



# National Transportation Safety Board

Washington, DC 20594

## Safety Recommendation Report

### Standards for Lithium-Ion Battery Shipments by Air

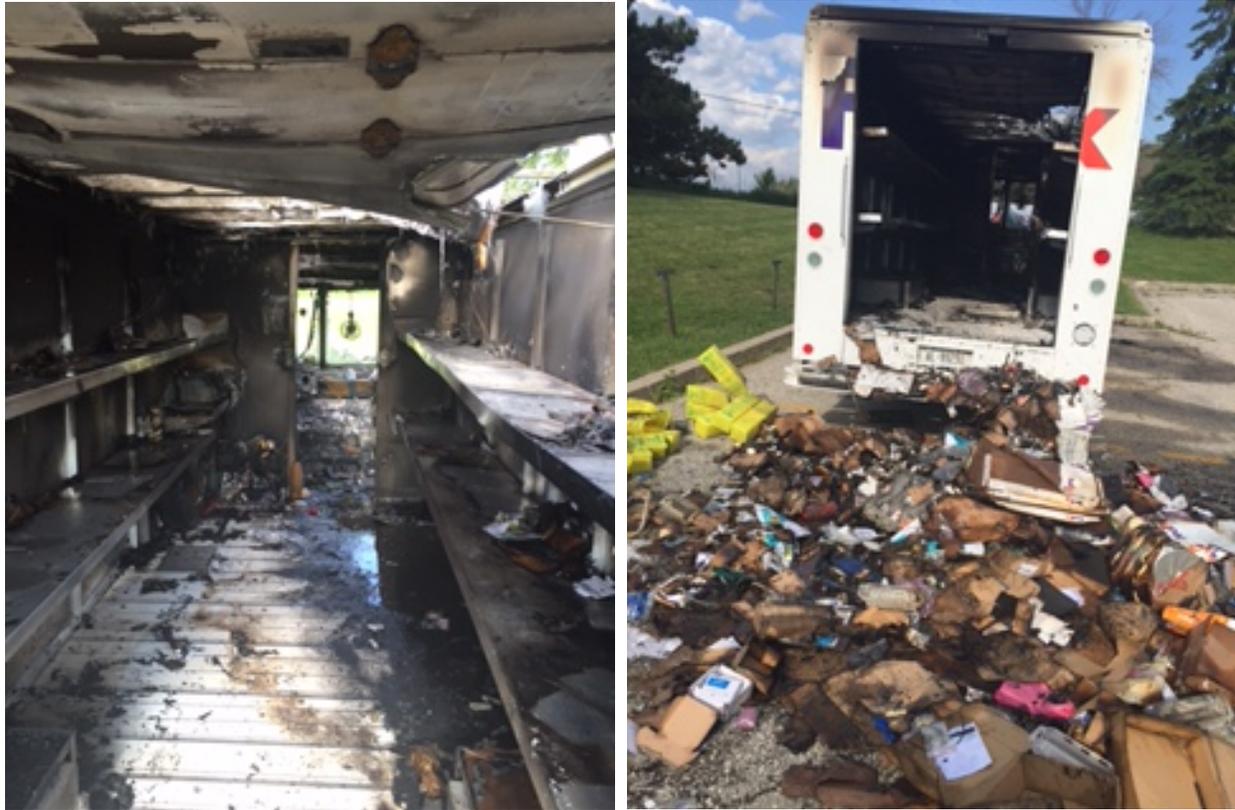
#### The Accident

On June 3, 2016, about 4:05 p.m. local time, a FedEx W900 local delivery truck and all of its cargo were destroyed by a fire while the driver was delivering packages to a business in Brampton, Ontario, Canada; no injuries were reported.<sup>1</sup> The fire began among a shipment of four large-format lithium-ion batteries, each of which was individually packaged in a fiberboard box. No other dangerous goods were on board.<sup>2</sup> The international shipment of the four lithium-ion batteries originated from Braille Battery, Inc. (Braille), a battery manufacturer located in Sarasota, Florida, and were destined for Brampton, Ontario, Canada. The batteries were initially transported by FedEx on two separate US-registered cargo airplanes before being transferred to the delivery truck. The fire occurred about 10 hours after the batteries were offloaded from the cargo airplane at the Toronto, Canada, international airport. Figure 1 shows both the interior and exterior damage to the FedEx truck. Estimated damages were over \$71,000. The Federal Aviation Administration (FAA) notified the National Transportation Safety Board (NTSB) of the accident over concerns that the fire could also occur during air transport.

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<sup>1</sup> For additional information on this accident, including the probable cause, please see the accident brief, *Lithium-Ion Battery Truck Fire Following Aerial Transport, Brampton, Ontario, Canada, June 3, 2016*, HZB-20/01 (Washington, DC: National Transportation Safety Board, 2020). Additional information about this accident investigation can be found in the public docket for this accident (DCA16SH001) by accessing the [Accident Dockets](#) link for the Docket Management System at [www.nts.gov](http://www.nts.gov). For more information on our safety recommendations, see the [Safety Recommendation Database](#) at [www.nts.gov](http://www.nts.gov).

<sup>2</sup> *Dangerous goods* is the phrase used internationally to describe hazardous materials.



**Figure 1.** The fire damage to the FedEx truck and its contents. The contents of the truck were removed by firefighters following the fire. (Courtesy of FedEx.)

## Shipping Regulations

Lithium-ion batteries are classified as Class 9 miscellaneous hazardous materials, one of nine hazard classes that present a hazard during transportation.<sup>3</sup> Title 49 *Code of Federal Regulations (CFR)* 173.185 describes the packaging requirements that lithium-ion batteries must meet for transport.<sup>4</sup> This shipment did not have noncombustible interior packaging. The combustible packaging facilitated the spread of the fire from the box and involved other boxes in the shipment. When shipped internationally by air, United States Department of Transportation (DOT) hazardous materials regulations (HMR) also require lithium-ion batteries to comply with International Civil Aviation Organization (ICAO) standards.<sup>5</sup>

ICAO Annex 18 contains the standards for transporting dangerous goods (hazardous materials) by air. One of the standards requires hazardous materials be shipped in accordance with ICAO's *Technical Instructions for the Safe Transport of Dangerous Goods by Air* (Technical

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<sup>3</sup> Title 49 *Code of Federal Regulations (CFR)* 172.101 and 49 *CFR* 173.140. Title 49 *CFR* 172.101 lists lithium-ion batteries as a Class 9 hazardous material. The hazard class of a hazardous material is indicated either by its class (or division) number. There are nine different classifications of hazardous materials that are defined in 49 *CFR* 173.140.

<sup>4</sup> Title 49 *CFR* 173.185 (e)(1) also requires cushioning material that is noncombustible for low-production runs and prototype lithium-ion cells and batteries.

<sup>5</sup> Title 49 *CFR* 171.22.

Instructions).<sup>6</sup> This standard includes provisions for the classification of dangerous goods, circumstances when dangerous goods are forbidden on passenger or cargo airplanes, and hazard communication and packing instructions (PI). Within the Technical Instructions are specific PIs, such as PI 965, which is required for United Nations (UN) 3480 lithium-ion batteries that meet the quantity and capacity limits under the HMR. Braille certified in the shipping declaration that it was packaged in accordance with PI 965.<sup>7</sup> However, the packaging consisted of three foam modules made of polyurethane foam encased in a polyethylene film bag, which is a combustible material that does not comply with PI 965.

PI 965 requires that before transport, lithium-ion batteries be able to pass each test stipulated in the UN *Manual of Tests and Criteria*, Part III, Section 38.3 (UN 38.3).<sup>8</sup> These tests subject the battery or cell to different pressures, vibrations, temperatures, shock, external short circuiting, overcharge or forced discharge, and either impact or crushing force that would lead to internal short circuiting.<sup>9</sup> If a lithium cell or battery assembly fails the tests, the standards require that the battery or cell manufacturer correct the failure before the battery or cell is tested again.

Braille was unable to produce records showing that the battery design was tested in accordance with UN 38.3. The short circuits observed in the batteries during postaccident testing suggested that had an iM3124D-100 battery been subject to the vibration or shock tests stipulated in UN 38.3 tests, it would likely have failed.<sup>10</sup> The vibration test involved firmly securing a battery on a platform of a vibration machine and was repeated multiple times over a span of a few hours. The shock test also involved securing the battery to a test machine and subjecting the battery to a timed frequency of pulse durations through a number of cycles. These tests would likely have created the conditions that caused the battery failure in this accident.

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<sup>6</sup> International Civil Aviation Organization, *Technical Instructions for the Safe Transport of Dangerous Goods by Air*, 2015-2016 edition. (Montreal, Quebec, Canada: 2015).

<sup>7</sup> In accordance with 49 *CFR* 172.200, the FAA requires that hazardous materials shipments include a form certifying that the cargo has been packed, labeled, and declared according to international regulations.

<sup>8</sup> UN Economic and Social Council's Subcommittee of Experts on the Transport of Dangerous Goods, *UN Manual of Tests and Criteria*, Fifth revised edition. (New York and Geneva, Switzerland: United Nations, 2009). *UN Manual of Tests and Criteria* is developed by the United Nations' Economic and Social Council's Subcommittee of Experts on the Transport of Dangerous Goods, of which ICAO is a specialized agency. At the time of the accident the fifth edition was in effect. A sixth edition has been published and manufacturers and distributors of lithium-ion batteries and cells must be in compliance with these new revisions by January 2020.

<sup>9</sup> Cells and batteries meet the testing requirement if there is no mass loss, no leakage, no venting, no disassembly, no rupture, and no fire, and if the open circuit voltage of each test cell or battery after testing is not less than 90 percent of its voltage immediately prior to this procedure. The requirement relating to voltage is not applicable to test cells and batteries at fully discharged states.

<sup>10</sup> (a) State of charge (SOC) measurement and testing was performed at the Carderock Division of the Naval Surface Warfare Center in Montgomery County, Maryland, at the request of the NTSB. SOC measurement is most commonly performed by one of three methods: open circuit voltage method; electrochemical impedance spectroscopy method; and charge/discharge cycling with coulomb counting method. There are no industry-standard protocols for measuring SOC, nor are testing variations, reproducibility, and repeatability aspects established.

On December 8, 2017, the FAA proposed a \$1.1 million civil penalty against Braille for the shipment of lithium-ion batteries involved in the June 3, 2016, accident, as well as other illegal shipments of lithium-ion batteries by air.<sup>11</sup> The company was cited for the following violations:

- not meeting the testing standards under the UN *Manual of Tests and Criteria* or DOT's HMR (49 *CFR* 173.185(a)(1));
- not equipping its batteries with a means to prevent dangerous reverse current flow (49 *CFR* 173.185(a)(3)(iii));
- not packaging the batteries for shipment to prevent sparks or generate heat (49 *CFR* 173.21(c));
- not providing its employees with required hazardous materials transportation training (49 *CFR* 172.702 (a));
- not following the DOT's HMR or acquiring the necessary exemption under an approval or special permit (49 *CFR* 171.2(b)).<sup>12</sup>

In addition, the FAA prohibited Braille from shipping lithium batteries by air for 2 years, issuing an Emergency Prohibition/Restriction Order in September 2016. The FAA rescinded the order in July 2018 after the agency determined Braille was complying with DOT regulations. Braille posted the UN testing documentation for its lithium-ion batteries on its website.

## Exemptions to Shipping Regulations

Although Braille failed to comply with federal regulations and international standards, the NTSB is concerned that a special provision within the ICAO Technical Instructions would have still allowed Braille to legally ship its batteries internationally by air, despite the serious flaws in the battery design. Special Provision A88 within ICAO's Technical Instructions allows prototype or low-production lithium batteries or cells to be exempt from UN 38.3 testing if approved by a "competent authority" of the state of origin.<sup>13</sup> In the US, the associate administrator for Hazardous Materials Safety, Pipeline and Hazardous Materials Safety Administration (PHMSA) serves as the "competent authority" and may grant approval through the use of a special permit to transport hazardous materials that are exempt from requirements under the HMR and/or international regulations. The special permit is granted based on whether the application demonstrates an "equivalent level of safety" that would otherwise be provided by the HMR and/or international

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<sup>11</sup> (a) The penalty amount was later reduced to \$235,000, which Braille is required to pay by September 2021. (b) Federal Aviation Administration, "FAA Proposes \$1.1 Million Civil Penalty Against Braille Battery Inc. For Alleged HazMat Violations," news release, December 8, 2017. [https://www.faa.gov/news/press\\_releases/news\\_story.cfm?newsId=22374&omniRss=press\\_releasesAoc&cid=102\\_P\\_R](https://www.faa.gov/news/press_releases/news_story.cfm?newsId=22374&omniRss=press_releasesAoc&cid=102_P_R), accessed January 6, 2020.

<sup>12</sup> *Federal Register* 81, no. 188 (September 28, 2016): 66713.

<sup>13</sup> According to ICAO *Technical Instructions*, A3-1-28, US Variation 3, when shipping prototype lithium-ion batteries and cells in accordance with Special Provision A88 to or from the US, the shipper must also seek approval from the appropriate US authority. According to 49 *CFR* 107.1, a *competent authority* is a national agency that is responsible, under its national law, for the control or regulation of some aspect of hazardous materials (dangerous goods) transportation.

regulations.<sup>14</sup> However, the testing required by PHSMA to demonstrate an “equivalent level of safety” is often less rigorous than those described in UN 38.3.

The batteries that were involved in the accident met the definition of a prototype or low-production battery, thereby making Braille eligible to apply for a special permit.<sup>15</sup> Title 49 *CFR* 173.185 describes the packaging requirements that the batteries must meet for transport. This shipment did not have noncombustible interior packaging. The combustible packaging allowed the fire to spread from the box and involve other boxes in the shipment. When shipped internationally by air, US hazardous materials transportation regulations also require lithium-ion batteries to comply with ICAO standards.<sup>16</sup> However, Braille did not apply for a special permit.<sup>17</sup> Had Braille applied for a special permit, they could have been eligible to use an existing one (SP20323), where the company would have only had to demonstrate that its batteries would pass a short-circuit test, rather than meeting all of the testing requirements under UN 38.3.<sup>18</sup> Had the Braille batteries been subjected to any short-circuit testing, it is unknown if they would have passed. Any internal failures of the individual cells may initially have been undetected. Nonetheless, the short-circuit test would not have been sufficient to show that the batteries met all of the requirements under UN 38.3 because the low-pressure conditions, extreme temperature changes, and vibrations that are experienced during air transport would not have been tested.

The NTSB previously investigated an accident involving a prototype lithium-ion battery that was transported under the special permit process.<sup>19</sup> On August 7, 2004, a battery caught fire while inside a unit load device (ULD) just prior to being loaded onto a FedEx airplane in Memphis, Tennessee. Loading personnel noticed the smoke from the ULD as it was about to be pushed into the cargo area of the airplane. Personnel returned the smoking ULD to the ground and called emergency responders, who then tried to open the ULD; a fire then ignited, destroying the ULD. Estimated damages were \$20,000. The NTSB determined that the probable cause of the fire was “the failure of the unapproved packaging ... which was inadequate to protect the lithium-ion battery modules from short circuits during transportation.”

The NTSB has found that in both the Brampton and Memphis accidents, the prototype and low-production batteries involved were not subject to the UN 38.3 tests but were authorized by a special permit or eligible for a special permit for air transport. Had the batteries been subjected to tests as outlined in the UN 38.3 standards, it is likely that the risks of battery short circuiting leading

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<sup>14</sup> Pipeline and Hazardous Materials Safety Administration, *Approvals Program Desk Guide, Version 2.2* (Washington, D.C.: US Department of Transportation, Pipeline and Hazardous Materials Safety Administration, 2016).

<sup>15</sup> A *prototype or low-production* battery is a battery with annual production runs consisting of not more than 100 lithium-ion batteries or cells, as defined by both the ICAO *Technical Instructions* and the HMR.

<sup>16</sup> Title 49 *CFR* 171.22.

<sup>17</sup> According to 49 *CFR* 107.105(d), applications for special permit proposals “must demonstrate that a special permit achieves a level of safety at least equal to that required by regulation, or if a required safety level does not exist, is consistent with the public interest.”

<sup>18</sup> See 49 *CFR* Part 107, Hazardous Materials Program Procedures. SP20323 is an existing permit that is currently authorizing air shipments of low-production and prototype batteries that have not undergone the UN 38.3 tests. The original 2017 permit expired but was renewed in 2019 with a different shipper.

<sup>19</sup> National Transportation Safety Board, *Cargo Fire Involving Lithium-Ion Batteries, Memphis, Tennessee, August 7, 2004*, HZB-05/01 (Washington, DC: National Transportation Safety Board: 2005).

to a thermal runaway condition would have been identified.<sup>20</sup> Because the risks associated with a fire aboard an airplane are greater than other modes of transportation, the NTSB concludes that had the thermal runaway event occurred on an airplane, the event could have resulted in significant damage to or the loss of the airplane.

Furthermore, the NTSB concludes that the PHMSA SP20323 special permit process does not require sufficient testing and evaluation of low-production or prototype batteries for thermal hazards compared to that which is provided under UN 38.3 testing, which simulates transportation conditions and, therefore, does not provide an “equivalent level of safety.”

Section 828 of the FAA Modernization and Reform Act of 2012 prohibits PHMSA from issuing or enforcing any regulation or other requirements regarding the air transportation of lithium-ion cells or batteries if the requirement is more stringent than the standard of the ICAO Technical Instructions.<sup>21</sup> The NTSB is concerned that similar accidents involving low-production or prototype special permitted lithium-ion batteries could occur on an airplane during transport, potentially leading to the loss of the airplane and its crew and, catastrophic property damage on the ground. It is imperative that all low-production and prototype batteries meet the testing process outlined in UN 38.3. Therefore, the NTSB recommends that PHMSA propose to ICAO to remove special provision A88 from its Technical Instructions allowing special permits for low-production or prototype lithium-ion cells or batteries shipped by airplane, and eliminate any exceptions to the testing of UN 38.3 requirements for all lithium-ion batteries before air transport. Further, the NTSB recommends that once ICAO removes special provision A88 from the Technical Instructions, PHMSA remove the exemption from UN 38.3 testing from 49 *CFR* 173.185(e) for low-production or prototype lithium-ion batteries, when transported by air.

## Findings

1. Had the thermal runaway event occurred on an airplane, the accident could have resulted in significant damage to or the loss of the airplane.
2. The Pipeline and Hazardous Materials Safety Administration SP 20323 special permit process does not require sufficient testing and evaluation of low-production or prototype batteries for thermal hazards compared to that which is provided under United Nations *Manual of Tests and Criteria, Part III, Sub-section 38.3* testing, which simulates transportation conditions and, therefore, does not provide an “equivalent level of safety.”

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<sup>20</sup> *Thermal runaway* occurs when the rate of internal rate generation exceeds the rate at which the heat can be expelled.

<sup>21</sup> (a) The only exception to this is if PHMSA can obtain credible evidence that demonstrates a deficiency in the ICAO Technical Instructions that has substantially contributed to the initiation or propagation of an onboard fire, which could be addressed with specialized packaging, additional stowage restrictions, or other measures. (b) Pub. L. 112-95, Stat. 133, Section 828(b)(2)(B), February 14, 2012.

## Recommendations

As a result of this investigation, the National Transportation Safety Board makes the following safety recommendations to address gaps in the existing regulations uncovered in this investigation:

### To the Pipeline and Hazardous Materials Safety Administration:

1. Propose to the International Civil Aviation Organization to remove its special provision A88 from its *Technical Instructions for the Safe Transport of Dangerous Goods by Air* allowing special permits for low-production or prototype lithium-ion cells or batteries shipped by airplane and eliminate any exceptions to the testing of United Nations *Manual of Tests and Criteria, Part III, Sub-section 38.3* requirements for all lithium-ion batteries before transport by air. (A-20-31)
2. Once the International Civil Aviation Organization removes special provision A88 from the *Technical Instructions for the Safe Transport of Dangerous Goods by Air*, remove the exemption from United Nations *Manual of Tests and Criteria, Part III, Sub-section 38.3* testing from Title 49 *Code of Federal Regulations* 173.185(e) for low-production or prototype lithium-ion batteries, when transported by air. (A-20-32)

## BY THE NATIONAL TRANSPORTATION SAFETY BOARD

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**Date: May 28, 2020**