Lithium Battery Hazards

You owe it to your passengers and crews to **know how to respond when the heat is on**

BY **DAVID ESLER** david.esler@comcast.net

Thermal runaways and resultant fires of lithium-ion batteries powering electronic devices brought aboard aircraft by passengers and crewmembers continue to vex regulatory agencies and operators.

And as the popularity of digital devices grows, from "smart" cellphones, tablets, laptop computers and related chargers to wireless headsets, electronic cigarettes (e-cigs), and even heated socks — all powered by li-ion batteries — aviation-related thermal runaway incidents are increasing year on year.

According to statistics compiled by the FAA's Office of Security and Hazardous Materials Safety, in 2017 internationally, there were 46 recorded li-ion thermal runaways in passengers' carry-on luggage and backpacks or while devices were in use, either aboard commercial airliners or in boarding lounges at airports, the majority of them aboard aircraft either on ramps or in flight. That's one approximately every eight days.

In 2016, there were 31 incidents; in 2015, 16; in 2014, nine; and in 2013, eight. As of the end of April 2018, 16 thermal incidents had been recorded. Given the popularity of digital devices, one can assume that just about any airline flight today must contain hundreds of li-ion batteries active in passengers' electronics or in chargers, either in carry-on baggage or plugged into the USB ports in seat rows. (Statistics on lithium battery thermal runaways aboard business and general aviation aircraft are lacking, but given the widespread use of such units, such events have occurred or likely will.)

A Threat to Aviation

"We never considered lithium batteries an aviation safety threat," Mark Millam, vice president, technical at the Flight Safety Foundation, told *BCA*. "But here you have a small battery that holds so much energy in comparison to its predecessors like NiCad and NiMH batteries, that now if something goes wrong, you can have explosive events. And they're so prevalent now in all kinds of applications, like cellular telephones, that statistically, and based on what we know about their stability in certain situations, they can be considered a threat." Note that this threat is conditional, and that if properly used and protected, li-ion batteries are a reliable and efficient power supply.

It is the ability to concentrate a relatively large amount of energy into a small and lightweight package that makes rechargeable lithium-ion batteries so useful and attractive to the manufacturers of digital electronic devices and other applications. Their "power density" allows high performance and long duration — up to 8 or 9 hr. for contemporary laptop computers (which will probably be extended by the time this is published) and several days for cellphones, depending on usage.

Lithium batteries work when lithium ions flow from the negative electrode (or anode), through an electrolyte, to a positive electrode (or cathode) during discharge; when charging, the process is reversed, and the ions flow back to the negative electrode. "Intercalation" is the process by which ions are sent from the anode to the cathode. Generally, the negative electrode is carbon-based (usually graphite), while the positive electrode is a metal oxide (generally, cobalt). The electrolyte, meanwhile, is a lithium salt in an organic solvent. Pure lithium is highly

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The heat and gases emitted in a lithium-ion thermal runaway can be extreme and toxic, as evidenced by the burn received by this young woman when the battery in the wireless headset she was wearing ignited.

reactive, responding violently with water to form lithium hydroxide and hydrogen gas. Consequently, a non-aqueous electrolyte is employed in lithium batteries, sequestered in a sealed container that protects the battery pack from moisture.

Problems occur when the electrolyte is compromised, as a short circuit can occur, and due to the power density of the battery — or a cell therein — the concentrated energy discharges very quickly. This causes the cell or battery to overheat, possibly catching fire and burning at temperatures in excess of 1,100F. In batteries made up of multiple cells, adjacent ones can, in turn, overheat and fail, causing the entire battery to rupture and ignite. Thus, a thermal runaway results. In rare cases, the power of the energy released can cause the battery to explode.

During the discharge process, either normal or runaway, the positive electrode produces oxygen, which can feed ignition during a rupture. Furthermore, the liquid electrolyte used in li-ion batteries is both flammable and highly toxic to human skin when released, causing burns. When ignited, the battery emits dense, highly irritating smoke, which, as we will see, was a factor in the loss of at least one aircraft that was carrying closely packed lithium-ion batteries as cargo.

Correctly designed and manufactured batteries contain management and "thermal interrupt" circuitry designed to prevent runaways. However, faulty chargers can compromise these built-in protections. Use of aftermarket chargers not matched to devices like cellphones has been known to be a culprit in bypassing battery-management circuitry and causing thermal runaways.

According to Louisa Fisher, cabin safety program manager at FlightSafety International, inexpensive "gray market" charging equipment for brand-name devices has become a frequent source of thermal runaways in digital equipment. "Something left unattended on a charger can overheat and catch fire or damage the device that's being charged," she said. "There is a great concern about using these off-market [charging] devices on quality equipment that they weren't designed for."

Do Not Spindle, Fold or Mutilate

Other li-ion thermal runaway causes include:

▶ Squeezing or crushing the battery pack or the device containing it, usually contemporary ultra-thin mobile phones, thus releasing the electrolyte or crossing terminals and creating a short circuit. On airliners, the most common breach is caused by phones crushed in reclined seats when they're retracted.

"You fumble your phone, it drops out of sight, and what do you do?" Fisher asked, rhetorically. "You straighten the seat so you can look for it, and if the phone is in exactly the right place, that action crushes or otherwise deforms it before you can find it and causes an overheating incident in the battery."

▶ Dropping or otherwise abusing a device or puncturing a battery accidentally so that, again, the electrolyte is released, precipitating a short.

▶ Overcharging, either by using the wrong charger for the device containing the battery or by "boosting" a free battery (*i.e.,* pumping more amps into it than the battery was designed to accept) with an adjustable charger used to charge lithium-polymer batteries for radio-controlled models and small drones. (Instructions for operating these sophisticated chargers must be followed explicitly.)

▶ Heating the battery above its recommended operating temperature. (Consider this when leaving a lithium-ion-powered device or loose batteries in a locked car parked on a blazing hot summer day.)

▶ Design flaws in digital devices. This was the attributing factor in the battery fires that resulted in the recall of the Samsung Note 7 phone a few years ago. As the Flight Safety Foundation's Millam pointed out, the device "had insufficient space for the battery to absorb any pressure on the case. If squashed or pinched in a certain way, the pressure on the battery could cause terminals to come into contact and the battery to overheat and explode." So, for the safety of a device, he explained, "you have to keep the cells [in the battery] properly separated and protected."

▶ Spare batteries and battery packs (i.e., uninstalled) with terminals unprotected either by a manufacturer-supplied plastic cap or tape. (This includes non-rechargeable lithium-metal batteries.) If terminals are somehow allowed to be crossed by a conductive material, the batteries could short and experience thermal runaway. Airlines and the FAA advise passengers carrying spare batteries to either keep them in the manufacturer's original packaging, securely in a charger (so that terminals are not exposed), or with the terminals capped or taped. Spare batteries are not allowed in checked baggage but can be brought into cabins if properly protected.

Given all these vulnerabilities, do lithium-ion batteries constitute more of a risk than should be accepted in aviation?

"That isn't clear," Millam answered, "as you can build those protections into any given battery so its reliability and safety can be well-managed. But you must have separation in whatever you're putting them into by design — a pouch or encasement of the electrodes. Some of the design flaws may be in the encasement or the wiring that leads to and from the batteries and how they are used after that. You could damage them in ways that were not anticipated by the designer and cause shorts."

Last year's ban of so-called "smart luggage" by major U.S. airlines once again swept the issue of lithium battery safety aboard aircraft into the mainstream news. In the disruptive world of high tech, we are accustomed to the almost daily appearance of yet another digital/wireless application, everything from household appliances that can learn and communicate with owners to robotic personal assistants (Siri, Alexa, *et al.*) ready to do our most intimate bidding, all controlled from the ubiquitous mobile telephone and equipped with GPS.

So, enter the smart lithium battery-powered suitcase that can weigh itself, whose locks can only be opened by a

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What happens to a smart phone after a lithium-ion battery thermal runaway. This one was purposely shorted in a Baker Aviation lab test for a containment bag.

phone app or your fingerprint, is equipped with Wi-Fi and a USB port to charge your devices, and which always knows where it is — a boon to tracking your luggage when you're flying to New York and the airline has sent your clothing and toiletries to Anchorage. One product, the Modobag, is even an EV (electric vehicle) that its owner can sit on and ride through the airline terminal like a virtual pooh-bah. And all through the magic of the li-ion battery.

And that's the problem. In truth, the smart luggage airline ban prohibits carriage of the devices as checked baggage unless the li-ion batteries can be removed — which on some products cannot — and transported in the cabin. (In most laptop computers today, batteries cannot be removed without disassembling the device, often a task best accomplished by a technician familiar with the product.) With the batteries still in them, the smart bags can still be brought onto the aircraft as carry-on luggage if they can fit into overhead bins. Nevertheless, two manufacturers of smart luggage, Bluesmart and Raden, went out of business, their executives blaming the airline li-ion battery ban for their companies' demise.

But consider this observation from Michael Mo, CEO of KULR Technology in San Diego, which engineers and makes thermal-management containment materials and enclosures: "There is consumer appeal to the smart luggage, but these intelligent suitcases can get banged around or punctured, and so how do you deal with the battery pack issue if there's a runaway? Hence, the ban was inevitable. You can't remove the batteries in some of them, and so you can't check them as unattended baggage. A wonderful product, but there are downsides with the battery safety issue."

Lithium Batteries as Cargo

Shipping lithium-ion batteries in bulk by air freight, either in cargo holds of passenger aircraft or in dedicated freighters, has been problematic. When batteries, either chargeable (lithium-ion) or non-chargeable (lithium-metal) are packed closely together in a shipping container or on a pallet without proper isolation between them, one defective cell can experience a thermal runaway and trigger a disaster. Given that a large roll-on shipping container can accommodate as many as 5,000 AA-size batteries and pallets can hold exponentially higher numbers, all packed choc-a-bloc, if something goes wrong, it's akin to having a bomb on board waiting to be detonated.

In September 2010, this possibility became reality when a fire erupted in the forward main-deck cargo compartment of a fully loaded UPS Airlines Boeing 747-400F while the aircraft was climbing out of Dubai en route to Cologne, Germany. Spreading rapidly, the fire burned extremely hot, and within 3 min. of the fire warning showing up on the cockpit EICAS, it had burned through the fire-resistant overhead liner in the cargo compartment and compromised the plane's elevator controls. Meanwhile, the fuselage and cockpit filled with extremely dense, toxic smoke.

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It was determined that the Samsung Note 7 was designed with insufficient space for the battery to absorb pressure on the case, which could cause the phone's li-ion battery to short circuit with this result.

The two-pilot crew donned their oxygen masks but had difficulty seeing either the instruments or through the cockpit windows. They declared an emergency with Bahrain ATC, in whose airspace they were flying, and successfully made a turn back to Dubai. Meanwhile, the captain's supplemental oxygen supply failed, and he left his seat to retrieve an EROS (Emergency Reserve Oxygen System) mask stowed in the aft cockpit but became incapacitated by the smoke, lost consciousness, and collapsed on the floor, leaving the first officer to fly the airplane alone.

ATC guided the stricken aircraft to Dubai International Airport and instructed the FO to attempt a landing on Runway 12L, but the 747 was too high and its landing gear failed to extend. It passed over the airport while the FO, unable to see the instruments and struggling with the controls, now attempted a turn toward a neighboring field 10 nm away. This airport was also over-flown, and turning back, control was lost, and the big Boeing struck the ground at a military installation, skidding for some distance before exploding. Both pilots perished in the crash.

In the ensuing investigation by the United Arab Emirates General Civil Aviation Authority (GCAA), the government of Bahrain, the U.S. NTSB, and UPS, it was revealed that the 747's cargo complement contained large numbers of lithium batteries in various configurations, both individual cells and battery packs of various sizes, as well as cellular phones with batteries installed. While ICAO and the FAA have since ruled that lithium batteries in bulk should be declared "dangerous goods," that requirement didn't exist at the time, and so the shipper of the batteries on the UPS 747, located in Hong Kong, the flight's previous stop before arriving in Dubai, had not so-identified the cargo.

For some time, investigators would only speculate that the battery shipment "was involved" in the inflight fire. (Attribution was complicated by the fact that nearly everything aboard the 747 and most of the airframe had been consumed in the post-crash fire, fueled by thousands of gallons of Jet-A.) But when the GCAA report was filed three years after the accident, one of the findings was that, "At some point prior to the fire warning, a cargo pallet on the main deck containing lithium batteries auto-ignited, causing a large and sustained cargo fire that was not detected by the smoke detectors when in the early stages of pyrolysis." That is, when a portion of the 81,000 lithium batteries on the pallet were entering thermal runaway.

"What's of concern to the aviation industry is when the shipper doesn't declare they are shipping these devices and have not provided the proper separation in the packaging," Millam observed. "If a fire started in a situation like that, you could have a condition on the aircraft where you could not respond quickly enough. We are aware that this is an emerging issue — not an accident trail but exposure to something new — so we are studying what other organizations are doing to understand it. Some airlines have taken steps to avoid bigger shipments of batteries or are requiring certain separation requirements from known manufactures and shippers."

Of even greater concern has been the shipping of lithium batteries in the baggage holds beneath passenger aircraft. "If you ask 100 passengers disembarking from an airliner what was under their feet," Lynn McGuigan, ICAO's technical officer, Cargo Safety Section, pointed out, "some will say baggage and some cargo, but most don't know that retailers are shipping large quantities by aircraft. Up to a few years ago, li-ion batteries by themselves [in bulk] were permitted to be carried in the holds of passenger aircraft."

Dangerous Goods

But now lithium batteries are classified as dangerous goods. ICAO Annex 18 stipulates safe transport of dangerous goods by air and includes links to a detailed technical instruction document for shippers, operators and governments covering both passenger and freight aircraft. As cargo, lithium-metal batteries have been banned by ICAO on passenger aircraft since January 2015; lithium-ion batteries were banned in April 2016. And as an ICAO signatory, the FAA has followed suit.

"Boeing and Airbus issued statements to customers that their fire extinguishing systems were not capable of handling fires of significant size," McGuigan said. "This discouraged operators from accepting lithium battery cargo before the ICAO ban. In order for an operator to carry dangerous goods as cargo they have to have specific approval. On the other hand, there is always the issue of people doing it anyway or unintentionally shipping batteries as dangerous goods." Added McGuigan's boss, Katherine Rooney, chief of the Cargo Safety Section, "There have been instances where batteries that have not been abused have still gone into thermal runaway, and we have to assume that they were incorrectly manufactured."

WEIBO

A lithium-ion battery fire burns in luggage stowed in an overhead bin of a China Southern Airlines B777 on the ground at Guangzhou International Airport on Feb. 26, 2018. It was fought and extinguished by cabin attendants and a passenger who threw water and fruit juice on it as the aircraft was evacuated.

So lithium batteries can still be shipped via dedicated air freight operators but not in cargo holds of passenger aircraft. We asked the FAA about its stance on lithium batteries and received this statement: "The U.S. Department of Transportation supports the ICAO Council's decision to prohibit the carriage of lithium-ion batteries as cargo aboard passenger aircraft until safer methods of transport are developed. The DOT and the FAA agree this is a necessary action to protect passengers, crews and aircraft from the risk to aviation safety. In addition, the FAA recommends that passengers safely pack their spare lithium batteries in their carry-on bags."

This means that spare lithium-metal and lithium-ion batteries as well as external battery packs are prohibited in checked luggage along with e-cigs and vaporizers and should be kept with the passenger in the cabin. Spare batteries should be protected from short circuiting with terminal caps or tape and never pocketed where they could come into contact with change, keys and other conductors, causing terminals to be bridged.

The FAA advises, based on successful experiences fighting thermal runaway fires of passenger devices, that if a device is overheating or beginning to smoke to notify flight attendants immediately. They are trained and equipped to handle in-cabin fires.

A variety of products has been developed to contain battery runaways, the most common being fireproof bags into which an affected device can be dropped and smothered. Airlines stock these in their cabins.

However, according to FlightSafety International's Fisher, there are considerations to observe when containing a lithium battery thermal runaway or, worse, a fire. She teaches a module on dealing with lithium fires as part of FlightSafety's business aviation cabin safety course for flight crews.

If the device or battery charger is smoking or deforming, she explained, remove it from the charging process immediately. "The FAA maintains that

That Laptop Ban

From March to July 2017, the U.S. Transportation Security Administration and its U.K. counterpart banned laptop computers in the cabins of commercial aircraft on flights from 12 countries as part of President Donald Trump's travel ban. Justification for the ban was that laptops could be modified by radical Islamic terrorists to conceal explosives and detonated by suicide bombers while aircraft were in flight.

However, the devices were allowed to be carried aboard aircraft in checked luggage until safety experts pointed out that there was an additional risk of putting the laptops and their lithium-ion battery power supplies in aircraft cargo holds. ICAO convened a task force to address the dilemma and security advisors came up with an alternate screening method plus other measures to address the perceived threat.

Thus, the laptop ban was withdrawn. **BCA**

you do not touch it until you can determine that it is cool. If it is overheated, it has already started a thermal runaway. The biggest discussion point people have trouble with is that you are not to touch it until it is cool."

But the conundrum is that to use the fire containment devices, users have to touch, or grasp, the device to get it into the bag or box until the runaway has ceased. "Most of these solutions come with fire gloves," Fisher said. "However, the FAA insists that, even with this protection, you don't touch it. Once you can touch it, the FAA recommends that you place the device in a container with a nonflammable liquid — water, any nonalcoholic liquid like soda, juice, and so forth — and leave it there until after landing." FAA Notice N8900.430, December 5, 2017, "Procedures for Fighting In-Flight Fires Associated With Portable Electronics Devices and Lithium Batteries When Using Commercially Marketed Containment Products" provides direction in dealing with thermal runaways.

If the device or battery has burst into flames, the FAA recommends using halon or water to extinguish the blaze. But halon is a fire extinguishing agent, not a cooling agent, and so the li-ion battery will still have to be cooled with water.

"In a corporate jet," Fisher said, "you still have to ensure the runaway has been stopped, which means pouring water in your beautiful corporate interior. You have to force yourself to do this."

Given that heat generated by li-ion battery fires can exceed 1,100F, the only way to cool a runaway is with "copious amounts of water" to ensure safety of flight. "And you have to ensure that, if it's a cell that is experiencing thermal runaway, it won't light off the cell next to it — an increased fire hazard," Fisher cautioned. "No one can ensure the gloves will protect a user and anyone nearby if the battery explodes."

Yes, she continued, "There are containment bags and cases available. It's becoming common that business aviation operators will have something on the airplane to be prepared to deal with an li-ion event. The key is to know what you have and how to use it while following the FAA guidelines."

Battery fire training is included in all of FlightSafety's emergency training programs. "A large focus on our part is to meet FAA guidelines, but because I believe this is a 'life skill,' it could be useful elsewhere than on an airplane." Fisher also insists that full flight crews, including pilots, should take cabin safety training together, as cases may occur where a pilot may need to enter the cabin to manage a fire situation absent a flight attendant trained for such an event.

In Pursuit of Solutions

ICAO's approach to the lithium battery safety risk has been multidisciplinary, McGuigan said. "For example, we've asked SAE to develop a package performance standard for lithium batteries [stipulating] that the package can ensure that a thermal runaway event will not propagate." ICAO is also reviewing Annex 6 risk assessment provisions to ensure that operators clearly understand it is their responsibility to ensure that, whatever they put into their cargo compartments, the aircraft is capable of mitigating an event if one were to occur. "So we have our operations experts dealing with that."

Finding a better mechanism for oversight of battery manufacturers, the supply chain and device producers is also on the agenda. "The industry [and its regulators] have to ensure that batteries have been manufactured safely with no defects."

In this vein, the larger air freight operators are testing new fire detection and containment/response systems, but safety hawks like the Flight Safety Foundation are convinced more needs to be done to protect the aircraft in worst-case situations like the 2010 UPS tragedy in the UAE. "A consortium of battery manufacturers, a pilot union and some operators is looking into proper labeling or identification of the batteries themselves," Millam said.

Cargo compartments are a separate issue, whether they can be designed to actually contain a fire. Toward that end, McGuigan revealed, ICAO is looking for a replacement for halon. "All of this has occupied an inordinate amount of our time in the last 10 years, as it's an incredibly broad area involving flight operations, airworthiness, safety management, security and cargo safety of dangerous goods."

Added Rooney: "These batteries aren't going away." **BCA**

Log of Lithium Runaways

According to the FAA, between March 20, 1991, and May 2, 2018, there were 206 thermal runaway incidents involving lithium batteries either at airports or on board aircraft. Here's a sampling of some of the most recent events:

▶ **June 24, 2018:** A Lufthansa Airbus A340-300, was en route from San Jose, California, to Frankfurt/Main, when a passenger's power bank (a special li-ion battery used to charge other li-ion batteries) experienced a thermal runaway and ignited. Cabin crew responded quickly and extinguished the fire, cooled down the power bank, and secured it. The flight proceeded on to Frankfurt and landed on schedule.

▶ **June 14, 2018:** A Westjet Boeing 737-700, was climbing out en route from Calgary to Vancouver, British Columbia, when the crew received an aft cargo compartment smoke indication. They arrested the climb and returned to Calgary for a safe landing. Emergency services inspected the cargo hold and found that a fire had occurred in a passenger's luggage.

▶ **May 9, 2018:** A KLM Boeing 777-200, en route from Amsterdam to Kuala Lumpur, was at FL 390 when 100 nm north of Phuket, Thailand, a passenger's mobile phone overheated and began emitting considerable smoke in the cabin. The runaway was handled by the cabin crew, while the captain elected to divert the flight to Phuket as a precaution, and the aircraft landed without incident.

▶ **March 12, 2018:** A SkyWest Embraer 175 operating as a Delta Connection was set to depart Salt Lake City for Bozeman, Montana, when ground crew smelled smoke while loading the aircraft and traced it to the cargo compartment. Upon unloading baggage, they found a checked bag in which a lithium-ion battery had overheated and burst into flame. The fire was extinguished and the flight proceeded to Bozeman.

Examination of the bag's contents revealed two pairs of heated socks powered by lithium-ion batteries, each sock equipped with one 3.7-volt cell. Due to a design defect in the on/off switch, one sock battery entered thermal runaway, which spread to the battery of the mated sock; the remaining two batteries were unaffected. Ironically — or perhaps, appropriately — the brand of the socks was "Flambeau."

▶ **March 12, 2018:** A Delta Airlines flight was en route from Sydney to Los Angeles when a passenger's phone became wedged in a seat and began to smoke. The passenger was moved to another seat while a flight attendant placed the phone in a containment bag. The flight landed without incident at LAX.

▶ **Feb. 26, 2018:** A fire broke out in an overhead storage bin of a China Southern Airlines Boeing 777 just before the flight was scheduled to depart Guangzhou for Shanghai and was fought by cabin attendants and a passenger who threw water and juice on it. The passengers were evacuated from the plane without injury. After the fire, which engulfed a passenger's carry-on bag and sent smoke through the cabin, was extinguished, it was determined that the blaze was started by a "portable charger" (probably a power bank) that was not in use at the time.

▶ **Feb. 3, 2018:** A Frontier Airlines Airbus A320 was en route from Orlando, Florida, to Phoenix when a passenger's smartphone connected to a power bank overheated, deformed and began filling the cabin with smoke. The passenger tossed the phone into the aisle, where another passenger picked it up, carried it to a lavatory, dropped it into the sink, ran water over it, and then covered it with ice. No fire occurred, but the flight was diverted to Tampa where the A320 landed safely. Both passengers were treated for burns and a third was examined for a respiratory issue due to smoke inhalation. Other passengers complained of nausea and headaches.

▶ **Jan. 30, 2018:** The battery in an e-cig device exploded in a passenger's carry-on bag during x-ray screening at a Transportation Security Administration (TSA) checkpoint at Denver International Airport, which was evacuated while the resulting fire was extinguished. **BCA**

How to Combat Thermal Runaways in Business Aircraft Cabins

Here are answers to five questions *BCA* addressed to Louisa Fisher, Cabin Safety Program manager at FlightSafety International, on how to deal with lithium-ion battery fires in the confined spaces of business aircraft.

BCA: Does a thermal runaway of a lithium-ion-powered device pose a serious problem in a business jet?

Fisher: Anything that happens on an aircraft is more serious than on the ground because of the limited ability to escape the hazard.

BCA: Should you drop the runaway device on the floor?

Fisher: Leave it in place. If you're holding it when it begins to heat up or deforms, try to get it into something where you can pour water on it. If it's on a charger, unplug it. If it is experiencing a runaway, the FAA recommends you don't try to handle it at all — leave it in place. It could explode in your hand.

BCA: What about using containment products like bags that require that the device be picked up and deposited into the bag?

Fisher: Because our training is FAA-approved and I'm teaching an FAR Part 141-approved cabin safety course, we stand with the FAA's recommendation on the handling of lithium batteries. It may be difficult to follow that logic, but you have to err on the side of safety. The FAA says to extinguish the fire with halon and copious amounts of water. [Note: Halon will not cool the device, only extinguish the fire.]

BCA: Put water on it? How much? Aren't water supplies limited on business aircraft, especially the smaller ones?

Fisher: It depends on where the device is. The goal is to cool the device with a nonalcoholic liquid to reduce the temperature and stop the thermal runaway. On a small aircraft, it would make sense to be prepared for the likelihood that it could happen — perhaps you want to consider having multiple bottles of water available if you know there will be lithium-ion-powered devices in use on the aircraft. And above all, make the awareness of the threat and how to respond to it a part of your cabin safety briefing. [And part of your emergency response plan, your ops manual and your SMS as well.]

BCA: Here's a scenario: A business jet passenger's laptop experiences a thermal runaway while in use. What do you do?

Fisher: The affected person will try to push it away and get away from it, and people will be scrambling around in the cabin. While establishing order, extinguish the fire and cool it immediately, and call for assistance from other passengers to get water on it. [Note: In operations and aircraft without cabin attendants, someone among the passengers should be designated to be in charge of the cabin and briefed accordingly by the captain or FO.]

Universally, there are halon extinguishers on just about all business aircraft. Halon is the standard as the most efficient and lightest-weight extinguisher available, and it does not leave residue after activation like some chemical extinguishers will. There are replacements out there, but they're not commonly seen, and halon is still the gold standard in aviation. **BCA**

Keeping Lithium Battery Packs 'KULR'

KULR Technology of San Diego and Campbell, California, designs and manufactures carbon-fiber containment solutions for lithium-ion battery applications.

Its anchor customer so far has been NASA, with which it has worked to design thermal management for spacecraft and the International Space Station's NICER (Neutron [star] Interior Composition ExploreR) instrument. KULR technology also cools the battery for NASA's X-38 and X-51 electric planes and a Mars Rover that will be launched to the red planet in 2020 and look for organic materials. It carries a KULR-designed heat sink for the SHERLOC (Scanning Habitable Environments with Raman and Luminescence for Organics and Chemicals) instrument.

"So we have a history of high-end space applications," KULR CEO Michael Mo told *BCA*. "In 2015, we were approached by the NASA Johnson Space Center about using lithium-ion batteries in space suits. They needed a lightweight carbon-fiber containment — a TRS, or Thermal Runaway Shield, made up of a carbon-fiber core with an internal liquid in a polymer enclosure." The liquid coolant can be water, and the complete TRS can function in a zero-gravity environment as well as on Earth, which made it especially attractive to the space agency.

The beauty of the TRS is that it could ultimately be adapted to smaller applications like battery packs as a way to contain a li-ion thermal runaway and keep it from propagating to adjacent cells or batteries. And indeed, Mo claimed that KULR has "engagements" with manufacturers of consumer electronic devices for testing and applying the TRS. "We are also working with EV [electrical vehicle] companies to place this technology in their products," he said. "And airframe OEMs are looking at hybrid propulsion devices that will require battery packs that could benefit from the technology, as well."

KULR TECHNOLOGIES

The objective of the KULR treatment is to contain a runaway within one cell and not let it propagate to others. "We want to prevent propagation and, at the same time, to test the battery pack for safety." The testing part is as important as the protection, Mo asserted, and again working with NASA, KULR engineers have devised a method to instigate a short circuit in a single cell in a battery pack or a collection of batteries in a shipping container to see if a containment solution will work.

The company is also working on a TRS packaging material solution for lithium-ion battery bulk shipping and will manufacture the material and sell it to the logistics companies. "Stopping the propagation is the solution," Mo said. "You have to deal with it on the individual cell level and get that fire out as quickly as possible." **BCA**

Contain It or Let It Cool?

Business aviation operators and airlines alike face a quandary when dealing with a thermal runaway of lithium-ion-powered electronic devices like mobile phones, laptops, tablets, wireless headphones, power banks (external charging batteries), electronic cigarettes/vaping devices, and the like.

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On one hand, the aviation safety and fire suppression industries have responded with various containment devices, the most common being fireproof bags, some containing fire-suppression compounds, into which a personal electronic device (PED) can be deposited and the bag sealed until the thermal runaway event has been quashed. Several airlines stock these containment bags and accompanying fire gloves for grasping affected devices. FAA incident tracking data show that the carriers often use the bags and gloves to suppress thermal runaways, which in 2017 occurred once every eight days.

On the other hand, the FAA's Dec. 5, 2017, Notice N8900.430 and Advisory Circular 120-80 advise not to touch a device in thermal runaway due to the high temperatures a lithium fire can generate until the device has cooled. And if the thing bursts into flame, the agency says the combustion should be extinguished with either halon or water — lots of H_2O.

Specifically, Notice N8900.430 states: "The FAA has no objection to the various commercially manufactured containment products, *provided the procedures recommended in FAA guidance are followed.*" [The caveat, and our emphasis.]

Further, FAA researchers have "concluded that containment devices should not be used in an attempt to extinguish a PED fire due to the dangers associated with picking up the PED while the device is in an unstable condition (*i.e.,* the fire is still actively burning or the device appears to be expanding or popping from heat). . . . . [I]f the device is hot, the potential for propagation exists; therefore, the device should not be moved until thoroughly cooled."

Once the fire is extinguished, the FAA advises, "containment devices can be used to secure the PED utilizing the procedures specified in SAFO [Safety Alert for Operators] 09013, AC 20-42 and AC 120-80 provided the PED has been adequately cooled to allow transfer to the containment device. Keeping an unstable device cool is critical. In order to do so, any such containment device should be capable of holding liquid so the device can be submerged during storage."

So, what are operators to do in fighting thermal runaways? Ray Goyco notes what he sees as flaws in the FAA's advice. The COO of Baker Aviation in Addison, Texas, which markets the Hot-Stop L line of containment kits, he says, "FAA information is advisory in nature and it's protocol until you implement your own safety management system."

First, he takes aim at the protocol of using water to fight a lithium thermal runaway, pointing out the scarcity of water aboard business aircraft. Then he reminds readers that many of the latest cellular phones, laptops and tablets have been designed and manufactured to be waterproof and therefore are immune to penetration by liquid. So much for submerging them in water.

The Hot-Stop L products are fabricated of multiple layers of fire-resistant fabrics. Two outer layers certified for a 2,080F melting point sandwich an inner felt core certified to withstand 3,200F. Extensive tests at various fire laboratories are claimed to have shown the bags can seal to absorb energy, sparks and flame while eliminating the escape of toxic smoke characteristic of li-ion battery runaways. Fire mitts sold with the bags for handling runaway devices and getting them into containment bags have been tested at up to 1,550F and rated for 3,000F radiant heat reflection.

Lithium-Ion Batteries in the Cockpit?

"If you get [the runaway device] into the bag, it will contain the event until it has burned itself out," Goyco said. "The bags allow you to control the event and contain the fire without toxins and smoke, and nothing will penetrate them."

Manufactured for Baker Aviation by Industrial Energy Products in Pennsylvania, the bags (Goyco prefers to call them "containment kits") are available in five sizes, each designed to accommodate a specific device, *e.g.,* cellphones and other small devices like power banks and chargers, tablets (two sizes), laptops and miscellaneous equipment like defibrillators. Prices range from $2,280 to $2,850 depending on the size of the bag and accessories.

Concerning the FAA's contention that a reacting lithium-powered device should not be touched until it is cooled and then dunked in water, Goyco pointed out the ubiquitous use of iPads and other tablets by flight crews in the cockpit as electronic flight bags. "If you have an event in the cockpit, what do the pilots do? Can they jump out of the cockpit and let the device cool, vacate the area and go find water? I don't think so. First, someone has to manage the airplane and, second, timing is everything in dealing with a thermal runaway."

The scenario is thought-provoking: With tablets clipped to brackets mounted near the instrument panel above the pilots' knees or, simply, laying in pilots' laps, the possibility of a rapid thermal runaway and related high temperatures while in the air is sobering. Obviously, an option would be to stow appropriately sized containment bags and at least one glove in the cockpit for a quick response to an incident.

Baker has been in the fire-suppression equipment business for 11 years and claims to be the pioneer in developing containment devices specifically oriented toward lithium-ion battery thermal runaways. Goyco said the company has placed Hot-Stop L kits with 17 airlines, having sold 14,000 in all, 10,000 to FAR Part 91 and 135 business aviation operators. More information on the products can be found at **http://www.hot-stopl.com**.

Why aren't Baker's and other manufacturers' containment kits FAA approved? "There is no FAA directive for approval of these products," Goyco answered. "You can't apply for an FAA Form 8130-3 or an 8110-10 for approvals. In the absence of a directive [from the FAA], it is impossible for anyone to get approved." And obviously, the whole containment strategy epitomized by these products flies in the face of the FAA's advisories on not touching a runaway lithium-powered device until it has cooled. Operators will have to make their own choices.

Baker's competitors in the thermal-containment business include CellBlock FCS (**http://www.cellblockfcs.com**), PlaneGard (**http://www.planegard.com**) and Viking Packing (**http://www.vikingpacking.com**). **BCA**