BY WAYNE ROSENKRANS

THERMAL

New guidance for extinguishing lithium-battery fires is on the way.

U.S. Federal Aviation Administration

U.S. Federal Aviation Administration

The proliferation of portable electronic devices that passengers carry aboard airliners would increase the risk of in-flight fires, it was thought, but airline pilots and flight attendants in the United Kingdom since 2003 have been reassured that the extinguishing agents normally aboard their aircraft would be up to this firefighting task. However, recent experience and research seem to indicate that the "all's well" take of the underlying research report issued by U.K. Civil Aviation Authority (CAA) is not entirely justified.

The report said in part, "Based on the information, design knowledge and expertise provided by [the research contractor] regarding the in-built safety devices used in lithium-ion battery packs, together with past in-service experience, it is considered that the likelihood of an incident (i.e., smoke, fire or explosion) involving a portable electronic device with a lithium-ion battery pack is relatively low. However, [if there were such a fire,] the fire extinguishers available to the flight [crew] and cabin crew have been shown by test to be effective in extinguishing the fire."[1] Although lithium battery–specific firefighting techniques were not covered, this report built a foundation for the updated techniques expected later in 2008 from a joint effort by the CAA, U.S. Federal Aviation Administration (FAA) and three other civil aviation authorities.[2]

A few airline crewmembers have reported their need for such enhanced guidance. A Boeing 737 captain said in March 2007 — after conducting a diversion and landing without further incident — "My reason for this report is a needed change to the 'Cabin Smoke From An Unknown Source' checklist. We obviously isolated the situation [a lithium-ion battery in a laptop computer overheated during in-flight charging from an in-seat power supply port] by turning off the power ports as part of the checklist. My concern is that if a laptop [computer] is in the overhead bin and spontaneously combusts, we will never know [that the source of smoke/fire] is not the airplane. The flight attendants' [checklist] or our checklist should have a place to require all passengers with battery-powered devices of any kind to locate them and inspect them during an emergency of this type."[3]

Another airline pilot, traveling in June 2007 as a passenger, used a

magazine when asked to handle a nearby passenger's 9-volt battery, which the pilot believed to be an "alkaline battery … [with increasing] heat of an intensity which would blister skin," placed the battery in a cup of ice in the aft galley and notified the aircraft captain by interphone. The pilot-passenger later said, "Passengers carrying on batteries which have overheated have become a cabin safety issue. A large laptop [computer battery] overheating could present increased problems. Question: Is there adequate flight crew guidance available in pilot and flight attendant manuals on procedures to handle an overheating battery in the cabin? Is placing the battery in ice the proper procedure?"[4]

Despite no passenger airliner accident caused in the intervening years by a lithium-battery fire, the U.S. National Transportation Safety Board (NTSB) has reiterated concerns based on its investigation of the UPS Flight 1307 accident, in which the airplane was destroyed by fire after landing and three flight crewmembers received minor injuries during evacuation, and its awareness of incomplete and inconsistent aviation battery-incident data.[5]

U.S. Federal Aviation Administration

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RUNAWAY

NTSB's work since 2006 has torpedoed a few comfortable assumptions: that the probability of such fires is low because of the safety systems designed into most of these batteries; that passengers heed battery makers' safety warnings against battery misuse/abuse and comply with applicable regulations; that extinguishing agents can put out equally all types of lithium-battery fires; and that flight attendants can respond proficiently to a potential or actual thermal runaway — the characteristic of special concern in these fires.

"The issuance of the safety alerts and advisories [by the Pipeline and Hazardous Materials Safety Administration (PHMSA) of the U.S. Department of Transportation (DOT) and FAA] and the new, more stringent requirements [by PHMSA effective in January 2008] demonstrate the growing awareness and concern within the DOT and the airline industry over the air transportation of primary [nonrechargeable] and secondary [rechargeable] lithium batteries and electronic equipment containing such batteries," NTSB said in the final accident report (Table 1, p. 44).

Lithium Battery Basics

Lithium-ion battery refers to a rechargeable type that contains lithium as one element of chemical compounds but no metallic lithium in its elemental form. Lithium-ion batteries typically power consumer electronics such as laptop computers, mobile telephones, music/video players,

Left, overheated lithium-ion cell releases flaming electrolyte; six cells burned in a carry-on spare laptop battery. Above, a thermal runaway charred a JetBlue Airways overhead compartment; one of the laptops shipped on UPS Flight 1307.

A Growing Understanding of Lithium Battery Risks to Airliners

Date	Battery	Occurrence/Report	Significance
1976–1983	Lithium (unspecified)	After adopting approved battery designs first marketed in 1970, the U.S. Navy reported six injuries and one death.	Launched in 1982, the Navy's Lithium Battery Safety Program currently provides a technical manual of specifications and procedures, safety-performance testing requirements for cell/battery approval, safety-data packages and training.
May 1994	Lithium-metal	Loose button-size batteries in a box emitted smoke and showed fire damage during transport by truck.	The U.K. Civil Aviation Authority (CAA) noted that these batteries were destined for shipment as cargo on a passenger flight from London Heathrow Airport; the resulting safety focus was on the absence of protection against short-circuiting.
April 1999	Lithium-metal	A total 120,000 batteries on two cargo pallets burned after being removed from a passenger flight and then mishandled/dropped on the apron at Los Angeles International Airport.	Airline employees' initial attempts to extinguish the fires with portable fire extinguishers and a fire hose failed; flare-ups recurred each time the fire appeared to be extinguished. No external ignition source was found. The U.S. National Transportation Safety Board (NTSB) called for evaluation of lithium battery issues and appropriate measures to protect passengers and aircraft.
July 2003	Lithium-ion	U.K. researchers tested some of the most common battery packs used in portable electronic devices carried into aircraft cabins.	The report for U.K. CAA found "the likelihood of an incident (i.e., smoke, fire or explosion) … is relatively low." The test results "verified the effectiveness of existing fire-extinguishing agents in coping with a lithium-ion battery fire."
August 2004	Lithium-ion	Smelling smoke during loading, handlers repositioned a cargo container from a freighter to the ground; one of two 136-cell battery modules soon ignited.	NTSB said the probable cause was the failure of unapproved packaging, which was inadequate to protect the modules from short circuits during transportation. This 2005 report cited 16 other U.S. and non-U.S. events as relevant for regulatory review.
September 2006	Lithium-ion	The U.S. Federal Aviation Administration (FAA) released a study of fire-related characteristics of the most common type of cell used inside laptop computer batteries.	Individual cells and bulk-packed cells packaged for shipment on cargo and passenger aircraft were tested. FAA found in part that Halon 1301, the only FAA-certified fire-suppressant agent for systems permitted in cargo compartments of passenger aircraft, is effective for fires but not in sufficiently cooling overheated cells to prevent them from explosively releasing flaming liquid electrolyte seconds to minutes after its application.
January 2008	Lithium-metal	A final U.S. Department of Transportation (DOT) rule, effective on an interim basis in December 2004, prohibited cargo shipments of specified lithium-metal batteries on passenger aircraft.	Reasons included evidence from FAA research that heat from a smoldering cargo fire could ignite a lithium-metal battery fire, fire propagation between these batteries was likely, and burning batteries could not be extinguished by Halon 1301.
January 2008	Lithium-ion and lithium-metal	A DOT rule prohibited airline passengers from carrying loose batteries in checked luggage; monitoring of safety issues continued.	The rule allowed carrying batteries of specified sizes and quantities only if installed in portable electronic devices in checked luggage or carry-on bags, or packed as spares in carry-on luggage with protection against short-circuiting by enclosure in original packaging or other acceptable methods.
February 2008	Lithium-ion	NTSB released the final report on the UPS Flight 1307 accident in Philadelphia.	Although lithium-ion battery packs in laptop computers were among cargo burned in the early stages of the fire, the fire origin was undetermined. As part of this investigation, NTSB issued additional safety recommendations related to lithium-ion and lithium-metal batteries carried in cargo and passenger operations.

Sources: DOT, FAA, NTSB, U.S. Navy

Table 1

digital cameras and video camcorders. *Lithium-metal battery* refers to a nonrechargeable type that does contain lithium as a distinct element. Lithium-metal batteries typically power film cameras, high-intensity flashlights, remote control devices, toys and many other devices that take batteries of small standard sizes.

Distinguishing between these types is important because of different characteristic fire behavior and how cabin fire extinguishers perform. For example, the chemical components in lithium-metal batteries responsible for the batteries' superior energy density compared with conventional carbon-zinc or alkaline batteries can contribute to increased risk of fire and explosion if they are misused or abused. NTSB noted in a 2004 hazardous materials accident brief that "lithium is a combustible alkali metal that self-ignites in air at 352 degrees F [178 degrees C]. When exposed to water, lithium … releases hydrogen, creating a dangerous fire risk. Fires involving lithium are extremely difficult to extinguish. Extinguishers using water, gas or certain dry chemicals cannot control this type of fire."

Thermal runaway — essentially an internal chemical reaction unleashed by overheating a lithium-ion or lithium-metal battery — concerns aviation safety researchers. This reaction can be triggered by a short circuit, improper use, physical abuse, failure of protective systems, manufacturing defects or extreme external heat. Thermal runaways are startling and disorienting for unwary crewmembers and passengers, and fires would be especially hazardous if they spread to hidden areas of the aircraft. Flight attendants therefore have to be vigilant and anticipate the possibility of a fire involving a portable electronic device or spare battery on tray tables or in seatback pockets, overhead bins, closets or under seats.

In a draft video about laptop computer fire fighting, FAA has induced thermal runaways with one or more lithium-ion cells exploding unpredictably in seconds to minutes. The thermal runaway of each of six or nine cells in each laptop computer battery pack tested produced a brilliant flash, loud bang, jets of flaming liquid electrolyte, intense heat and thick smoke. Part of the implied challenge for the cabin crew in responding to thermal runaways then is determining when the process has ended so that the battery or device can be handled without anyone being burned by the device/battery itself or flying debris, or sustaining smoke/fume inhalation or an eye injury.[6]

To reduce the risk of a thermal runaway, PHMSA — the lead agency in the United States responsible for determining how to regulate lithium batteries and whether restrictions actually protect the traveling public — recommended these safety measures on its comprehensive Web site at <safetravel.dot.gov>: Keep batteries installed in portable electronic devices and carefully handle batteries when replacing a discharged battery with a spare during flight; pack spare batteries in carry-on luggage because fires are easier to detect in the cabin and flight attendants have access to fire extinguishers; keep spare batteries in original retail packaging; if retail packaging is unavailable, effectively insulate battery terminals, using insulating tape to further protect batteries that have protruding or sharp terminals and enclose them with a sturdy resealable plastic bag; use only batteries purchased from reputable sources and do not carry onto aircraft recalled, damaged or counterfeit batteries, including lithium-metal batteries charged contrary to safety warnings; and protect portable electronic devices containing batteries from inadvertent activation by using such devices as locks on switches or protective cases. One U.S. manufacturer of lithium–manganese dioxide cells and batteries [one subtype of lithium-metal battery], citing industry standards, also said that consumers immediately must discontinue using a battery that "emits an unusual smell, feels hot, changes color or shape or appears abnormal in any other way."[7]

PHMSA in March 2007 said, "Airline passengers who carry batteries or electrical devices in carry-on or checked baggage are responsible [under U.S. hazardous materials regulations] for ensuring appropriate steps are taken to protect against dangerous levels of heat that can be generated by inadvertent activation or short-circuiting of these devices while in transportation."[8]

Wayne Rosenkrans

Placing each spare lithium-ion battery pack in a sturdy resealable plastic bag can prevent short-circuits; spare lithium-metal batteries require comparable protection.

Airlines rely on aircraft occupants to obey regulations and heed warnings on use of lithium battery–powered devices such as high-intensity flashlights.

Wayne Rosenkrans

By January 2008, however, NTSB had issued two safety recommendations urging PHMSA, FAA and the airline and battery industries to take further steps to ensure passenger and crewmember awareness of the risks of improper use of lithium batteries inside aircraft cabins, and to measure and publish the results of communication campaigns.[9]

Scope of Problem Debated

Interpretation of the sparse U.S. data about lithium-battery fires on passenger flights has been a continuing point of contention (see "Crew Experiences"). According to a 2005 study by the U.S. Institute of Standards and Technology, "About five safety incidents involving notebook computers [including those in aviation] occurred in 2002. Cell production was in the range of 770 million units, of which roughly 40 percent (350 million) were for installation in [battery packs of] notebook computers. This translated into five incidents in 308 million, or slightly more than one [incident per] 61 million cells."[10]

Counting lithium battery incidents in aviation without categorizing them also has been contentious. From Feb. 1, 1996, through July 25, 2007, FAA's battery-incident database showed 14 incidents involving lithium-ion batteries — six involving checked baggage and carry-on items intended for passenger flights — and 13 involving lithium-metal batteries, according to an NTSB analysis. "Of the seven incidents involving passenger aircraft, two occurred in flight, one causing the flight crew to divert; three occurred on board before takeoff; and two occurred in the airports before boarding the aircraft," NTSB said.[11]

Lithium-metal batteries were involved in six incidents involving carry-on items intended for passenger flights, and two incidents involved packages shipped as cargo on passenger flights. "Of the eight incidents involving passenger flights, four occurred in flight, two causing the flight crew to divert or land; two occurred or were detected postflight, either during unloading or sorting operations; and two occurred before boarding the aircraft," NTSB said.

Another argument was advanced in a November 2007 presentation to the Dangerous Goods Panel of the International Civil Aviation Organization (ICAO) by the Portable Rechargeable Battery Association (PRBA), which said that some incidents cited from FAA's battery-incident database lack sufficient detail for useful safety analysis.[12]

"While there appear to be several reasons for these incidents, the majority of incidents were caused by non-compliance with the current regulations that govern the transport of lithium batteries and equipment powered by them, and passengers who failed to protect batteries from damage and short circuits," the association said. "Therefore, PRBA does not believe significant revisions to the current lithium battery dangerous goods regulations are necessary. … However, it is important to recognize that what is missing from this [FAA] list of incidents is any meaningful 'root cause' analysis of the purported incidents."

PRBA also said that some of the incidents in FAA's database involved batteries or devices that could have been subject to recall, damaged or counterfeited — yet such root causes could not be determined without failure analyses, which typically did not occur. In its comments on a letter to NTSB from the Air Line Pilots Association, International (ALPA) concerning the UPS Flight 1307 accident, PRBA also said, "There have been fewer than 50 incidents of [battery packs worldwide] overheating — fewer than 10 of which have involved flames — during a period in which over 5 billion lithium-ion cells have been produced. The [2006] Sony recall, which has received the most notoriety, has involved only a subset of this handful of incidents, even though apparently over 9 million battery packs were in service that may have contained cells from the same production runs."[13] Safety devices within each lithium-ion cell are designed to power off the cell if an internal cell short-circuit and spontaneous overheating occur because of contamination of parts of the cell by microscopic metal particles during manufacturing — which prompted, for example, the 2006 recall of Sony cells built into various laptop computer manufacturers' battery packs.

Crew Experiences

U.S. government investigations of cabin fires linked to a lithium-ion or lithium-metal battery typically find it difficult or impossible to obtain complete factual details and produce optimal analyses in the absence of standardized reporting, some aviation safety specialists say. The following summaries reflect issues that crewmembers have encountered in the relatively few situations in public records:

- Flight attendants preparing for the departure of a Boeing 767 smelled fumes, then saw smoke from a passenger's carry-on bag by opening an overhead bin. Removed to the airbridge, the bag contained scorched/melted clothing packed around an extremely hot video camcorder battery of unspecified type; a maintenance technician received a thermal injury to his hand while removing the battery.[1]
- The flight crew of a chartered 727 returned to the departure airport and landed without further incident after flight attendants and federal security agents extinguished a passenger-seat fire ignited after the explosion of a 9-volt lithium-ion video camera battery as it was being handled by a news media videographer.[2]
- During boarding and baggage loading, fire in a checked bag was discovered by a baggage handler who saw flames. Firefighters later told a crewmember of the Airbus aircraft that the fire had been ignited by a lithium-ion battery pack, designed for a handheld video game player, which had been packed loosely among wires and cables.[3]
- The flight crew diverted a 737 and landed without further incident after passengers and a flight attendant smelled electrical smoke, which at first seemed to have dissipated after completion of emergency-checklist items. Firefighters within 30 seconds of entry located smoke still being emitted by an extremely hot battery pack inside a passenger's laptop computer, which had been recharging from an in-seat power supply port.[4]
- A flight attendant notified the captain during an international flight that a battery of unknown type had exploded in the coach section of the widebody transport airplane. The crew continued to the destination after the captain determined that no injuries had occurred, smoke had dissipated without further indication of fire, one seat cushion had been damaged and only a few pieces of the battery could be found. No passenger would take responsibility for owning the battery.[5]
- During cruise, the flight crew of an A320 identified the source of a loud popping sound and acrid burning odor as an explosion involving the xenon lamp and lens in the captain's high-intensity flashlight, which had been used during the preflight inspection. After donning oxygen masks and clearing the odor from the cockpit, the crew found that this flashlight was hotter than normal and its lithium-metal batteries were charred.[6]

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Notes

1. U.S. National Aeronautics and Space Administration (NASA) Aviation Safety Reporting System (ASRS) report no. 440497, June 1999.
2. U.S. Federal Aviation Administration Accident/Incident Data System report no. 20041029028789c, Oct. 29, 2004.
3. NASA ASRS report no. 730630, March 2007.
4. NASA ASRS report no. 731104, March 2007.
5. NASA ASRS report no. 732079, March 2007.
6. NASA ASRS report no. 760318, November 2007.

Dramatic Video Demonstrations

Though not released as official guidance, the FAA's draft firefighting videos have been presented in public forums and posted to a Web site for industry comment. The draft video showing laptop computers, positioned as used on a cabin tray table, said that any installed battery pack may malfunction and overheat, often during the charging process, causing the pack to ignite. "A cell, in a thermal runaway, gets extremely hot, then overpressures, releasing flammable liquid electrolyte," FAA said. "Cells may explode."

This draft video shows scenarios of thermal runaways, induced during tests by external heating with either an electric hot plate or alcohol flame. Extinguishing options discussed include Halon 1211 fire extinguishers, water fire extinguishers, and bottles or pitchers of water, juice, soda, carbonated drinks and other nonalcoholic liquids typically found on a beverage service cart.

"The objective is to extinguish the fire and cool the battery pack, preventing additional cells from reaching thermal runaway," FAA said. "Water fire extinguishers are effective at extinguishing the fire and cooling the battery pack. Halon 1211 fire extinguisher followed by the available water source [was the second-best option in tests because] Halon 1211 extinguishes the fire and water cools the battery pack. [The third-best option was] using a Halon 1211 fire extinguisher alone, which extinguished the fire and prevented spread of fire as the battery cells consumed themselves [but] Halon 1211 did not prevent additional cells from reaching thermal runaway. Avoid using ice or smothering substances that act as an insulator; containing heat forced adjacent cells to explode."

As of February 2008, this draft video contained the following summary language for these scenarios:

- "Do not attempt to pick up and move the computer [because of the] extreme danger of bodily harm.
- "Relocate passengers away from the computer.
- "If a water [fire] extinguisher is available, utilize it to cool the computer and prevent additional cells from reaching thermal runaway.
- "Use Halon 1211 to extinguish the fire and prevent spread to adjacent flammable materials. Follow this [action] by dousing the laptop with water or other nonalcoholic liquids from the drink cart or any other source.
- "Avoid the use of ice or other covering materials [to cool or suffocate the fire]. These will insulate the laptop, making it more likely that more cells will reach thermal runaway."

In May 2007, ALPA suggested ways that airlines can supplement the guidance in FAA Advisory Circular 120-80, *In-Flight Fires* until the next revision. "Once ignited, a [lithium] battery fire may … have many characteristics that are not traditionally covered in firefighting training for crewmembers," ALPA said. "Once the fire appears to have been extinguished, consider moving the [portable electronic] device to an area without flammable material, such as a galley oven (if not adjacent to the cockpit); the device should not be moved if it is still on fire, or if it is too hot to be moved safely. … Remove power to the remaining passenger outlets [in-seat power supply ports] until the aircraft's system can be determined to be free from faults, if the device was previously plugged in [to a port]."

In the context of airlines enhancing guidance for cabin crews on lithium-battery fires, FAA said in August 2007, "Crewmembers should be aware of the content of the PHMSA guidance for the transport of batteries and battery-powered devices, and should continue to be vigilant as batteries become more powerful and battery-powered devices more numerous." ●

Notes

1. Lain, M.J.; Teagle, D.A.; Cullen, J.; Dass, V. "Dealing With In-Flight Lithium Battery Fires In Portable Electronic Devices." Safety Regulation Group, CAA. CAA Paper 2003/4. July 30, 2003.
2. Cabin Safety Research Technical Group (CSRTG). "Aircraft In-Flight Firefighting." October 2007. This draft video was posted for airline industry review and comment at <www.fire.tc.faa.gov/2007Conference/files/Training_Videos/ThursPM/Videos/BlakeFirefightingVideo1.wmv>. The CSRTG comprises representatives of Agência Nacional de Aviação Civil of Brazil, U.K. CAA, Direction Générale de l'Aviation Civile of France, the FAA and Transport Canada.
3. U.S. National Aeronautics and Space Administration (NASA) Aviation Safety Reporting System (ASRS) report no. 731104, March 2007.
4. NASA ASRS report no. 740664, June 2007.
5. NTSB. "Inflight Cargo Fire, United Parcel Service Company Flight 1307, McDonnell Douglas DC-8-71F, N748UP, Philadelphia, Pennsylvania, February 7, 2006." Accident Report no. NTSB/AAR-07/07. Dec. 4, 2007.
6. FAA. "Extinguishing In-Flight Laptop Computer Fires." October 2007. This draft video was posted by Advanced Imaging, Operations Planning, FAA Air Traffic Organization, for airline industry review and comment at <www.fire.tc.faa.gov/2007Conference/files/Training_Videos/ThursPM/Videos/Laptop_master.wmv>.
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13. Kerchner, George A. Letter to NTSB Member Deborah Hersman. Oct. 26, 2006.