



# Three Accidents Involving Lithium Batteries

**1**<sup>st</sup> Edition

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## Three Accidents Involving Lithium Batteries

A brief review of three aircraft accidents where lithium batteries were known to have been on board as cargo



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# Chapter 1: Executive Summary

The cases in question are the three aviation accidents that occurred within the last ten years, where lithium batteries are known, or suspected, to have been involved in a significant way.

Due to the small number of accidents in relation to the number of passenger and cargo flights operated over this ten year period, it is almost meaningless to calculate a rate.

	<b>Accident/Incident #1 B744 Jeju</b>	<b>Accident/Incident #2 B744 Dubai</b>	<b>Accident/Incident #3 DC-8 Philadelphia</b>
LI batteries on board	Yes	Yes	Yes
Declared?	Yes	No	Lithium – Yes other items – no (not considered to be a factor)
Hull loss	Yes	Yes	Yes
Fatalities (%)	2 (100%)	2 (100%)	0 (0%)
Phase of flight	Early cruise	Early cruise	descent
Time into flight	50 minutes	22 minutes	c. 2 hours
Time to uncontained fire	17 minutes	23 minutes	27:45 minutes

As can be seen from the table above, in the first two incidents, the fires broke out early into the flight; the third occurred during the descent.

For the first incident, the fire broke out in the area where dangerous goods, including lithium batteries, were stored. For the second incident, it was found that “with reasonable certainty” that the fire which caused the crash originated in a cargo container which held thousands of lithium batteries. For the third incident, it is believed that the fire started elsewhere in the cargo and spread to the lithium batteries.

For all three incidents, it is clear that once there is a fire with large quantities of lithium batteries, the time from ignition to uncontrollable fire is quite short – 17 minutes, 23 minutes and 27 minutes respectively. However, *it must be noted that* each of these incidents are dealing with large quantities of lithium metal



and/or lithium ion batteries, which have now been limited and restricted to cargo only, in line with recent legislation.

### **Précis of Incident Number 1**

The investigation determined that cargo stored on the aircraft between FS1 700 and the aft bulkhead had caught fire. A total of 2,092 kg was declared as dangerous goods, loaded near the left cargo door on the main deck. These goods consisted of flammable liquids, corrosive liquids and lithium-ion batteries. All dangerous cargo had been placed onto 2 pallets and had been loaded without problems, no observation of damage or leakages. The goods had been previously stored according to regulations. It was impossible to say what caused the fire, other than cargo stored on the aircraft between FS 1700 and the aft bulkhead, which includes (but is not limited to) the dangerous goods as described above.

### **Précis of Incident Number 2**

The investigating authority report found "*with reasonable certainty*" that the fire which caused the crash originated in a cargo container which held thousands of lithium batteries. The report made 36 recommendations for safety improvements, including improvements to systems that warn pilots of cargo hold fires, and use of additional systems to improve pilot visibility during aircraft fire scenarios. Partly as a result of this investigation, the International Civil Aviation Organization (ICAO) adopted a ban on the shipment of lithium metal batteries as cargo aboard passenger aircraft. The prohibition came into effect on January 1, 2015.

### **Précis of Incident Number 3**

The first indication of the fire was the first officer's query to the other crewmembers about the smell of burning wood, which occurred about 20 minutes before the main cargo compartment Cargo Smoke warning light activated. The flight engineer first saw smoke when he exited the cockpit to close the main cargo air shutoff valve and black smoke emanated from the valve's access panel. About 2 minutes later, almost immediately after touchdown, the flight engineer reported that smoke had begun entering the cockpit. The smoke continued to worsen after the airplane came to a stop, and the smoke in the cockpit became so thick that the two pilots could not see each other before evacuating the airplane.



# Chapter 2: Introduction and Purpose

This report was commissioned by IATA Safety to see if anything could be gained from an understanding of the three cases when viewed together. In particular, it was requested to look at the lithium batteries in cargo, review the position of these batteries in the aircraft, review burn times of cargo wherever possible, consider the time from detection of fire to catastrophic loss of the aircraft and determine if any recommendations could be made from this information.

This report was commissioned in order to support the IATA safety position on the carriage of lithium batteries, in particular to provide IATA with input to the discussions which took place at the Third International Multidisciplinary Lithium Battery Transport Coordination Meeting, held at ICAO Headquarters from 28 to 30 July 2015.

A secondary use for the report was agreed. IATA Safety has also produced a Safety Risk Assessment (SRA) on the carriage of Lithium batteries. This report will be used in conjunction with the SRA (and other guidance material) and form a 'tool kit' for operators requiring more information on the implications of the carriage of lithium batteries on their aircraft.

The three incidents under review are as follows:

Accident/Incident	Probable Causes/findings	LI Batteries on Manifest?
B744 near Jeju July 28, 2011 Fire in Cargo Hold	The investigation determined that cargo stored on the aircraft between FS1700 and the aft bulkhead had caught fire.	Yes
B744 Dubai September 3, 2010 Cargo Fire	A large fire developed in palletized cargo on the main deck at or near pallet positions 4 or 5, in Fire Zone 3, consisting of consignments of mixed cargo including a significant number of lithium batteries and other combustible materials. The fire escalated rapidly into a catastrophic uncontained fire.	Yes
DC-8 Philadelphia, Pennsylvania February 7, 2006 Inflight Cargo Fire	The National Transportation Safety Board determined that the probable cause of this accident was an in-flight cargo fire that initiated from an unknown source, which was most likely located within cargo container 12, 13 or 14. Contributing to the loss of the aircraft were the inadequate certification test requirements for smoke and fire detection systems and the lack of an on-board fire suppression system, aircraft rescue and firefighting training, cargo airplane emergency exit requirements, hazardous materials information dissemination procedures, and transport of lithium batteries on board aircraft.	Yes

An in-depth review of the published material was carried out. For the first two incidents the published reports were available. For the third incident, the full investigation docket was available.

## Chapter 3: Method and Limitations

The method used for this study is simply one of review of available documentation pertaining to the investigations.

The limitations for this study are both of time and material available. For the first two incidents the published reports were available. These reports are very in-depth but do not give as much information as is available for the third incident where the full investigation docket was available. For the third incident, a total of 168 documents (some 2,300 pages) were available for review.

### 3.1 Incident Number 1

#### Cargo Flight B747

The subject aircraft was a cargo flight which crashed into the Korea Strait on 28 July 2011. The two crew members aboard died. The aircraft involved, a Boeing 747-400 freighter, was operating a scheduled international cargo service from Incheon International Airport, South Korea to Shanghai Pudong International Airport, China. The crash occurred off the coast of Jeju Island after the crew reported a fire in the cargo compartment and had been attempting to divert to Jeju International Airport.

The aircraft was built in 2006, had completed around 26,300 flight hours and was powered by four General Electric CF6-80C2 engines.

The flight departed Incheon International Airport at 16:47 UTC on 27 July 2011 (2:47 AM on 28 July 2011 local time), bound for Shanghai Pudong International Airport. At 4:03 AM, the crew reported a fire and diverted to Jeju Airport for an emergency landing. Radio contact was lost with the aircraft at 4:11 AM when it is believed the aircraft crashed 107 kilometers (66 mi) southwest off Jeju Island.

The captain of the flight was 52-years old, while the first officer was 44-years old; together, the two had over 19,000 hours of flight time.

The flight to Shanghai was loaded with 58 tonnes (57 long tons; 64 short tons) of cargo; 90% of the freight was standard cargo, semi-conductors, mobile phones, liquid crystal displays and light-emitting diodes. The remainder included 400 kg (880 lbs.) of lithium batteries, paint, resin solutions and other liquids. The crew reported that the cargo was on fire to Shanghai Center and was diverting to Jeju Airport when it crashed about 70 nm west of the Island at 04:12 local time, 67 minutes after it had taken off from Seoul.

The aircraft had been carrying 39,331 kg of cargo, 18,934 kg of which were loaded at Incheon Airport. A total of 2,092 kg was declared as dangerous goods, loaded near the left cargo door on the main deck. These goods consisted of flammable liquids, corrosive liquids and lithium-ion batteries, the shipment consisting of 198 cells rated at 25Ah at 3.65V. All dangerous cargo had been placed onto 2 pallets and had been loaded without problems, no observation of damage or leakages. The goods had been previously stored according to regulations.

The captain had supervised the transport from the warehouse and loading of the two pallets onto position ML and PR on the aircraft.

Declared dangerous goods loaded on the accident aircraft were products of 6 companies on 8 master airwaybills. All dangerous goods were loaded on the main cargo deck. Of them, two items were loaded on the ML pallet and the other five items were loaded on the PR pallet, and all of them were positioned adjacent to the main deck side cargo door. Dangerous goods included flammable liquids, corrosive liquids and lithium-ion batteries.

PMC13389OZ 1,575 65

LITHIUM ION BATTERY, PAINT,

AMINES LIQUID CORROSIVE, PAINT,

PHOTO COLOR RESIST, AUTOMOTIVE PART

FLAMMABLE LIQUID

Dangerous Goods	AWB No. 988 -	Departure Point	Total Weight (kg)	Net Quantity	Item Description
Lithium-ion batteries	-63857393	Osaka Japan	258.6	243.6 Kg	Lithium-ion battery for hybrid automobile

The investigation determined that cargo stored on the aircraft between FS1700 and the aft bulkhead had caught fire. There was no evidence of fire/thermal damage aft of the pressure bulkhead; sections forward of FS1700 showed damage by sooting.

The aircraft had been carrying 39,331 kg of cargo, 18,934 kg of which were loaded at Incheon Airport. A total of 2,092 kg was declared as dangerous goods, loaded near the left cargo door on the main deck. These goods consisted of flammable liquids, corrosive liquids and lithium-ion batteries, **consisting of 198 cells rated at 25Ah at 3.65V**. All dangerous cargo had been placed onto 2 pallets and had been loaded without problems, no observation of damage or leakages. The goods had been previously stored according to regulations. The captain had supervised the transport from the warehouse and loading of the two pallets onto position ML and PR on the aircraft.

Palette MR was recovered from the sea floor, films contained in the palette showed burns and blackened traces. Recovered containers 43L and 44L from the lower deck showed no signs of fire or soot.

The cargo pallets recovered from the sea floor showed:

Bottom floor: no traces of fire or soot

SL: traces of soot and melting

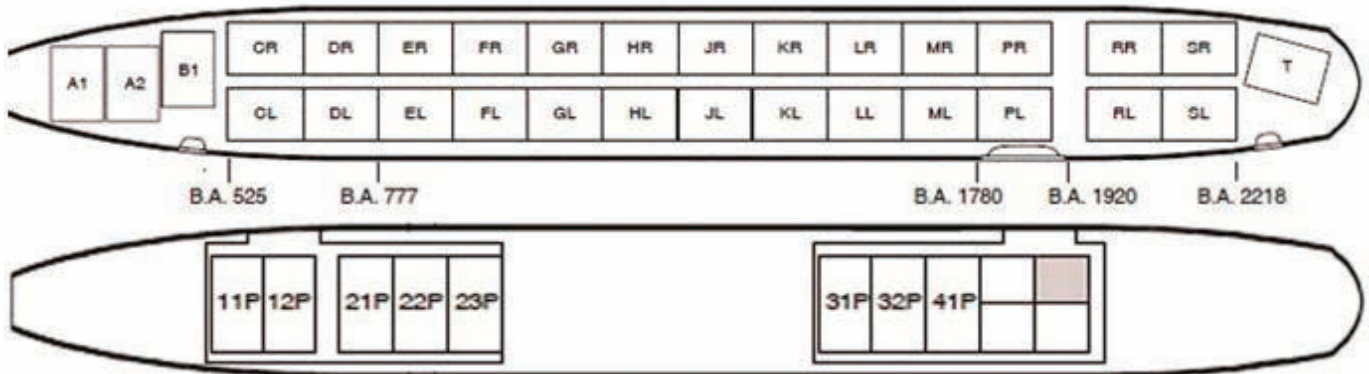
SR: traces of soot and light melting, severe corrosion

PR: traces of soot and blue dye splatters, cargo net with burnt traces

ML: traces of burning and soot

LR: no traces of fire

The cargo pallet positions (Graphics: ARAIB):



### Excerpt from page 74 of the final report:

The Dangerous Goods Declaration for the shipment of lithium-ion batteries loaded onto the accident aircraft indicated that packaging was in accordance with ICAO TI Packing Instruction 965.

One box can be packed with two 6-cell batteries or one 12-cell battery. Since the weight of two 6-cell batteries is about 16 kg and the weight of one 12-cell battery is about 14 kg, the battery weight 14 - 16 kg to the packing limit weight of the box 40 kg is 40% or less.

The manufacturer stated that safety margins were taken into consideration while packing at or below 40% of the packing limit weight. Under the Dangerous Goods Regulations in force at the time, the lithium battery package quantity limitation for cargo aircraft was 35 kg.

### 3.1.1 Dangerous Goods Training

It was recorded that the instructor exclusively in charge of DG training stated that he had trained all pilots with an emphasis on cargo safety standards for lithium ion batteries and cargo fire procedures during the first half-year type training in 2011 after the fatal cargo aircraft crash in 2010. In addition, it was confirmed that the pilots had been notified of the cargo jet fire accident.

### What probable causes are cited?

The investigation determined that cargo stored on the aircraft between FS1700 and the aft bulkhead had caught fire.

### Where these batteries on the manifest?

Yes:

A total of 2,092 kg was declared as dangerous goods, loaded near the left cargo door on the main deck. These goods consisted of flammable liquids, corrosive liquids and lithium-ion batteries, the shipment consisting of 198 cells rated at 25Ah at 3.65V. All dangerous cargo had been placed onto 2 pallets and had been loaded without

problems, no observation of damage or leakages. The goods had been previously stored according to regulations.

### Conclusions

- The investigation determined that cargo stored on the aircraft between FS1700 and the aft bulkhead had caught fire.
- A total of 2,092 kg was declared as dangerous goods, loaded near the left cargo door on the main deck.
- These goods consisted of flammable liquids, corrosive liquids and lithium-ion batteries.
- All dangerous cargo had been placed onto 2 pallets and had been loaded without problems, no observation of damage or leakages. The goods had been previously stored according to regulations. The captain had supervised the transport from the warehouse and loading of the two pallets onto position ML and PR on the aircraft. Position ML had traces of burning and soot, whereas position LR showed no traces of fire.
- From this, it is impossible to say what caused the fire, other than cargo stored on the aircraft between FS1700 and the aft bulkhead, which includes (but is not limited to) the dangerous goods as described above.

## 3.2 Incident Number 2

### Cargo Flight B747

On September 3, 2010, a Boeing 747-400 flying between Dubai International Airport and Cologne Bonn Airport developed an in-flight fire, with the fumes and subsequent crash resulting in the death of the two crewmembers. The aircraft had departed Dubai International earlier, but returned after reporting smoke in the cockpit.

The aircraft involved in the accident was a Boeing 747-400F and was delivered in 2007. It had flown for a total of 9,977 hours and had a major inspection performed in June 2010.

The flight departed from Dubai International at 14:53 UTC and at 15:15 the crew reported a fire in the cockpit when the aircraft was around 120 nautical miles (220 km) west-northwest of Dubai, and declared an emergency. The pilots were under the control of Bahrain's air traffic control, and they could not initially contact Dubai air traffic control due to a radio failure. Although they were offered a diversion to Doha, Qatar, the pilots returned to Dubai, and were instructed to land on the airport's runway 12L. The aircraft was too high on the approach and passed over the airport before making a tight turn; radar contact was lost shortly thereafter at 15:42 UTC. The aircraft crashed in an unpopulated area between the Emirates Road and Al Ain Highway, barely missing Dubai's Silicon Oasis.

On September 24, 2013, the GCAA released its comprehensive, 322-page report on the crash, which found "with reasonable certainty" that the fire which caused the crash originated in a cargo container which held thousands of lithium batteries. The report made more than thirty recommendations for safety improvements,



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including improvements to systems that warn pilots of cargo hold fires, and use of additional systems to improve pilot visibility during aircraft fire scenarios.

There follows some pertinent information on the investigation, followed by key findings and conclusions.

### **Inbound Flight Arrival from Hong Kong**

On September 3, 2010, the Boeing 747-400AF aircraft, arrived from Hong Kong [HKG] on a scheduled cargo service flight to Dubai International Airport carrying, among other items, significant consignments of cargo that included lithium batteries. The aircraft was parked at the loading position, chocks on/block in at 11:35 UTC.

The following scheduled sector was Dubai (OMDB/DXB) direct to Koln-Bonn, Cologne (EDDK/CGN) scheduled to depart at 14:50 UTC on the 03 September 2010 - this is the accident flight.

### **Cargo Loading**

Prior to the flight to Dubai, cargo was loaded into all positions in Hong Kong. A consignment of mixed cargo including a significant number of batteries, including lithium types, was loaded onto the pallets located at MD positions 4, 5 and 6, amongst other positions. Upon arriving in Dubai, the Unit Load Devices (ULD) in positions 13L, 14L, 14R, 18L, 19L, and 20 were removed from the aircraft. Some of these ULD's were replaced with other out-bound ULD's. No cargo was unloaded from the forward section of the main deck.

The Cargo Group examined shipping invoices for the cargo on board the aircraft, and at least three shipments of lithium batteries which should have been declared as hazardous materials were identified in the pallets at positions 4 and 5. There were no *declared shipments* of hazardous materials on board the accident flight.

### **Cargo Identified In the debris**

The cargo identified on scene included clothing, machined parts and subassemblies, flashlights, gun parts, costume jeweler, cases for electronic equipment, USB flash drives, un-populated circuit boards, espresso makers, automotive entertainment and navigation systems, bike frames, pellets for injection molding, wrist watch components, rubber bracelets, cell phones, MP3 and MP4 players, mannequin heads, wigs, shoes. No items posing a flammable fuel load or capable of acting as an ignition source were visually identified *except for batteries and battery containing devices*.

### **Fire Testing - Batteries and Cargo Containers**

The investigation conducted tests to examine the fire load contribution of lithium and lithium-ion batteries, and large scale testing of the burning characteristics of cargo pallets and containers using full scale fires to quantify the cargo fire behavior. The objectives were to determine baseline quantifiable data to support recommendations for fire safety improvements. Testing was conducted at the Fire Research Branch of the Federal Aviation Administration's Technical Center in Atlantic City, New Jersey, and at the Fire Research Laboratory of the Bureau of Alcohol, Tobacco, Firearms and Explosives.

From the tests involving batteries, the following conclusions were made:

- At the single-cell level, the energy release rate of lithium and lithium-ion type batteries is relatively small when compared to other ordinary materials.
- In addition to the energy release from batteries resulting in combustion, there is an associated mechanical energy release. This mechanical energy release is capable of compromising the integrity of packaging and creating incendiary projectiles.
- Lithium (primary) batteries tend to exhibit more energetic failures than lithium-ion (secondary) batteries.
- The total energy release of a box of 100 lithium-ion batteries can be fairly accurately predicted based on single battery cell calorimetry data.
- The thermal runaway of lithium-ion batteries is capable of spreading from cell to cell within a package of batteries.
- The thermal runaway of lithium-ion batteries is capable of causing adjacent combustibles to ignite.

Testing conducted by the FAA William J. Hughes Technical Center (FAA Tech Center) indicates that there are particular propagation characteristics associated with lithium batteries, as follows:

- Overheating has the potential to create thermal runaway, a chain reaction leading to self-heating and release of a battery's stored energy.
- In a fire situation, the air temperature in a cargo compartment fire may be above the auto-ignition temperature of lithium. For this reason, batteries that are not involved in an initial fire may ignite and propagate, creating a risk of a catastrophic event.
- The existence and magnitude of the risk will depend on such factors as the total number and type of batteries on board an aircraft, the batteries' proximity to one another, and existing risk mitigation measures in place, which can include the type of fire suppression system on an aircraft, appropriate packaging and stowage of batteries.

### **The UN "T" tests required by the UN Regulator Scheme**

The UN Manual of Tests and Criteria, Fifth Revised Edition (2009), contains the UN T1-T8 Tests that are listed below. These tests only have to be performed once for each cell and battery of a given design, and must be completed prior to shipment.

The following tests must be performed on all primary lithium (metal), rechargeable lithium-ion and lithium-ion polymer cells or batteries.

Test T1: Altitude Simulation - Simulates air transport under low-pressure conditions. Store at 11.6 kPa or less for six (6) hours at 20°C

Test T2: Thermal Test - Assesses cell and battery seal integrity and internal electrical connections using thermal cycling to simulate rapid and extreme temperature changes. Perform ten (10) cycles between 75°C and -40°C, six (6) hours per cycle with no more than 30 minutes between cycles, and then observe for 24 hours.



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Test T3: Vibration - Simulates vibration during transport. Sinusoidal waveform with a logarithmic sweep between 7 Hz and 200 Hz and back to 7 Hz in 15 minutes. This cycle must be repeated 12 times for a total of three (3) hours for each of three (3) mutually perpendicular mounting positions of the cell or battery.

Test T4: Shock - Simulates possible impacts during transport. Half-sine shock of peak acceleration of the positive direction and three (3) shocks in the negative direction of three (3) mutually perpendicular mounting positions for a total of 18 shocks.

Test T5: External Short Circuit - Simulated an external short circuit. After stabilizing at 5°C, apply an external resistance of less than 0.1 ohm for one (1) hour and then observe for six (6) hours.

Test T6: Impact - Simulates an impact. Place a 15.8 mm diameter bar across the sample and then drop a 9.1 kg mass from a height of 61 cm on to the bar, and then observe for six (6) hours.

Test T7: Overcharge - Evaluates the ability of a rechargeable battery to withstand overcharge. Charge at twice the manufacturer's recommended maximum continuous charge current for 24 hours, and then observe for seven (7) days.

Test T8: Forced Discharge - Evaluates the ability of a primary or a rechargeable cell to withstand forced discharge. Force discharge at an initial current equal to the maximum

### **Lithium Batteries - Assessing the Risk**

Large quantities of lithium metal batteries are a Class D fire/combustible metals risk item covered by dangerous goods regulations relating to transport by air. Class D fires are a chemical reaction which is self-sustaining. Battery fires are electric fires: to extinguish the fire the short must be removed and the temperature reduced as the short is internal to the cell during a thermal runaway, the thermal runaway has to be stopped to contain the fire hazard. Uncontained, the battery discharge can spread to adjacent cells establishing a chain reaction.

The explosive potential of lithium metal cells can easily damage (and potentially perforate) cargo liners, or activate the pressure relief panels in a cargo compartment. Either of these circumstances can potentially lead to a loss of Halon 1301 [in class C cargo compartments], allowing rapid fire spread within a cargo compartment to other flammable materials. For this reason, lithium metal cells are prohibited as bulk cargo shipments on passenger carrying aircraft.

Lithium batteries are currently classified as Class 9 materials under the Hazardous Materials Regulations (HMR) (49 CFR 180 185). Nonetheless, most small lithium batteries and devices were exempted from the Class 9 provisions of the HMR *at the time of the accident*. Because of this exception, they did not require a Notice to the Pilot in Command (NOTOC) to alert the crew of their presence on-board an aircraft.

The organic electrolytes are composed of a volatile and flammable chemicals which in an inert state are not considered hazardous; but if damaged, subjected to water ingress or to increased energy levels from an external source, either thermal, acoustic or mechanical can be considered hazardous. Lithium ion batteries



are highly flammable when agitated, which can lead to an exothermic reaction, which is referred to as 'thermal runaway'.

FAA testing and research indicates that a single cell in thermal runaway has a thermodynamic effect on adjacent cells in a bulk shipment cardboard box. It was determined that a single cell in thermal runaway produces enough heat to cause other nearby cells within the shipping box to also go into thermal runaway. This process has been shown to propagate to all cells within the box as well as to adjacent boxes of cells, as shown in a test with three 100 cell boxes. Halon 1301, the fire suppressant used in class C aircraft cargo compartments is ineffective in stopping the propagation of thermal runaway in lithium-ion and metal cells, though it does suppress the open flame from a lithium ion battery and will spread to other combustibles. It is ineffective against a flaming lithium metal battery.

This research has been the basis for banning the bulk shipment of lithium metal batteries as cargo on-board passenger carrying aircraft.

### **Probable time of ignition**

The time that the fire was detected by the smoke detectors was around 15:13 UTC.

According to the investigation report - Fire load contribution of lithium and lithium-ion batteries, which includes the pallet fire testing which in the controlled conditions was in an uncontained fire condition at around ten minutes from the initial point of ignition.

Providing the fire rate of acceleration remained constant, it is possible that the initial time of ignition was approximately 10-15 minutes prior to the smoke alarm, which establishes the time of ignition in the initial cruise.

### **Source of Ignition and Cargo Fire Sequence**

As the wreckage was subjected to a large post-accident fire and the aircraft had an on-board fire for approximate 35 minutes prior to the accident, retrieval of evidence was limited to several relatively small components.

It has been established that there were consignments of significant quantities of lithium batteries or derivatives of lithium type batteries on-board.

Through a process of cross referencing the location of the ACARS fire detection messages and other system indications and anomalies recorded on the FDR, with the cargo manifest for the type, number, location and of the lithium batteries on board, the investigation concludes with reasonable certainty that the location of the fire was in an element of the cargo that contained, among other items, lithium batteries. It is possible that a lithium type battery or batteries, for reasons which cannot be established, went into an energetic failure characterized by thermal runaway and auto ignited starting a chain reaction which spread to the available combustible material.

This may have ignited the cargo providing sufficient thermal energy to ignite the adjacent cargo, which included, but did not entirely consist of, lithium batteries.

It is probable that the remaining cargo, the cargo pallet and the adjacent cargo ignited and continued in a sustained process of combustion for an indeterminate period of time; the sustained state of combustion in all probability continued up until the aircraft data ceased to record.

As found in the cargo container fire testing, particularly in the case of the collapsible DMZ containers, the short time interval between a fire being detectable and peak energy release rate precludes any mitigating action to suppress the fire and protect the aircraft structure. The FAA regulation for cargo compartments certified with smoke detection (14 CFR 25.858) requires a 1 minute detection time from the start of a fire. The regulation does not account for any delay in detection caused by the container. Current certification tests do not use containers. **Although 14 CFR 25.858 for cargo compartments certified with smoke detection does not specify any performance metric for what goes on after detection, the results of these fire tests suggest that the intent of the regulation as stipulated in paragraph (b) of 14 CFR 25.858, "the system must be capable of detecting a fire at a temperature significantly below that at which the structural integrity of the aircraft is substantially decreased," is not being met.**

### Fire Suppression Methodology

The report went into great detail on this aspect and reported the following:

- Main deck cargo compartments on ICAO class E/F aircraft are large and fires can develop before any passive suppression due to oxygen deprivation can help slow down the fire.
- For example, in this accident, the time interval between fire detection and the onset of aircraft system failures was about 2 minutes 30 seconds. The crew attempted to depressurize the aircraft to slow down the fire 30 seconds after the loss of aircraft systems and flight controls.
- Additionally, experiments performed at the FAA's William J. Hughes Technical Center in Atlantic City, New Jersey have shown that, although depressurization can suppress flaming combustion, the fire continues to propagate, increasing overall compartment temperatures and pyrolyzing fuel such that upon the reintroduction of oxygen (for example, as the aircraft descends for landing), the fire resumes at an even greater intensity. Experience from this accident investigation in conjunction with FAA experiments suggest passive fire suppression in large cargo compartments due to oxygen deprivation may not be effective.
- The addition of oxygen from the crews' damaged supplementary oxygen system venting directly into the fire in the cargo compartment environment - the introduction of oxygen can directly contribute to the sustaining and propagation of a fire event.
- Based on the cargo container and pallet trials it has been established that the time it takes for a fire detection system to detect a fire originating within a cargo container with a rain cover may easily exceed the one minute time frame specified in USA/Title 14 Code of Federal Regulations (CFR) 25.858(a).
- The fire detection system detects fire by sampling the cabin air for smoke only. There is no active fire detection system required which can identify heat or ongoing pyrolysis.
- The fire suppression methodology of venting airflow and depressurization of the cargo hold is a passive system of fire suppression which works through controlling the available oxygen to a conventional fire with the presumed effect of cancelling the fire triangle, preventing or inerting further combustion.

- One other factor for the 25,000 ft. limit is that when the fire suppression depressurization is activated, the avionics bay vents are in reduced flow, affecting the avionics bay cooling.
- The manufacturer and the operators fire suppression methodology is based on suppressing a conventional fire where the normal fire triangle operates, not a class D metal fire where a sustained exothermic reaction (i.e. *not* ambient oxygen dependent) is in the process.
- Class D fires are caused by burning metals that combust easily on contact with air, such as magnesium and lithium. Either powder extinguishers are required or a method of cooling the metal below auto ignition temperatures.
- **The current regulatory framework and the practical requirements for extinguishing large cargo fires are unsynchronized regarding the requirement of the regulation and the intention of fire suppression.**

### Single Point of Failure Analysis

The risk associated with the current cargo fire potential is that the carriage of standard cargo consignments can expose the cargo compartment liner to a fire or thermal load that exceeds the certification design requirements.

The single point of failure in this accident was the inability of the cargo compartment liner to prevent the fire and smoke penetration of the area above pallet locations in main deck fire zone 3. This resulted in severe damage to the aircraft control and crew survivability systems, resulting in numerous cascading failures.

As the cargo compartment liner failed, the thermal energy available was immediately affecting the systems above the fire location: this included the control assembly trusses, the oxygen system, the ECS ducting and the habitable area above the fire in the supernumerary compartment and in the cockpit.

### General information on the Findings, Causes and Contributing Factors

From the evidence available, the following causes, contributing factors, safety issues and other key findings were made with respect to this accident (there were a total of 95 findings but we are considering findings relevant to lithium batteries only):

3. A consignment of mixed cargo including a significant number of batteries, including lithium types, was loaded on the inbound flight from Hong Kong onto the pallets located at MD positions 4, 5 and 6, amongst other positions. This cargo was not unloaded in Dubai.
4. At least three shipments including lithium type batteries should have been classified and fully regulated as Class 9 materials per ICAO Technical Instructions, and thus should have appeared on the cargo manifest. These shipments were located in the cargo at MD positions 4 and 5.
5. Shippers of some of the lithium battery cargo loaded in Hong Kong did not properly declare these shipments and did not provide Test Reports in compliance with the UN Recommendations on the Transport of Dangerous Goods Manual of Tests and Criteria, Section 38.3, to verify that such these battery designs were in conformance with UN Modal Regulations.



## Three Accidents Involving Lithium Batteries

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16. At some point prior to the fire warning, contents of a cargo pallet, which included lithium batteries, auto-ignited, causing a large and sustained cargo fire which was not detected by the smoke detectors when in the early stages of Pyrolysis.

25. In addition to the energy release from Lithium batteries resulting in combustion, there is an associated mechanical energy release. This mechanical energy release is capable of compromising the integrity of packaging and creating incendiary projectiles.

41. Lithium-metal cell thermal stability and reactions that occur within a cell with elevated temperatures, up to the point of thermal runaway are not oxygen dependent. Electrolyte or vent gas combustion properties and the fire hazards associated with thermal runaway reactions do not respond to the FL 250 hazard mitigation methodology.

42. The Class E cargo compartment fire suppression strategy of preventing venting airflow in to cargo compartment, depressurization and maintaining 25,000 ft. cabin altitude may not be effective for Class D metal fires.

Following from this, the following causes were identified (only causes relevant to this analysis are reproduced here):

- 3.2.1 A large fire developed in palletized cargo on the main deck at or near pallet positions 4 or 5, in Fire Zone 3, consisting of consignments of mixed cargo including a significant number of lithium type batteries and other combustible materials. The fire escalated rapidly into a catastrophic uncontained fire.
- 3.2.2 The large, uncontained cargo fire that originated in the main cargo deck caused the cargo compartment liners to fail under combined thermal and mechanical loads.
- 3.2.5 The progressive failure of the cargo compartment liner increased the area available for the smoke and fire penetration into the fuselage crown area.
- 3.2.6 The rate and volume of the continuous toxic smoke, contiguous with the cockpit and supernumerary habitable area, resulted in inadequate visibility in the cockpit, obscuring the view of the primary flight displays, audio control panels and the view outside the cockpit which prevented all normal cockpit functioning.
- 3.2.8 The fire detection methodology of detecting smoke sampling as an indicator of a fire is inadequate as pallet smoke masking can delay the time it takes for a smoke detection system to detect a fire originating within a cargo container or a pallet with a rain cover.

There were a total of 16 contributing factors; factors relevant to this report are reproduced below:

- 3.3.1 There is no regulatory FAA requirement in class E cargo compartments for active fire suppression.
- 3.3.2 Freighter main deck class E fire suppression procedures which rely on venting airflow and depressurization as the primary means of controlling a fire are not effective for large Class E cargo fires involving dangerous goods capable of Class D metal fire combustion.
- 3.3.6 Class 9 Hazmat packing regulations do not address the total or potential fire risk that can result from lithium battery heat release during thermal runaway. Although non-bulk specification packaging is

designed to contain leaks and protect the package from failure, the packaging for Class 9 does not function to contain thermal release.

- 3.3.11 Task saturation due to smoke and multiple systems failures prevented effective use of the checklist by the crew.
- 3.3.16 The crew was not equipped with an alternative vision system or method for managing a smoke filled cockpit that would allow the crew to view the primary instruments.

Following on from this, there were a total of 36 safety recommendations. The relevant ones for this study are reproduced below:

### **SR 29/2013:**

GCAA recommends that PHMSA standardize the battery packaging regulation to be in harmony with the ICAO Technical Instructions. The requirement is the complete harmonization of the U.S. HMR with the ICAO TI's for the Safe Transport of Dangerous Good by Air regarding lithium batteries. This includes incorporation of quality management provisions provided in Part 2; 9.3.1 e.

### **SR 50/2013:**

The local authority, FAA and/or EASA fire test divisions to perform a test on lithium batteries to determine the ignition properties for lithium type batteries when subjected to external sources of mechanical energy, including acoustic energy in flight range modes, acoustic harmonic modes and a separate test to determine the susceptibility of lithium batteries to vibration from a mechanical source. The purpose of this testing is to determine the safe limits for the air carriage of lithium type batteries in dynamic aeroelastic, vibrating structures where the battery electrolyte composed of an organic solvent [and dissolved lithium salt] could become unstable when exposed to these forms of mechanical energy.

### **SR 51/2013:**

ICAO to review the hazardous materials classification for Class 9 materials packaging, where the reconsideration of lithium batteries and other energy storage devices that are currently classified as a Class 9 hazardous material be subjected to a higher level of hazardous material classification as at present time, it is not clear that the current Class 9 hazard communication or quantity limits adequately reflect the inherent risks to aviation safety.

### **SR 52/2013:**

ICAO to develop a SARP for package level protection of batteries being shipped to include protection from thermal degradation and damage to individual cells or cell combinations in thermal runaway, and to retard the propagation of lithium battery initiated fires to other packages in the same cargo stowage location as well as to increase the amount of time it would require for the contents of the package containing lithium batteries to provide an additional source of fuel for on-board fires initiated by other sources.

### **SR 57/2013:**

ICAO Dangerous Goods Panel to amend the ICAO Technical Instructions regarding the safe carriage of lithium batteries. Specifically, the request is to establish a dedicated task force within the DG panel, including

the representation of qualified stakeholders, to study the safe carriage of lithium batteries and other potentially hazardous cargo and develop recommendations to the UN Manual of Tests and Criteria, The Manual of Tests and Criteria Revision 5, Lithium Metal and Lithium Ion Batteries, 38.3.4.3, Test T3-Vibration.

**Note:** Classification of lithium batteries as Class 9 is not something that ICAO can change, this is a UN issue. There was discussion at the UN Subcommittee around 20012/13 and it was felt inappropriate to change the classification. The Subcommittee chose not to create a Class 10, which would only have lithium batteries, or having divisions within Class 9, as once again it would be a division for a single item. There has though been agreement to adopt some specific hazard communication for lithium batteries. This was done at the UN and will come into effect as of 1 January 2017.

Structural-acoustic coupling phenomenon in an aircraft fuselage is a known characteristic. In large Class E cargo compartments, the structural and acoustic modes can be derived for vibration analysis. Structural and acoustic analysis can determine possible occurrences of vibration in the fuselage structure during predetermined phases of flight where the vibro-acoustic signatures can be used to determine the principle sources and transmitting paths of the vibration.

Given the active failure modes of lithium batteries, the battery risk factors concerning possible susceptibility to various extraneous forms of mechanical energy, for example vibration, possibly in a harmonic form, could be an initiating action risk.

ICAO Dangerous Goods Panel was requested to evaluate data relative to the UN Manual of Tests and Criteria, Lithium Metal and Lithium Ion Batteries, 38.3.4.3, Test T3-Vibration and advise the UNECE Committee of Experts/Working Party on the Transport of Dangerous Goods if additional criteria should be adopted for the carriage lithium metal and lithium ion batteries by air transport.

### Conclusions

The investigating authority report found “with reasonable certainty” that the fire which caused the crash originated in a cargo container which held thousands of lithium batteries. The report made 36 recommendations for safety improvements, including improvements to systems that warn pilots of cargo hold fires, and use of additional systems to improve pilot visibility during aircraft fire scenarios.

The report also recommends ICAO to review the hazardous materials classification for Class 9 materials packaging where the reconsideration of lithium batteries and other energy storage devices that are currently classified as a Class 9 hazardous material be subjected to a higher level of hazardous material classification. Classification of lithium batteries as Class 9 is not something that ICAO can change, this is a UN issue. There was some discussion at the UN Subcommittee however there was no change the classification. The Subcommittee were not interested in creating a Class 10, which would only have lithium batteries, or having divisions within Class 9, as once again it would be a division for a single item.

There has though been agreement to adopt some specific hazard communication for lithium batteries. This was carried out at the UN and will come into effect as of 1 January 2017. The International Civil Aviation Organization (ICAO) adopted a ban on the shipment of lithium metal batteries as cargo aboard passenger aircraft. The prohibition came into effect on Jan. 1, 2015. Much work has been called for and is ongoing within

ICAO, the FAA and battery manufacturers associations. A multidisciplinary working group has been created by ICAO and will look into various mitigations.

### **3.3 Incident Number 3**

#### **Cargo Flight, Douglas DC-8**

On February 7, 2006, a Douglas DC-8 cargo plane suffered an in-flight cargo fire and made an emergency landing at Philadelphia International Airport. There were no injuries other than smoke inhalation affecting the crew but the plane burned on the ground for several hours. Though most of the cargo survived, the aircraft was a total loss, with multiple holes burned through the roof skin.

The following is an extract from the Executive Summary of the official report into the accident published by the investigating authority:

"On February 7, 2006, about 23:59 eastern standard time, a McDonnell Douglas DC-8-71F, landed at its destination airport, Philadelphia International Airport, Philadelphia, Pennsylvania, after a cargo smoke indication in the cockpit. The captain, first officer and flight engineer evacuated the airplane after landing. The flight crewmembers sustained minor injuries, and the airplane and most of the cargo were destroyed by fire after landing...Night visual conditions prevailed at the time of the accident. The National Transportation Safety Board determines that the probable cause of this accident was an in-flight cargo fire that initiated from an unknown source, which was most likely located within cargo container 12, 13 or 14. Contributing to the loss of the aircraft were the inadequate certification test requirements for smoke and fire detection systems and the lack of an on-board fire suppression system."

The following extract is taken from the History of Flight section of the accident report and gives an appreciation of the discussions and actions of the flight crew following first indications of a fire:

"The accident flight crew reported that the flight was uneventful until just after beginning the descent to PHL. At 23:34:39, while the airplane was descending through flight level 3103 about 50 nautical miles southwest of Washington, D.C., the cockpit voice recorder (CVR) recorded the first officer asking the captain and the flight engineer if they detected an odor that smelled "like wood burning." The flight engineer replied that he had "smelled it for a couple of seconds." About 1 minute later, the first officer stated, "[it's] pretty strong now." Subsequently, the CVR recorded a sound similar to the cockpit door or seat operating and the flight engineer stating, "[it's] more in the back." About 3 1/2 minutes later, the first officer again stated that the odor smelled like wood, and the flight engineer agreed that the odor did smell like wood burning and stated that it did not smell electrical in nature."

During post-accident interviews, the captain stated that he considered diverting to another airport soon after the odor was first detected but that he chose to continue to PHL because there was no evidence of a problem, such as the illumination of the cargo smoke warning lights. The first officer stated that the odor did not appear to be a threat because the flight engineer did not see any visible smoke; therefore, the first officer did not believe that there was any need to divert. Further, the flight crew stated that unusual odors could be common from nonthreatening factors (such as flying over forest fires or unusual cargo). Over the next 4 minutes, the captain and flight engineer tried to identify the source of the odor by conducting several



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emergency checklist steps, including increasing the bleed air flow and checking the bleed air switches. As the airplane was descending through about 18,000 feet and was about 65 miles from PHL, the CVR recorded the flight engineer stating that he set the air conditioning packs to maximum flow and turned off the recirculation fan. Shortly thereafter, the flight engineer and captain conducted the Approach checklist. At 23:44:59, the first officer contacted the PHL Terminal Radar Approach Control, and the approach controller instructed the flight to descend to 6,000 feet.

The CVR then recorded the captain asking, "Can you still smell it in the back there?" The flight engineer replied, "Yeah . . . smells like it was more to the back there." The first officer then asked, "Smells like cardboard burning doesn't it? You didn't see smoke though something like that?" The flight engineer again went back to check the main cargo compartment with his flashlight, and he stated that the odor was "definitely stronger in the back" but that there was no smoke or haze. Over the next 10 minutes, the captain and flight engineer continued to troubleshoot the problem.

At 23:54:42, as the airplane was descending through about 3,600 feet, the flight engineer stated, "we got cargo smoke." The captain replied, "Let's do that checklist if you got time." The first officer then stated that he would be turning toward the airport. At 23:55:01, the PHL approach controller cleared the visual approach to runway 27R and then instructed the flight crew to contact the air traffic control tower. Ten seconds later, the captain made initial contact with the ATC local controller, who cleared the flight to land on runway 27R. After acknowledging the clearance, the captain reported that the cargo smoke indicator had illuminated and requested that emergency response equipment meet them upon landing. The local controller immediately activated the crash phone and advised approach control of the emergency.

At 23:55:57, the flight engineer stated, "[it's] showing that we have a lower aft cargo fire section C." Subsequently, the captain told the first officer and flight engineer to don their oxygen masks if they had not done so already. The captain then asked the flight engineer to accomplish the Lower and/or Main Cargo Compartment Smoke or Fire checklist by himself, and the flight engineer proceeded to execute the checklist. According to air traffic control (ATC) transcripts, the Philadelphia approach controller asked the PHL ATC local controller whether the flight was going to land on the left side, referring to runway 27L, which is the runway at PHL designated for use in emergency situations. At 23:56:12, the local controller cleared the flight to land on runway 27L, and the captain acknowledged the landing clearance but not the change in landing runway. The flight engineer continued the Lower and/or Main Cargo Compartment Smoke or Fire checklist items. When he reached the step to close the cargo air shut-off valve, he stated that he had to "go in the back and do that."

During post-accident interviews, the flight engineer stated that, when he opened the door of the access panel to the cargo air shut-off valve, black smoke billowed out of the access panel. At 23:57:47, the first officer called for the Landing checklist. About 21 seconds later, the ACT local controller stated, "just confirmed you are lined up for the left side it appears that you are lined up for the right." The first officer replied, "I thought we were cleared for the right...are we cleared to land on the right?" At 23:58:16, the local controller replied, "you are cleared to land on the right we will just tell fire." The airplane landed on runway 27R about 23:59. Immediately after touchdown, the flight engineer reported smoke in the cockpit. After the airplane came to a stop, the first officer called for an emergency evacuation, and the captain and first officer conducted the Emergency Evacuation checklist. All of the flight crew successfully evacuated the airplane, using the emergency slide located at the left forward (L1) door."



According to the investigating authority, the firefighting crew did not have adequate training on using their skin-piercing extinguishing equipment and not knowing how to open the main cargo door, attempted to force the handle and broke the latch, rendering the door inoperable. There were also difficulties in obtaining the cargo manifest to determine what hazardous materials were on board, due to confusion about protocol. However, despite these failings, the airport staff, including the firefighting staff, managed the incident successfully without injury or major disruption of the airport. ***The investigating authority suspected lithium ion batteries were the source of ignition*** and made recommendations for rules that are more stringent and restrictions on their air transport, especially on passenger aircraft.

For a cause of the incident, the investigating authority focused on the delayed indication of fire by the required onboard fire detection system and criticized the standards to which such systems are tested, noting that ***the tests use an empty cargo hold and do not represent the real-world performance of the detection systems with the hold full of cargo***, which significantly changes the flow patterns of hot air and smoke. The crew and air traffic control personnel were found to have behaved properly (with minor exceptions) and not to be at fault for the incident or its outcome.

To reiterate, the National Transportation Safety Board “determines that the probable cause of this accident was an in-flight cargo fire that initiated from an unknown source...” The report also lists the transport of lithium batteries on board aircraft as an area of concern.

The following are the relevant points, extracted from the findings of the investigating authority:

20. Testing and incident data indicate that lithium batteries can pose a fire hazard.
21. Because many incidents involving lithium batteries are exempt from reporting requirements, the data regarding such incidents are incomplete, which has prevented a thorough assessment of the causes of these failures and the risks associated with transporting lithium batteries.
22. An in-depth analysis of the causes of secondary and primary lithium battery failures would improve the safe transportation of these batteries.
23. The Pipeline and Hazardous Materials Safety Administration’s August 2007 final rule regarding the transportation of lithium batteries did not establish sufficient levels of safety for air transportation of small secondary lithium batteries (no more than 8 grams equivalent lithium content).

From these findings, the investigating authority made the following safety recommendations:

- 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)
- Until fire suppression systems are required on cargo-only aircraft, as asked for in Safety Recommendation A-07-99, require that cargo shipments of secondary lithium batteries, including those contained in or packed with equipment, be transported in crew-accessible locations where portable fire suppression systems can be used. (A-07-105)
- Require aircraft operators that transport hazardous materials to immediately provide consolidated and specific information about hazardous materials on board an aircraft, including proper shipping name,

hazard class, quantity, number of packages, and location, to on-scene emergency responders upon notification of an accident or incident. (A-07-106)

- Require commercial cargo and passenger operators to report to the Pipeline and Hazardous Materials Safety Administration all incidents involving primary and secondary lithium batteries, including those contained in or packed with equipment, that occur either on board or during loading or unloading operations and retain the failed items for evaluation purposes. (A-07-107)
- Analyze the causes of all thermal failures and fires involving secondary and primary lithium batteries and, based on this analysis, take appropriate action to mitigate any risks determined to be posed by transporting lithium batteries, including those contained in or packed with equipment, on board cargo and passenger aircraft as cargo; checked baggage; or carry-on items. (A-07-108)
- Eliminate regulatory exemptions for the packaging, marking, and labeling of cargo shipments of small secondary lithium batteries (no more than 8 grams equivalent lithium content) until the analysis of the failures and the implementation of risk based requirements asked for in Safety Recommendation A-07-108 are completed. (A-07-109)

The report also went on to reiterate the previously issued safety recommendations, as follows. As a result of a fire in April, 1999 that destroyed freight, including lithium batteries, on two aircraft cargo pallets at a cargo facility, the Safety Board issued the following safety recommendations to the Research and Special Programs Administration on November 16, 1999:

- With the Federal Aviation Administration, evaluate the fire hazards posed by lithium batteries in an air transportation environment and require that appropriate safety measures be taken to protect aircraft and occupants. The evaluation should consider the testing requirements for lithium batteries in the United Nations' *Transport of Dangerous Goods Manual of Tests and Criteria*, the involvement of packages containing large quantities of tightly packed batteries in a cargo compartment fire, and the possible exposure of batteries to rough handling in an air transportation environment, including being crushed or abraded open. (A-99-80)
- Require that packages containing lithium batteries be identified as hazardous materials, including appropriate marking and labeling of the packages and proper identification in shipping documents, when transported on aircraft. (A-99-82)

The investigating authority also issued the following safety recommendation to the Federal Aviation Administration on November 16, 1999:

- With the Research and Special Programs Administration, evaluate the fire hazards posed by lithium batteries in an air transportation environment and require that appropriate safety measures be taken to protect aircraft and occupants. The evaluation should consider the testing requirements for lithium batteries in the United Nations' *Transport of Dangerous Goods Manual of Tests and Criteria*, the involvement of packages containing large quantities of tightly packed batteries in a cargo compartment fire, and the possible exposure of batteries to rough handling in an air transportation environment, including being crushed or abraded open. (A-99-85)

Significantly, for airline operators, recommendation A-07-104 states:

- 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)

This of course needs to be enshrined into some form of mandated or legislated requirement, which has not yet happened. However, the second ICAO international multidisciplinary lithium battery transport coordination meeting addressed many of these issues and made recommendations for further research and work to be carried out. In particular, Recommendation 8/14 – Performance Based Packaging of Lithium Batteries - stated:

- “That further research and testing be completed as soon as possible on packagings for lithium batteries, that may include the use of cooling agents such as gel packs as a means to add additional protective layers to mitigate the risks associated with the carriage of lithium batteries.”

(This work is ongoing in several arenas of the industry with manufacturers, international agencies and airline operators.)

Overall, the investigating authority investigation of this incident could not draw a conclusion as to the cause of the fire, although much attention was paid to the presence of lithium batteries on board. Unfortunately, without a clear indication of either cause of fire or the contribution of dangerous goods on board to the process of fire propagation, it is impossible to make any clear recommendations outside of those already being addressed within the multidisciplinary lithium battery transport task force.

It is also difficult to state with any degree of accuracy how long from the commencement of the fire to the time where the situation became critical, as it is likely that the fire broke out during the initial descent phase and flames were first observed about 40 minutes after the airplane landed when ARFF personnel entered the aircraft, as the report states:

“The first indication of the fire was the first officer’s query to the other crewmembers about the smell of burning wood, which occurred about 20 minutes before the main cargo compartment Cargo Smoke warning light activated, indicating that the fire had been burning for at least that long. However, the flight engineer saw no smoke either of the two times that he visually checked the main cargo compartment. This evidence indicates that the fire initially did not generate a significant amount of smoke and was most likely initiated as a smoldering fire inside a cargo container. The construction of the cargo containers, which results in restricted airflow in or out of the container, likely inhibited the growth and detection of the fire in its initial stages. On the basis of this evidence, the Safety Board concludes that the fire on board the accident airplane initiated as a smoldering fire.”

### **Conclusions for incident 3**

The recommendations from this report are being taken up by ICAO dangerous goods panel sub-task force (ICAO international multidisciplinary lithium battery transport coordination meeting), which brings together industry experts from all disciplines. IATA is supporting this task force.

# Chapter 4: Phase of Flight Review

## 4.1 Incident Number 1

The aircraft was in its cruise when the fire broke out and was detected. The crew reported a cargo fire to air traffic control and declared an emergency 50 minutes after takeoff from Incheon. It was during the attempt to reach the diversion airport that the aircraft was lost. The timeline is as follows:

Order	Time	Summary Of ATC/Pilot Communications
1	03:51:15	Made initial contact with ATC (FO)
2	03:54:23	Requested ATC to allow emergency descent and declared emergency due to a fire (FO)
3	03:55:08	Requested a diversion to Jeju (FO)
4	03:56:02 - 03:58:03	ATC had communication with pilots about diversion, descent altitude and airport for diversion
5	03:59:26	Reported to ATC descent to 10,000 ft due to a rear cargo fire and requested a radar vector to Jeju airport
6	04:05:32	Other aircraft relayed to ATC instructions to accident aircraft captain, and captain replied "Heading 060, descent to 7,000ft."
7	04:05:49 - 04:06:30	ATC conversation with other aircraft to confirm heading and descent altitude
8	04:36:32	Accident aircraft captain conversation with other aircraft " We are now that rudder control is not working"
9	04:07:34	The captain stated, "We have to open the hatch"
10	04:09:47	The Captain replied to other aircraft question about control, "Rudder control...flight control, all are not working"
11	04:10:06	The FO stated, "We have heavy vibration on the airplane, may need to make an emergency landing, emergency ditching."
12	04:10:15	The FO stated, "Altitude control is not available due to heavy vibration, going to ditch...ah" Afterwards, there was no more communication between ATC and subject aircraft.

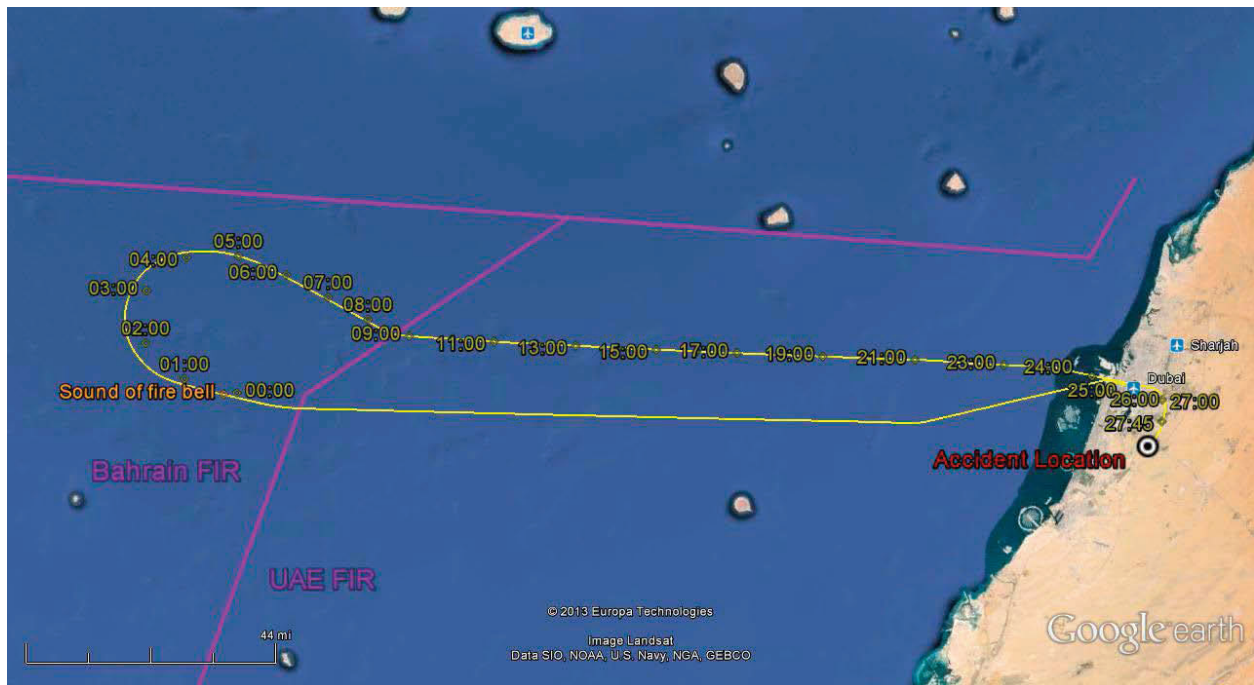
That is, from the fire being detected at 03:53 [CARGO FIRE MAIN DECK ZONE-11] to ditching at 04:10, there elapsed only 17 minutes.

## 4.2 Incident Number 2

Flight departed from Dubai International at 14:53 UTC and at 15:15 the crew reported a fire in the cockpit when the aircraft was around 120 nautical miles (220 km) west-northwest of Dubai, and declared an emergency. The pilots were under the control of Bahrain's air traffic control, and they could not initially contact Dubai air traffic control due to a radio failure. Although they were offered a diversion to Doha, Qatar, the pilots returned to Dubai, and were instructed to land on the airport's runway 12L. The aircraft was too high on the approach and passed over the airport before making a tight turn; radar contact was lost shortly thereafter at 15:42 UTC.

The use of maps and location graphics was used in the final report to simplify the overview of information. To gauge the timeline chronologically from the time of the Fire Master Warning alert, a time from the first fire warning is a sub heading in minutes of elapsed time, is shown in the figure below:

As can be seen, there was a total time of 27: 45 minutes from the fire warning to ditching.



## 4.3 Incident Number 3

### Douglas DC-8

The first indication of the fire was the first officer's query to the other crewmembers about the smell of burning wood, which occurred about 20 minutes before the main cargo compartment Cargo Smoke warning light activated, indicating that the fire had been burning for at least that long. Once the fire breached the cargo container in which it initiated, it would have begun to spread to adjacent containers. Detection of the

fire by the main cargo compartment smoke detectors most likely occurred around the time of the first container burn-through. The smoke detector in lower cargo compartment 33 alerted about 1 minute after the main cargo compartment alert, and some of the captain's displays then began to falter, indicating the continued progression of the fire. The flight engineer first saw smoke when he exited the cockpit to close the main cargo air shutoff valve and black smoke emanated from the valve's access panel. About 2 minutes later, almost immediately after touchdown, the flight engineer reported that smoke had begun entering the cockpit. The smoke continued to worsen after the airplane came to a stop, and the smoke in the cockpit became so thick that the two pilots could not see each other before evacuating the airplane.

The significant factors in this incident are that it occurred during the descent; there was no smoke warning until around 20 minutes after the fire is suspected to have started; and from first indications (smell of burning wood) to 'thick black smoke' was around 23 minutes. [Please note that the factual information in this report does not give a precise timeline to events].

# Chapter 5: Conclusions on Phase of Flight for each Incident

## 5.1 Incident Number 1

Cruise: The aircraft was in its cruise when the fire broke out and was detected and declared an emergency 50 minutes after takeoff.

From the fire being detected at 03:53 to ditching at 04:10, there elapsed only 17 minutes.

## 5.2 Incident Number 2

Cruise: Flight 6 departed at 14:53 UTC and the crew reported a fire in the cockpit at 15:15, when the aircraft was around 120 nautical miles (220 km) west-northwest of Dubai, and declared an emergency.

There was a total time of 27: 45 minutes from the fire warning to ditching.

## 5.3 Incident Number 3

Descent: This incident occurred during the descent; there was no smoke warning until around 20 minutes after the fire is suspected to have started; and from first indications (smell of burning wood) to 'thick black smoke' was around 23 minutes.

# Chapter 6: Recommendations from Investigative Bodies

The GCAA recommended that ICAO reviewed the hazardous materials classification for Class 9 materials packaging, where lithium batteries and other energy storage devices that are currently classified as a Class 9 hazardous material be subjected to a higher level of hazardous material classification.

The International Civil Aviation Organization (ICAO) adopted a ban on the shipment of lithium metal batteries as cargo aboard passenger aircraft. The prohibition came into effect on Jan. 1, 2015.

For incident 3, the recommendations are being taken up by ICAO dangerous goods panel sub-task force (ICAO international multidisciplinary lithium battery transport coordination meeting), which brings together industry experts from all disciplines. IATA is supporting this task force.



# Chapter 7: Consolidated Conclusions and Recommendations

Due to the small number of accidents in relation to the number of flights operated over this ten-year period, it is almost meaningless to calculate a rate. However, based on the number of sectors flown during the period when the three accidents occurred, an accident rate  $1.47 \text{ e-}8$  (0.0000000147) can be inferred. It should be noted that when compared to CFIT rate, LOC-I rate and Runway Excursions (three areas identified as high risk by IATA), this event rate is negligible.

Furthermore, since the data set is too small to draw defensible conclusions, it is only possible to make some general comments.

In the first two incidents, the fires broke out very early into the flight. For the third incident, it is believed that the fire started elsewhere in the cargo and spread to the lithium batteries. As of January 2015, lithium batteries have been prohibited from carriage on passenger aircraft. This prohibition has also served to raise awareness of the potential hazards in the carriage of lithium batteries.

For all three incidents, it is clear that once there is a fire with large quantities of lithium batteries, the time from ignition to uncontrollable fire may be quite short – 17 minutes, 23 minutes and 27 minutes respectively. However, it must be noted that each of these incidents are dealing with large quantities of lithium metal and/or lithium ion batteries and recent regulatory changes have limited the amounts to be carried and the manner in which they are carried.

A full understanding of the complete risk scenario is necessary to properly identify and leverage risk mitigation opportunities. For this reason it is recommended that all operators conduct robust system analysis and safety risk assessments, in order to implement appropriate mitigations. Therefore, it is recommended that all pertinent factors are taken into account when conducting the risk assessment.

Following on from various strands within IATA and the industry, it is strongly recommended that operators conduct a Safety Risk Assessment (SRA) to identify all risks relating to the transport of lithium batteries in cargo, mail and passenger baggage. Risk management seeks to be proactive by identifying hazards and assessing risks before they become events. The objective of risk management is to minimize operational risk and maximize business opportunities. It may also be used to ensure regulatory compliance. Therefore, all risk-laden activities should come under the scrutiny of the basic principles of risk management, and this certainly applies to the carriage of lithium batteries. However, risk assessments should not be limited to scenarios where lithium batteries are known to be present because operators are vulnerable to carrying undeclared lithium batteries.

The risk assessment should be performed by a team of senior-level representatives with appropriate knowledge on the subject from Cargo, Safety and Flight Operations. This risk assessment needs to consider the potential risk of all points of entry for cargo, mail and passenger baggage, as applicable, and the types of



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aircraft being operated (passenger and/or cargo). Based on the risk assessment, an identification of potential risk mitigation strategies should follow.

Sample safety risk assessments are available for industry to use a model, notably by IATA Safety department and the Australian delegation to the ICAO Dangerous Goods Panel (DGP).

Airlines should take cognizance of the FAA testing that has been carried out at the William J Hughes Technical Center and consider this data in the safety risk analysis.

# Chapter 8: References

ICAO SMM - Doc 9859 Edition 3

Dangerous Goods Regulations (DGR) - 2015 (56th edition)

Technical Instructions for the Safe Transport of Dangerous Goods by Air Doc 9284 - 2015-2016 Edition.

United Nations Recommendations on the Transport of Dangerous Goods, Model Regulations (Revision 19) – July 2015

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Report of the Third Meeting of the International Multidisciplinary Lithium Battery Transport Coordination Meeting, held at Montréal - July 2015

International Coordination Council for Aerospace Industry Association (ICCAIA) paper regarding cargo compartment fire protection capability, especially related to the carriage of lithium batteries as cargo - April 2015

IATA Lithium Battery Risk Mitigation Guidance for Operators 1st Edition – January 2015

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