National Transportation Safety Board

Washington, DC 20594

Safety Recommendation

Date: February 9, 2016

In reply refer to: A-16-001 and -002

The Honorable Marie Therese Dominguez
Administrator
Pipeline and Hazardous Materials
Safety Administration
Washington, DC 20590

The National Transportation Safety Board (NTSB) urges the Pipeline and Hazardous Materials Safety Administration (PHMSA) to take action on the safety recommendations issued in this letter. These recommendations address cargo loading controls by limiting the density of lithium batteries loaded in one place on an aircraft and segregating them from flammable liquids to reduce the severity of potential cargo fires and to provide additional time to safely land an airplane in the event a cargo fire is detected.[1] These recommendations are derived from the NTSB's participation in the Aviation and Railway Accident Investigation Board (ARAIB), Republic of Korea, investigation of the July 28, 2011, in-flight fire and crash of Asiana Airlines Flight 991 in international waters about 130 kilometers (km) west of Jeju International Airport.[2] As a result of this investigation, we are making two safety recommendations to PHMSA. Information supporting these recommendations is discussed below.

Background

On July 28, 2011, about 04:11 Korean standard time, Asiana Airlines Flight 991, a B747-400F airplane on a scheduled cargo flight from Incheon, Republic of Korea, to Shanghai, China, crashed into international waters about 130 km west of Jeju International Airport. The flight crew reported a cargo fire to Shanghai Area Control Center and attempted to divert to Jeju

[1] In this document, unless otherwise specified, the term *lithium battery* refers to lithium metal, lithium alloy, lithium-ion, and lithium polymer batteries.

[2] Aviation and Railway Accident Investigation Board, *Crash Into The Sea After An In-Flight Fire, Asiana Airlines, Boeing 747-400F, HL7604, International Waters 130 km West Of Jeju International Airport, 28 July 2011* ARAIB/AAR-1105 (Sejong Special Self-governing City, Republic of Korea: Aviation and Railway Accident Investigation Board, 2015). The NTSB appointed a US-accredited representative in accordance with the International Civil Aviation Organization (ICAO) Annex 13, because the United States is the state of manufacture of the airplane.

International Airport. The two pilots aboard the flight died. The wreckage of the airplane was distributed on the sea floor at an average depth of 85 meters (m), in an area 3 km by 4 km in a southwest-northeast direction.

The ARAIB determined that the cause of this accident was a fire that developed on or near two pallets containing dangerous goods packages, including hybrid-electric vehicle lithium-ion batteries and flammable liquids, but no physical evidence of the cause of the fire was found.[3] The fire rapidly grew large and uncontained, which resulted in a loss of control and some portions of the fuselage separating from the aircraft in midair, thereby resulting in the crash. The ARAIB report cited as a contributing factor the flammable materials and lithium-ion batteries that were loaded together either in the same or adjacent pallets.

The carriage of lithium cells and batteries in aircraft cargo compartments presents three distinct hazards.[4]

1. Lithium cells and batteries can be an ignition source. A damaged, shorted, overheated or defective cell (from impurities, manufacturing defects, or foreign object deposits) can spontaneously go into thermal runaway.[5] Thermal runaway can cause the cell to ignite or explode, and may propagate to adjacent cells and surrounding materials.

2. Lithium cells and batteries can be a source of fuel for an existing fire. Cells when heated and forced into thermal runaway release flammable electrolytes and gases.

3. Lithium cells and batteries produce a pressure pulse when in thermal runaway. The gases produced, when contained, can result in an explosive mixture. This may increase the pressure within a loaded pallet or cargo compartment, activate pressure relief features, and cause damage to cargo covers and liners. This may result in a reduced suppressant agent concentration and rapid fire escalation, and may force smoke into other areas of the aircraft.

Federal Aviation Administration (FAA) research has found that a lithium cell in thermal runaway will generate enough heat to induce adjacent cells into thermal runaway.[6] The thermal runaway reaction generates very high temperatures and pressures within the cell. A cell in thermal runaway can reach 1100°F or higher, and the high pressure can cause the cell to expel flammable electrolytes. Once this occurs, propagation to the entire shipment can occur because the ignition temperature of most ordinary combustibles, including paper and cardboard, typical

[3] The term "dangerous goods" used in international regulations is synonymous with the term "hazardous materials" used in domestic regulations.

[4] *Discussion of Issues Regarding Performance-Based Standards for Air Transportation of Lithium Batteries*. (Presentation before the ICAO International Multidisciplinary Lithium Battery Transport Coordination Meeting, Third Meeting, Montréal, Quebec, Canada, July 28–30, 2015).

[5] Overheating a cell or battery has the potential to create *thermal runaway*, a chain reaction leading to the self-heating and release of stored energy.

[6] FAA lithium battery research may be accessed at https://www.fire.tc.faa.gov/systems/Lithium-Batteries.

materials used to ship lithium batteries, is much lower than 1100°F. The 1100°F temperature is within the melting-point range of aircraft aluminum (935° to 1180°F), and a large shipment of lithium cells could generate enough heat to potentially damage aircraft structures.

The principles governing the international transport of dangerous goods by air are contained in Annex 18 to the Convention on International Civil Aviation.[7] ICAO *Technical Instructions for the Safe Transport of Dangerous Goods by Air* are international standards that each member state, under the provisions of Annex 18, is required to introduce into national legislation to provide worldwide harmonization of safety standards to the greatest extent possible.[8] The ICAO Technical Instructions provide six packing instructions depending on whether the cells and batteries are lithium metal/lithium alloy or lithium-ion/lithium polymer, and whether the batteries are contained in equipment, packed with equipment, or shipped in bulk. The lithium-ion batteries that were shipped on board Flight 991 were packaged in accordance with Packing Instruction 965, Section 1A, which included the following general requirements:

- limited net quantity per package on cargo aircraft to 35 kilogram (kg) per package
- protection to prevent short circuits
- inner packaging that completely encloses the cell or battery
- outer packaging that conforms to Packing Group II requirements

Part 7 of the ICAO Technical Instructions details the responsibilities of operators regarding acceptance, handling, and loading of dangerous goods. Chapter 2, Storage and Loading, Paragraph 2.2.1, Segregation, states that packages containing dangerous goods that might react dangerously with one another must not be stowed on an aircraft next to each other or in a position that would allow interaction between them in the event of leakage. At a minimum, the segregation scheme must maintain acceptable segregation between packages containing dangerous goods having different hazards. However, the Technical Instructions do not prohibit storing and loading hazard class 3 flammable materials and hazard class 9 lithium cells and batteries next to one another on board an aircraft, as was the case with Asiana Flight 991.[9] Further, the ICAO Technical Instructions do not specify measures operators should implement to reduce the density of lithium batteries and flammable materials cargoes in a single location within an aircraft.

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[7] International Civil Aviation Organization, *Convention on International Civil Aviation*, 9th Edition. Doc. 7300/9. (Montréal, Quebec, Canada: International Civil Aviation Organization, 2010).

[8] International Civil Aviation Organization, *Technical Instructions for the Safe Transport of Dangerous Goods by Air* 2015-2016 Edition. Doc. 9284 AN/905. (Montréal, Quebec, Canada: International Civil Aviation Organization, 2010).

[9] A *Class 3* flammable liquid means a liquid having a flash point of not more than 60°C (140°F) or any material in a liquid phase with a flash point at or above 37.8°C (100°F) that is intentionally heated and offered for transportation or transported at or above its flash point in bulk packaging, with certain exceptions.

A *Class 9* lithium cell means a material which presents a hazard during transportation, but which does not meet the definition of any other hazard class.

In the United States, the PHMSA Hazardous Materials Regulations (HMR) are harmonized with the ICAO Technical Instructions to control stowage and compatibility of aircraft cargo. Title 49 *Code of Federal Regulations* (*CFR*) 175.78(a) states:

> For stowage on an aircraft, in a cargo facility, or in any other area at an airport designated for the stowage of hazardous materials, packages containing hazardous materials which might react dangerously with one another may not be placed next to each other or in a position that would allow a dangerous interaction in the event of leakage.

Similar to the ICAO Technical Instructions, the only stowage restriction currently required for Class 3 flammable materials is proximity to material classified as a Division 5.1 oxidizer.[10] The HMR currently provides no segregation or loading density requirements for Class 3 flammable materials and Class 9 lithium cells and batteries.

On October 8, 2010, the FAA issued *Safety Alert for Operators* (SAFO) 10017 recommending that air carriers stow bulk shipments of lithium batteries in Class C cargo compartments or in locations where alternative fire suppression is available, and evaluate the training, stowage, and communication protocols in their operations with respect to the transportation of lithium batteries in the event of an unrelated fire.[11] However, the safety alert stopped short of recommending the segregation of lithium batteries from other classes of dangerous goods.

In August 2011, the NTSB conducted tests as part of a study to better understand the characteristics of cargo container fires, the threats these fires pose to the aircraft, and whether the current fire protection strategy is suitable for those threats.[12] The study concluded the following:

- Container design has a significant effect on the time it takes for an internal fire to become detectable to a smoke detector outside the container.
- Container construction materials have a significant effect on the total fire load and energy release rate of a cargo fire.[13]
- The time it takes for a fire detection system to detect a fire originating within a cargo container may easily exceed the 1-minute time frame specified in 14 *CFR* 25.858(a).

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[10] *Oxidizer* (Division 5.1) means a material that may, generally by yielding oxygen, cause or enhance the combustion of other materials.

[11] Federal Aviation Administration, *Risks in Transporting Lithium Batteries in Cargo Aircraft*. Safety Alert for Operators, SAFO 10017 (Washington, DC: US Department of Transportation, Federal Aviation Administration, 2010).

A *Class C* cargo compartment, as defined in 14 *CFR* Part 25.857(c), is a compartment equipped with a separate approved smoke detector or fire detector system to give warning at the pilot or flight engineer station; has an approved built-in fire extinguishing or suppression system controllable from the cockpit; has a means to exclude hazardous quantities of smoke, flames, or extinguishing agent from any compartment occupied by crew or passengers; and has a means to control ventilation and drafts within the compartment.

[12] NTSB Materials Laboratory Study Report 12-019, March 21, 2012, fire load contribution of lithium and lithium-ion batteries and burning characteristics of aircraft cargo container fires. See case number DCA10RA092 on the NTSB website at http://www.ntsb.gov/investigations/dms.html.

[13] *Fire load* refers to the amount of heat that can be generated by a substance if ignited within a given area.

- The growth rate of container fires after they become detectable by the aircraft's smoke detection system can be extremely fast, precluding any mitigating action and resulting in an overwhelming fire.

Based on this research and test data, the NTSB is concerned that when fires inside containers become detectable to an aircraft's smoke detection system, there is little time until the fires reach levels that can compromise the integrity of the cargo compartment and then threaten the structure and systems of the aircraft. The NTSB is further concerned that in a cargo fire situation, the close proximity of lithium cells and batteries with other flammable materials would significantly increase the severity of the fire and reduce the time for flight crews to react.

The International Air Transport Association (IATA) recently published lithium battery risk mitigation guidance for aircraft operators, which includes recommended practices for cargo acceptance and handling.[14] This guidance was designed to outline potential strategies airlines should consider to reduce the risks associated with the transport of lithium batteries. With respect to loading lithium batteries on board aircraft, the guidance states:

> As an item of dangerous goods in Class 9 (miscellaneous dangerous goods), there is no requirement for packages of lithium batteries to be segregated from other types of dangerous goods. However, operators may wish to consider segregating packages of fully regulated lithium batteries from packages of other dangerous goods except those of classes 6, 7, or 9.

In October 2015, the International Civil Aviation Organization (ICAO) Dangerous Goods Panel (DGP/25) Working Group met in Montréal, Quebec, Canada, to discuss the development of measures to mitigate the risks associated with the transport of lithium batteries when carried as cargo. The ICAO DGP/25 considered limiting the number of batteries loaded in one place and segregating them from other classes of dangerous goods, as addressed in this recommendation letter. However, the ICAO DBP/25 did not adopt the amendments and deferred discussion on these issues until its next biennium meeting.

Findings

Asiana Airlines Flight 991 was carrying 18 (258.6 kg) lithium-ion batteries configured for use in hybrid-electric vehicles. Each battery was comprised of 6 or 12 cells, each rated about 90 watt-hours (Wh). The lithium-ion batteries were regulated as Class 9, UN3480, Packing Group II, hazardous materials. Figures 1 and 2 show a lithium-ion cell and battery packaging identical to that which was loaded on board the accident aircraft.

[14] International Air Transport Association, *Lithium Batteries Risk Mitigation Guidance for Operators, Effective 1 January – 31 December, 2015*. 1st edition, (Montréal, Quebec, Canada: International Air Transportation Association, 2014).

Figure 1. A 12-cell lithium-ion battery contained in a Packing Group II fiberboard box.

Figure 2. Individual 90 Wh cell removed from the battery module.

In addition, packages containing about 519 liters (137 gallons) of Class 3 flammable materials and other hazardous materials were commingled with the lithium-ion batteries on a single pallet. An adjacent pallet contained an additional 439 liters (116 gallons) of Class 3 flammable materials; no other hazardous materials were identified elsewhere on the main cargo deck. Thus, all of the declared hazardous materials were concentrated in a single location on the airplane.

Based on analysis of Aircraft Communications Addressing and Reporting System (ACARS) messages from the accident aircraft, investigators determined that smoke detectors first detected fire in the aft fire zones near the two hazardous materials pallets. Recovered debris showed that structural damage to the aircraft was greatest in the region of the pallets with the hazardous materials, leading the ARAIB to conclude that the origin of the fire was in or around the pallets where hazardous materials had been loaded onto the aircraft. (Figure 3.) About 3 to 4 minutes after detection, the smoke and fire spread rapidly throughout the main deck cargo compartment. Analysis of thermal damage to the recovered wreckage revealed that the greatest damage was concentrated at the location where the hazardous materials were stowed. The practice employed by Asiana Airlines to concentrate all of the multiple classes of hazardous materials on the aircraft in a single location on the cargo deck, as authorized by current regulations, intensified the fire. The airplane broke up in flight and crashed within 17 minutes of the pilots reporting the cargo deck fire.

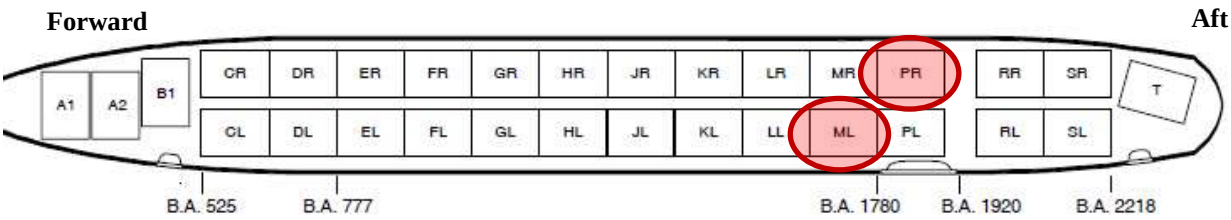

Figure 3. Location of hazardous materials and fire origin on board Asiana Flight 991.

The ARAIB report stated that for safer transportation of dangerous goods, flammable dangerous goods (Class 3) and lithium batteries (Class 9) bearing the "Cargo Aircraft Only" label should be loaded and transported only in a Class C cargo compartment equipped with a separate smoke detector or fire detection system and with an approved built-in fire extinguishing or suppression system controllable from the cockpit, and that lithium batteries (Class 9) should be loaded in a separate unit load device (ULD) and segregated from other flammable dangerous goods (Class 3).[15] While ARAIB recommended these actions to Asiana Airlines and to the Republic of Korea Ministry of Land, Infrastructure, and Transport, it did not issue recommendations to ICAO or other foreign entities regarding lithium battery transport requirements.

The ARAIB issued the following safety recommendations pertaining to the stowage of lithium batteries and flammable materials:

To Asiana Airlines:

1. Ensure that flammable liquid dangerous goods (Class 3) and lithium batteries (Section 1, 1A) which are bearing the "Cargo Aircraft Only (CAO)" label are segregated and loaded on separate ULDs.[16]

To Ministry of Land, Infrastructure and Transport, Republic of Korea:

1. Develop relevant standards for ensuring that flammable liquid dangerous goods (Class 3) and lithium batteries (Section 1, 1A) which are bearing the "Cargo Aircraft Only (CAO)" label are segregated and loaded on separate ULDs (pallets, etc.).

2. Develop loading standards for ensuring that various kinds of flammable dangerous goods (Class 3) are not concentrated in a single ULD within an aircraft.

[15] A *ULD* is a pallet or container used to load freight onto an aircraft. It allows a large quantity of cargo to be bundled into a single unit.

[16] *Section 1A* refers to fully regulated lithium batteries under ICAO Packaging Instructions 965-967.

As a result of the NTSB investigation of the February 7, 2006, in-flight fire on United Parcel Service Flight 1307 in Philadelphia, Pennsylvania, the NTSB issued Safety Recommendation A-07-104 to PHMSA.[17]

> Require aircraft operators to implement measures to reduce the risk of primary lithium batteries becoming involved in fires on cargo-only aircraft, such as transporting such batteries in fire resistant containers and/or in restricted quantities at any single location on the aircraft. (A-07-104) (*Closed—Reconsidered*).

The NTSB closed this safety recommendation as "reconsidered" because it was never actualized. PHMSA did not implement the safety recommendation because of the provisions of Section 828 of the FAA Modernization and Reform Act of 2012 (FAA Act)."[18] Under the FAA Act, the US Department of Transportation is prohibited from issuing or enforcing any regulation or other requirement regarding the air transportation of lithium cells or batteries if the requirement is more stringent than the requirements of the ICAO Technical Instructions.[19] However, the FAA Act allows PHMSA to issue permanent regulations if it obtains credible evidence that demonstrates a deficiency in the ICAO Technical Instructions that has substantially contributed to the initiation or propagation of an on board fire, which could be addressed with specialized packaging, additional stowage restrictions, or other measures.[20]

The NTSB believes that the circumstances and findings in the Asiana Flight 991 accident constitutes such credible evidence that demonstrates a deficiency in cargo segregation requirements that would permit the HMR to be changed to be more stringent than the current ICAO requirements. Current regulations that allow the loading of packages containing lithium batteries, a potential ignition source, in close proximity to packages of flammable materials and other classes of hazardous materials, and also allows these materials to be stowed on board aircraft in large quantities in a single location constitute an unacceptable risk to the safe transportation of these hazardous materials.

Therefore, the National Transportation Safety Board makes the following safety recommendations to the Pipeline and Hazardous Materials Safety Administration:

A-16-001

> Require that Class 3 flammable liquids and fully regulated Class 9 lithium batteries be physically segregated when stowed on board an aircraft such that packages containing these materials may not be placed on the same or adjacent pallets or ULDs.

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[17] National Transportation Safety Board, *Inflight Cargo Fire United Parcel Service Company Flight 1307 McDonnell Douglas DC-8-71F, N748UP, Philadelphia, Pennsylvania, February 7, 2006*, NTSB/AAR-07/07 (Washington, DC: National Transportation Safety Board, 2007).

[18] Section 828 of the "FAA Modernization and Reform Act of 2012." Pub. L 112–95, 126 Stat. 133 (February 14, 2012).

[19] *See* Section 828(a), Pub. L. 112-95, Stat. 133 (February 14, 2012).

[20] *See* Section 828(b)(2)(B), Pub. L. 112-95, Stat. 133 (February 14, 2012).

A-16-002

Establish maximum loading density requirements that restrict the quantities of Class 3 flammable hazardous materials or Class 9 lithium batteries stowed on a single pallet or ULD, or on a group of pallets or ULDs, within an aircraft such that cargo fires can be effectively managed by on-board fire suppression capabilities.

Chairman HART, Vice Chairman DINH-ZARR, and Members SUMWALT and WEENER concurred in these recommendations.

The NTSB is vitally interested in these recommendations because they are designed to prevent accidents and save lives. We would appreciate receiving a response from you within 90 days detailing the actions you have taken or intend to take to implement them. When replying, please refer to the safety recommendations by number. We encourage you to submit your response electronically to correspondence@ntsb.gov.

[Original Signed]

By: Christopher A. Hart,
Chairman