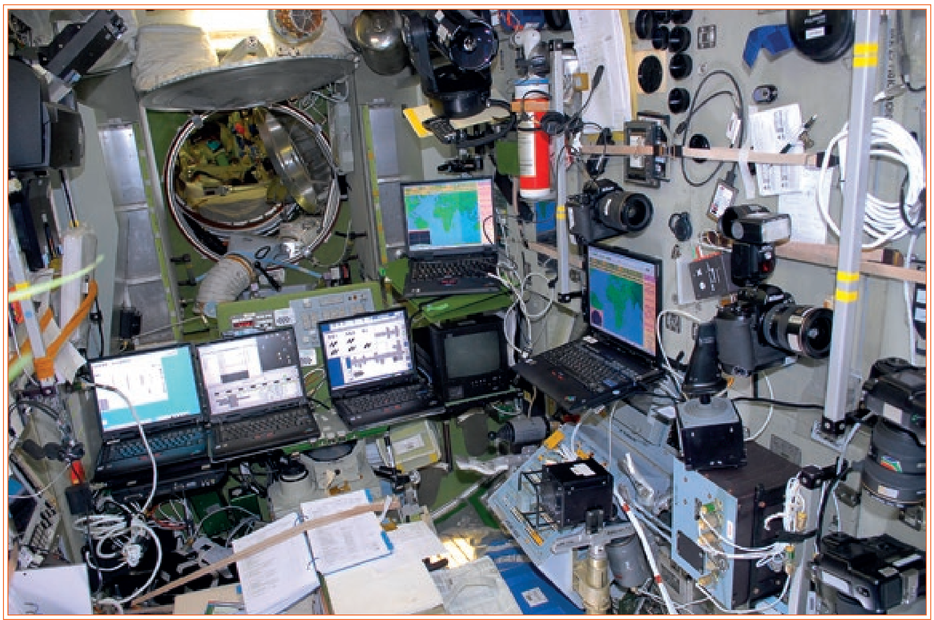
Tesla's battery has been used, with appropriate modifications, in SpaceX's Falcon 9 space launch vehicle and Dragon Capsule. However, Musk's comments must be seen in the context of SpaceX's competition with United Launch Alliance, a Boeing/Lockheed Martin joint venture, for the launch market.

Musk's claim was backed-up by Donald Sadoway, a professor of electrical engineering at the Massachusetts Institute of Technology. "I'm glad someone with such a big reputation put it on the line," said Sadoway to Flightglobal.com. "He's engineered [Tesla's battery] to prevent the domino effect, while Boeing evidently doesn't have that engineering." Sadoway suggested Boeing implement an active cooling system including temperature sensors to monitor the temperature of each of the cells or switch to Nickel metal-hydride battery chemistry: less efficient in terms of energy storage, but safer.

A Difficult History

Li-ion batteries have been used for 10 years in many commercial devices like laptops and mobile phones. Recently, they have been used also in electric cars including the Tesla Roadster, Chrysler Volt, and Nissan Leaf. Planes and spacecraft are more recent entries to Li-ion application.

The industrial implementation of Li-ion technology, however, presented technical and economical problems even in earlier, smaller devices. Dell recalled 4.1 million laptops in 2006 after several battery units overheated or caught fire. Defective batteries inside the iPhone 3GS have been known to overheat, expand, and even split apart the device's housing. Replacing the battery in the all-electric Tesla Roadster because of ignored low-charge warnings could cost up to $40,000. American Li-Ion battery manufacturer A123 went bankrupt in 2012 after a series of safety issues that forced the company to spend $51 million to replace faulty batteries manufactured for the Fisker Karma hybrid car.



ThinkPad laptops aboard the International Space Station mount Li-ion batteries just like laptops on Earth. - Credits: Lenovo

Consequences for Space Applications

The Li-ion battery chemistry has been used over the past decade for long term satellite applications in low Earth and geostationary orbits for its superior performance efficiency and longevity. Li-ion batteries are used to power laptops aboard the International Space Station. In November 2012, Boeing's battery supplier, GS Yuasa Lithium Power, Inc. (GYLP) was awarded a contract to provide Li-ion batteries for use in the ISS Electrical Power System as an upgrade to existing Nickel Hydrogen batteries.

In a January 18 interview, Dr. Judith Jeevarajan, NASA Johnson Space Center's Battery Group Lead for Safety and Advanced Technology, told Space Safety Magazine that, "Although the cells are made by the same manufacturer who made the batteries for the Dreamliner, they are of different capacity and construction." She also highlighted that the result of the Dreamliner's investigation will enhance NASA's capability to prevent future issues on the station.

Although it is too early to predict when the Dreamliner will be cleared to take to the sky again, the crisis has already provoked the significant consequence of forcing Airbus to drop its plans to use Li-ion batteries on its forthcoming A350-XWB. While Airbus doesn't want to delay production for the tricky chemistry, trusting to the older Nickel-Cadmium chemistry instead, Boeing is sticking with Li-ion technology, proposing a brand new design of the battery. However, the root cause of the original issue is still not clearly identified. The Seattle company is probably worried that a backward step to a previous technology will lead to a recertification of the whole electrical system, further delaying Dreamliner's return to operations. And Boeing is losing money and customers for every day that the Dreamliner fleet remains grounded.