Aircraft Accident Report

Crash Into The Sea After An In-Flight Fire
Asiana Airlines
Boeing 747-400F, HL7604
International Waters 130 km West Of Jeju Int'l Airport
28 July 2011

24 July 2015

Aircraft and Railway Accident Investigation Board
This aircraft accident report has been prepared in accordance with the Article 25 of the Aviation and Railway Accident Investigation Act of the Republic of Korea.

According to the provisions of the Article 30 of the Aviation and Railway Accident Investigation Act, it is stipulated;

*The accident investigation shall be conducted separately from any judicial, administrative disposition or administrative lawsuit proceedings associated with civil or criminal liability.*

And in the Annex 13 to the Convention on International Civil Aviation, Paragraphs 3.1 and 5.4.1, it is stipulated as follows:

*The sole objective of the investigation of an accident or incident shall be the prevention of accidents and incidents. It is not the purpose of the activity to apportion blame or liability. Any investigation conducted in accordance with the provision of this Annex shall be separate from any judicial or administrative proceedings to apportion blame or liability.*

Thus, this investigation report shall not be used for any other purpose than to improve aviation safety.

In case of divergent interpretation of this report between the Korean and English languages, the Korean text shall prevail.
Aircraft Accident Report


The Aviation and Railway Accident Investigation Board (ARAIB), Republic of Korea, is a government organization established for independent investigation of aviation and railway accident, and the ARAIB conducts accident investigation in accordance with the provisions of the Aviation and Railway Accident Investigation Act of the Republic of Korea and Annex 13 to the Convention on International Civil Aviation.

The objective of the investigation by the ARAIB is not to apportion blame or liability but to prevent accidents and incidents.

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## Abbreviations

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<th>Description</th>
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<tr>
<td>ACARS</td>
<td>Aircraft Communications Addressing and Reporting System</td>
</tr>
<tr>
<td>ACC</td>
<td>Area Control Center</td>
</tr>
<tr>
<td>ACM</td>
<td>Air Cycle Machine</td>
</tr>
<tr>
<td>ACM</td>
<td>Air Cycle Machine</td>
</tr>
<tr>
<td>ACMS</td>
<td>Aircraft Condition Monitoring System</td>
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<tr>
<td>AFOLTS</td>
<td>Automatic Fire Overheat Logic Test System Cards</td>
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<tr>
<td>AOC</td>
<td>Air Operator Certificate</td>
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<tr>
<td>APB</td>
<td>Aft Pressure Bulkhead</td>
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<tr>
<td>APU</td>
<td>Auxiliary Power Unit</td>
</tr>
<tr>
<td>ATA</td>
<td>Air Transportation Association</td>
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<tr>
<td>ATC</td>
<td>Air Traffic Control</td>
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<tr>
<td>AWB</td>
<td>Airwaybill</td>
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<tr>
<td>CCL</td>
<td>Cambridge Communication Ltd</td>
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<tr>
<td>CCTV</td>
<td>Closed-Circuit Television</td>
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<tr>
<td>CDU</td>
<td>Control Display Unit</td>
</tr>
<tr>
<td>CG</td>
<td>Center of Gravity</td>
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<tr>
<td>CMC</td>
<td>Central Maintenance Computer</td>
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<tr>
<td>COSPAS/SARSAT</td>
<td>COsmicheskaya Sistema Poiska Avariynich Sudov/Search And Rescue Satellite-Aided Tracking</td>
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<tr>
<td>CRM</td>
<td>Cockpit Resource Management</td>
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<td>CSMU</td>
<td>Crash Survival Memory Unit</td>
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<td>CST</td>
<td>Coast</td>
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<tr>
<td>CVR</td>
<td>Cockpit Voice Recorder</td>
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<tr>
<td>DC</td>
<td>Direct Current</td>
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<tr>
<td>DG</td>
<td>Dangerous Goods</td>
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<td>DGR</td>
<td>Dangerous Goods Regulations</td>
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<tr>
<td>EICAS</td>
<td>Engine Indication and Crew Alerting System</td>
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<tr>
<td>EIU</td>
<td>EFIS/EICAS Interface Unit</td>
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<tr>
<td>ELT</td>
<td>Emergency Locator Transmitter</td>
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<tr>
<td>ETA</td>
<td>Estimated Time of Arrival</td>
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<tr>
<td>EUROCAE</td>
<td>European Organization for Civil Equipment</td>
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<tr>
<td>FAA</td>
<td>Federal Aviation Administration</td>
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<tr>
<td>FCOM</td>
<td>Flight Crew Operations Manual</td>
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<td>FDE</td>
<td>Flight Deck Effect</td>
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<td>FDR</td>
<td>Flight Data Recorder</td>
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<tr>
<td>FMC</td>
<td>Flight Management Computer</td>
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<td>FOB</td>
<td>Fuel On Board</td>
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<tr>
<td>FOM</td>
<td>Flight Operations Manual</td>
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<tr>
<td>FOQA</td>
<td>Flight Operations Quality Assurance</td>
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<tr>
<td>fpm</td>
<td>feet per minute</td>
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<td>Definition</td>
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<tr>
<td>FS</td>
<td>Fuselage Station</td>
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<td>G</td>
<td>Gravity</td>
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<tr>
<td>HF</td>
<td>High Frequency</td>
</tr>
<tr>
<td>IATA</td>
<td>International Air Transport Association</td>
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<tr>
<td>IC</td>
<td>Integrated Circuit</td>
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<tr>
<td>ICAO</td>
<td>International Civil Aviation Organization</td>
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<tr>
<td>ICN ACC</td>
<td>Incheon Area Control Center</td>
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<tr>
<td>KAL</td>
<td>Korean Airlines</td>
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<tr>
<td>kg</td>
<td>kilogram</td>
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<tr>
<td>KPa</td>
<td>Kilopascal</td>
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<tr>
<td>L.A.</td>
<td>Los Angeles</td>
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<tr>
<td>LCD</td>
<td>Liquid Crystal Display</td>
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<tr>
<td>LOFT</td>
<td>Line-Oriented Flight Training</td>
</tr>
<tr>
<td>MAWB</td>
<td>Master Airwaybill</td>
</tr>
<tr>
<td>MAC</td>
<td>Mean Aerodynamic Chord</td>
</tr>
<tr>
<td>MCRC</td>
<td>Master Control and Report Center</td>
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<tr>
<td>METAR</td>
<td>Meteorological Aerodrome Report</td>
</tr>
<tr>
<td>MHz</td>
<td>Megahertz</td>
</tr>
<tr>
<td>MIE</td>
<td>Minimum Ignition Energy</td>
</tr>
<tr>
<td>(M)LDW</td>
<td>(Maximum) Landing weight</td>
</tr>
<tr>
<td>MSA</td>
<td>Minimum Safety Altitude</td>
</tr>
<tr>
<td>MSDS</td>
<td>Material Safety Data Sheets</td>
</tr>
<tr>
<td>(M)TOW</td>
<td>(Maximum) Takeoff Weight</td>
</tr>
<tr>
<td>MU</td>
<td>Management Unit</td>
</tr>
<tr>
<td>(M)ZFW</td>
<td>(Maximum) Zero Fuel Weight</td>
</tr>
<tr>
<td>NFPA</td>
<td>National Fire Protection Association</td>
</tr>
<tr>
<td>NNC</td>
<td>Non-Normal Checklist</td>
</tr>
<tr>
<td>N.O.S.</td>
<td>Not Otherwise Specified</td>
</tr>
<tr>
<td>NOTOC</td>
<td>Notification TO Captain for special load</td>
</tr>
<tr>
<td>NTSB</td>
<td>National Transportation Safety Board</td>
</tr>
<tr>
<td>PBE</td>
<td>Protective Bleeding Equipment</td>
</tr>
<tr>
<td>PF</td>
<td>Pilot Flying</td>
</tr>
<tr>
<td>PGMEA</td>
<td>Propylene Glycol Monomethyl Ether Acetate</td>
</tr>
<tr>
<td>PLF</td>
<td>Present Leg Fault</td>
</tr>
<tr>
<td>PM</td>
<td>Pilot Monitoring</td>
</tr>
<tr>
<td>POM</td>
<td>Pilot Operations Manual</td>
</tr>
<tr>
<td>QRH</td>
<td>Quick Reference Handbook</td>
</tr>
<tr>
<td>ROV</td>
<td>Remotely Operated Vehicle</td>
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<tr>
<td>SACOM</td>
<td>Satellite Communication</td>
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SHI  Shanghai
SMS  Safety Management System
STA  Station
STC  Supplemental Type Certificate
TEM  Threat and Error Management
TOD  Top Of Decent
ULB  Underwater Locator Beacon
ULD  Unit Load Device
UN  United Nations
UPS  United Parcel Service
U.S.  United States of America
VHF  Very High Frequency
VSD  Video Smoke Detection
Wh  Watt hour
WS  Wing Station
3D  Three Dimension
Crash Into The Sea After An In-Flight Fire

- Operator: Asiana Airlines
- Manufacturer: The Boeing Company
- Type: B747-400F
- Registration Mark: HL7604
- Location: International waters 130 km west of Jeju International Airport
  N33°15'04.56" E124°59'31.02"
- Date & Time: 28 July 2011, about 04:11 (Korean Standard Time)

Synopsis

On 28 July 2011, about 04:11, Asiana Airlines flight 991, a B747-400F airplane, a scheduled cargo flight from Incheon, Republic of Korea, to Shanghai, China, crashed into the international waters about 130 km west of Jeju International Airport after the flight crew reported a cargo fire to Shanghai Area Control Center (SHI ACC) near a reporting point SADLI on airway A593 about 03:54 and attempted to divert to Jeju International Airport.

Aboard the flight were two pilots. Due to this accident, they were fatally injured, and some portions of the fuselage separated from the airplane in midair. The wreckage of the airplane was distributed under the sea in the area 3 km by 4 km in southwest-northeast direction.

The Aviation and Railway Accident Investigation Board (ARAIB) determined that the cause of this accident was 「A fire developed on or near the pallets containing dangerous goods but no physical evidence of the cause of the fire was found. The fire rapidly escalated into a large uncontained fire, and this caused some portions of the fuselage to separate from the aircraft in midair, thereby resulting in the crash.」
As a result of this investigation, the ARAIB makes 5 recommendations to Asiana Airlines, 11 recommendations to the Ministry of Land, Infrastructure and Transport (MOLIT), 3 recommendations to the Boeing Company, and 1 recommendation to ICAO.
1. Factual Information

1.1 History of Flight

On 28 July 2011, about 04:11 Korean Standard Time\(^1\), Asiana Airlines flight 991, a B747-400F airplane, HL7604 (hereafter referred to as AAR991), a scheduled cargo flight from Incheon, Republic of Korea, to Shanghai, China, crashed into the international waters about 130 km west of Jeju International Airport (hereafter referred to as Jeju Airport) after the flight crew reported a cargo fire to SHI ACC near a reporting point SADLI on airway A593 about 03:54 and attempted to divert to Jeju Airport.

Due to the crash impact and fire, the captain and the first officer (FO) were fatally injured, the aircraft was destroyed, and the cargo shipments were damaged, incapable of being recovered, or washed away.

AAR991 was a scheduled international cargo flight operated at night under the instrument flight rule in accordance with the Aviation Act of the Republic of Korea and the Convention on International Civil Aviation.

The captain and the FO showed up at the flight crew ready room of Asiana Airlines in Incheon International Airport (hereafter referred to as Incheon Airport) an hour before the scheduled time of departure\(^2\) and signed the "show-up log," respectively.

The line mechanic stated that on 28 July, about 02:00, the flight crew arrived at the airplane and that the captain performed the ramp inspection. The loadmaster stated that about 02:15, under the guidance with him, the captain inspected the loaded status of dangerous goods and other shipments in the main

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\(^1\) Unless otherwise indicated, all times in this report are Korean Standard Time, based on a 24-hour clock.
\(^2\) At 02:45 on 28 July 2011.
deck cargo compartment.

The transcript\(^3\) of ATC radio communications shows that at 03:04:28, AAR991 took off from runway 15L in Incheon Airport. From this moment, the captain\(^4\) took control of radio communications.

At 03:05:48, AAR991 made initial contact with Seoul Area Control Center (SEL ACC) after takeoff and was instructed to climb to 34,000 ft and fly direct to MALPA. At 03:12:19, the flight crew were advised to contact Incheon Area Control Center (ICN ACC).

At 03:12:35, AAR991 was climbing to 34,000 ft on a permitted route when it made initial contact with ICN ACC, and at 03:13:05, was allowed to fly direct to NIRAT.

At 03:26:05, ICN ACC instructed AAR991 to change its radio frequency to 124.52 MHz. From this moment, the FO mainly assumed control of radio communications, but the captain also occasionally made communication. At 03:26:21, the crew were instructed to fly direct to SADLI, and at 03:50:46, ICN ACC advised AAR991 to contact SHI ACC on frequency 134.0 MHz.

At 03:51:15, AAR991 stated that it was maintaining at 34,000 ft and flying direct to SADLI when it made initial contact with SHI ACC.

At 03:52:39, SHI ACC instructed AAR991, "AAR991 radar contact, off-set 5 miles right of track," and the flight crew carried out this instruction at 03:52:51.

The Aircraft Communications Addressing and Reporting System (ACARS)

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\(^3\) Unless otherwise indicated, all communications records hereinafter are excerpts from the ATC transcript.

\(^4\) When the ATC transcript was prepared, voices of the captain and the FO were identified with the help of Asiana Airlines' B747-400 captain.
messages received by the ground station were as follows: about 03:53, "EQUIPMENT SMOKE," "EQUIP COOLING," and "CGO DET 11 MN DK"; and about 03:54, "CGO DET 6 MN DK" and "CGO DET 10 MN DK."

At 03:54:23, the FO stated, "Shanghai control, Shanghai control, AAR991 request emergency descent, emergency, declare emergency due to fire main deck. Request descent, and descent to one-zero thousand."

At 03:54:37, SHI ACC gave AAR991 a descent clearance and instructed it to turn at its discretion, and the FO acknowledged this instruction. The radar data of ICN ACC shows that AAR991 started descending at 03:54:59.

At 03:55:08, the FO requested a diversion to Jeju Airport, stating "We have fire main deck, AAR991, return to Jeju AAR991," and SHI ACC approved the request.

At 03:58:03, SHI ACC instructed AAR991 to maintain 10,000 ft, however, followed by no response from AAR991. At 03:58:25, SHI ACC requested KAL886 flying near AAR991 to relay any information from AAR991 to SHI ACC. KAL886 stated that AAR991 was descending to 10,000 ft and flying direct to Jeju. According to the radar data of ICN ACC, AAR991 was flying at 16,000 ft at a ground speed of 452 kt on a heading of 345°.

At 03:59:13, AAR991 requested a radar vector to Jeju. At 03:59:50, SHI ACC instructed AAR991 to fly heading 045, and AAR991 acknowledged this instruction.

At 03:59:26, according to the ATC transcript, the sound of the FO's breathing

5) ACARS messages were further received as shown in Section 1.6.5.2.
6) Between 03:55:29 and 03:57:48, SHI ACC and AAR991 tried to communicate about descent altitude and a change of destination but failed to understand each other's intention, whereas KAL886 comprehended their communication.
through an oxygen mask was recorded four times when he communicated with SHI ACC.

The last ACARS messages received by the ground station about 04:00 are as follows: "YAW DAMPER UPR," "RUD RATIO DUAL," and "FLAPS CONTROL."

At 04:00:23, SHI ACC instructed AAR991 to contact ICN ACC on 124.52 MHz for a radar vector to Jeju, however, AAR991 stated that it was unable to contact on this frequency. Consequently, SHI ACC instructed the crew to monitor frequency 134.0 MHz.

The radar data of ICN ACC shows that at 04:01:43, AAR991 was flying at 8,200 ft at a ground speed of 404 kt on a heading of 033°, and after this, AAR991's altitude, ground speed, and heading changed inconsistently7).

At 04:02:00, SHI ACC instructed AAR991 to contact Fukuoka Area Control Center (FUK ACC) on 133.6 MHz. At 04:02:10, the FO stated, "AAR991" and 12 seconds later, added, "Fukuoka AAR991 mayday mayday mayday, we have cargo fire, request direct to Jeju please," followed by no response from FUK ACC.

At 04:03:01, the FO called SHI ACC and stated that it was unable to contact FUK ACC. Consequently, SHI ACC instructed AAR991 to pass information to KAL886 and let KAL886 relay the information to FUK ACC and ICN ACC.

At 04:03:01, the flight track data of the Incheon radar shows that AAR991's transponder code in Mode 3/A was set to 7700 from 6353 when the aircraft was flying at 8,500 ft at a ground speed of 410 kt on a heading of 027°.

7) Refer to [Figure 2], [Figure 3], and Appendix 3 (Radar Data of ICN ACC).
At 04:03:24, KAL886 advised AAR991 that it would relay its message to ICN ACC, and the FO stated, "Yes, now direct Jeju heading 030." KAL886 informed AAR991 that SHI ACC gave it heading 045, and the FO acknowledged this instruction.

At 04:04:14, SHI ACC instructed KAL886 to use another transmitter to contact ICN ACC on 124.52 MHz, to request heading to Jeju from its present position, and to report back to SHI ACC. Regarding this, KAL886 gave an affirmative response.

At 04:05:30, the captain\(^8\) called KAL886, and KAL886 responded, "Relay from Incheon Control, from Incheon Control, maintain heading 060, radar vector for final, and you may descend to 7,000 ft." At 04:05:52, KAL886 again relayed the message, "Maintain heading 060, radar vector for final, and descend to 7,000 ft," followed by the captain's response, "Descend 7,000 ft."

Beginning 04:06:25, the captain called "Korean Air" twice. At 04:06:30, KAL886 responded, "Stand by, stand by," followed by the captain's statement at 04:06:32, "Ah… we are now that rudder control is not working and seems to be fired… (jamming)."

At 04:06:41, SHI ACC instructed KAL886 to contact ICN ACC on 124.52 MHz, and at 04:07:16, instructed AAR991 to try contacting KAL886 on 124.52 MHz, followed by the captain's acknowledgement.

At 04:07:34, the captain stated, "We have to open the hatch, hatch." Subsequently, KAL886 instructed AAR991 to change its frequency to ICN ACC frequency 124.52 MHz.

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\(^8\) From this moment, the captain took control of radio communications.
At 04:08:52, ICN ACC instructed KAL886 to relay the message to AAR991 that JEJ APP established radar contact with AAR991 and that AAR991 should contact JEJ APP on 121.2 MHz. At 04:09:08, KAL886 relayed this message to AAR991.

At 04:09:47, the captain said to JEJ ACC, "Rudder control… flight control, all are not working." The FO said to JEJ ACC, "Did you contact? Uh… do you contact us?" and JEJ ACC responded, "AAR991… yes, I can hear you."

At 04:10:06, the FO stated, "We have heavy vibration on the airplane, may need to make an emergency landing, emergency ditching," and JEJ ACC responded, "Yes, say again, please." He stated, "Altitude control is not available due to heavy vibration, going to ditch… ah."

At 04:10:26, JEJ ACC asked AAR991, "Can you make approach to Jeju?" and subsequently, tried to contact AAR991 three times, however, followed by no response from AAR991.

[Figure 1] shows AAR991's whole flight track from the takeoff point to the crash point. [Figure 2] and [Figure 3] are AAR991's horizontal and vertical flight track, respectively, from pre/post-emergency declaration to the crash, reconstructed on the basis of ICN ACC radar data, with major ATC radio communications and ACARS messages incorporated. The upper and bottom figures in [Figure 3] depict the vertical flight track based on distance from the crash point, and time elapsed after 04:00:10, respectively.
[Figure 1] AAR991's Whole Flight Track
[Figure 2] Horizontal Flight Track before/after Emergency Declaration Including Major ATC Radio Communications & ACARS Messages
Vertical Flight Track Based on Distance from the Crash Point

Vertical Flight Track Based on Time Elapsed after 04:00:10

[Figure 3] Vertical Flight Track Including Major ATC Radio Communications & ACARS Messages
1.2 Injuries to Persons

<table>
<thead>
<tr>
<th>Injuries</th>
<th>Crew</th>
<th>Passengers</th>
<th>Other</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fatal</td>
<td>2</td>
<td>0</td>
<td>-</td>
</tr>
<tr>
<td>Serious</td>
<td>0</td>
<td>0</td>
<td>-</td>
</tr>
<tr>
<td>Minor/None</td>
<td>0</td>
<td>0</td>
<td>-</td>
</tr>
</tbody>
</table>

1.3 Damage to Aircraft

The aircraft was destroyed by in-flight fire damage and impact forces caused by the crash into the sea.

1.4 Other Damage

Cargo shipments aboard the aircraft were damaged, incapable of being recovered, or washed away due to fire, impact forces by the crash, and submergence in seawater.

1.5 Personnel Information

1.5.1 The Captain

The captain (male, age 52) was hired by Asiana Airlines on 2 July 1991. After working as B737 and B747-400 first officer, he was promoted to B737 captain on 24 December 1996, and to B747-400 captain on 3 July 2001.

The captain held a valid air transport pilot license, B737 type rating, B747-400 type rating, an aeronautical radio operator license, level 4 ICAO English Proficiency Certificate\(^9\), and a first-class airman medical certificate\(^{10}\),

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issued on 9 December 2010, with the limitation that he must wear corrective
glasses during flight; possess a reserve pair of corrective glasses.

The company's personnel record shows that the captain had accumulated
14,123 total flight hours including 2,501 hours as the ROK Air Force pilot.
Since hired by Asiana Airlines, he had flown 4,726 hours in B737 airplanes
including 3,340 hours as pilot-in-command, and 6,896 hours in B747-400
airplanes including 5,666 hours as pilot-in-command. He had flown 946, 269, 86,
and 27 hours in the 1 year, 3 months, 1 month, and 1 week, respectively,
before the accident flight.

The captain's training record shows that, as part of regular ground training, he
received his half-yearly B747-400 type training on 25 February 2011 and
common subject training on 19 April 2011. He also received his CRM training
on 17 December 2010 and recurrent training in a flight simulator on 2 March
2011. He passed his proficiency check and line check on 3 March 2011 and 2
June 2011, respectively.

As for the captain's whereabouts in the 72 hours before flight, he operated
AAR965 (Los Angeles-Beijing-Incheon) on 24 July 2011. His family stated that
he, as usual, took a walk near his apartment and did house chores like cleaning
his house on 25 (Mon) and 26 (Tue) July. On 27 July (Wed), he departed his
home in Cheongju12) for his mother's house in Seoul13) and rested there to
prepare for the AAR 991 flight.

His colleagues stated that the captain was active and very considerate of

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11) In order to meet the flight crew recurrent training criteria required by Flight Safety Regulations, Asiana
   Airlines semiannually offers ground training, flight training, and a check in the first and second half of
   the year, in accordance with the flight crew training regulation.
12) Cheongju is located approximately 150 km from Incheon Airport, and it takes approximately 3 hrs 30
   min by public transportation from Cheongju to Incheon Airport.
13) Seoul is located approximately 40 km from Incheon Airport, and it takes approximately 1 hr by public
   transportation from Seoul to Incheon Airport.
others' feelings. His medical record shows that he had no special medical history or hospitalization record, and that he had no health problem which could have affected his flight performance.

1.5.2 The First Officer

The first officer (male, age 43) was hired by Asiana Airlines on 2 April 2007. He was promoted to B767 first officer on 5 February 2008 and B747 first officer on 4 November 2010.

The first officer held a valid air transport pilot license, B767 type rating, B747-400 type rating, an aeronautical radio operator license, level 4 ICAO English Proficiency Certificate¹⁴, and a first-class airman medical certificate¹⁵ with the limitation that he must wear corrective glasses during flight; possess a reserve pair of corrective glasses.

The company's personnel record shows that the first officer had accumulated 5,211 total flight hours including 3,010 hours as the ROK Air Force pilot. Since hired by Asiana Airlines, he had flown 1,709 hours in B767 airplanes as second-in-command and 492 hours in B747-400 airplanes as second-in-command. He had flown 748, 232, 77, and 18 hours in the 1 year, 3 months, 1 month, and 1 week, respectively, before the accident flight.

The first officer's training record shows that, as part of regular ground training, he received his half-yearly B747-400 type training on 25 January 2011 and common subject training on 10 February 2011. He also received initial CRM training on 28 November 2007, regular CRM training on 10 February 2011, and recurrent training in a flight simulator on 25 February 2011. He passed his proficiency check on 26 February 2011.

As for the first officer's whereabouts in the 72 hours before flight, he operated AAR588 (New York-Brussels-Incheon) on 24 July 2011. His family stated that he had his usual daily life like taking a walk near his house, except for receiving 8-hour recurrent type training at work on 26 July.

His family and colleagues stated that the first officer was a family man, sincere and active in doing everything, with a strong sense of responsibility, and that he did not drink any alcohol, smoke, or take any illegal medication and was in good health. His medical record shows that he had never had special medical history or hospitalization record since hired.

1.6 Aircraft Information

1.6.1 Aircraft History

The aircraft, HL7604, whose serial number is 29907, was manufactured\(^{16}\) by the Boeing Company on 15 February 2006 as a B747-48EF freighter. On 22 February 2006, it was delivered to Asiana Airlines and registered under the Korean Airworthiness Authority. The aircraft held a valid airworthiness certificate issued on 24 February 2006.

The aircraft had accumulated 28,752 total flight hours and 4,799 total cycles at the time of the accident.

It was equipped with four CF6-80C2B1F engines manufactured by General Electric. Their thrust amounted to 57,900 lb × 4, and the APU model was PW901A.

The dimensions of the aircraft are shown in [Figure 4].

\(^{16}\) Manufacturing Line Number: 1370; Manual Application Number: 103.
On the upper deck of the aircraft were 8 seats for passengers and supernumerary crew members. The cargo configuration of AAR991 is shown in Figure 5.

1.6.2 Scheduled Maintenance and Fault History

Scheduled maintenance performed in the 5 months before the accident\(^\text{17}\) is shown in [Table 1].

\(^{17}\) From 4 March to 25 July.
Review of the maintenance history of the 5 months before the accident confirmed that there were 208 faults and corrective actions on the aircraft journey log. Out of these faults, those with the air conditioning and pressurization (ATA\textsuperscript{18}) 21), electrical system (ATA 24), equipment and furnishings (ATA 25), and fire detection system (ATA 26), which were determined to be of interest, and their corrective actions were examined.

There were 11 faults with the air conditioning and pressurization system. As faults repeatedly occurred with outflow valves, both left and right valves were replaced. In particular, on 18 April 2011, as the "EQUIP COOLING" warning message was displayed on AAR774 (Frankfurt/Incheon), the aircraft diverted to and landed at Koltsovo Airport in Russia. This fault turned out to be with the equipment cooling printed circuit assembly, which was then replaced.

Ten faults occurred with the electrical system, but five of them were concerned with the generator while the other five with the replacement of bulbs in the switches.

There were 22 faults with the equipment and furnishings, which were mainly

\textsuperscript{18} ATA stands for the Air Transportation Association, which categorizes the aircraft system by number, and this categorization is universally used by the aviation industry.
related to a pallet power drive unit (PDU) and a locking device.

Three faults occurred with the fire detection system. On 26 April 2011, as the "AFT CGO 4 LOOP" message was displayed, the fire detection system was tested on the ground after landing, but no fault was found. Aisana Airlines determined that "AFT CGO 4 LOOP" message was a false fire warning due to moisture. Smoke detectors sometimes false alarm due to moisture and thus, the Boeing Company issued a service letter19) about actions to correct such a fault. The remaining two faults with the fire detection system were concerned with engine fire detector loops.

1.6.3 Aircraft System

1.6.3.1 Air Conditioning and Pressurization System

The air conditioning and pressurization system converts hot pneumatic air at high pressure, which comes from the engines, to temperature controlled conditioned air at low pressure and distributes the converted air to the various airplane compartments including flight deck.

Air flown into the compartments is discharged overboard through the modulation of the pressurization outflow valves aft of the airplane, and accordingly, cabin pressure is regulated.

The airplane is equipped with three air conditioning packs. In each pack, pneumatic bleed air is metered through a flow control and shutoff valve and is initially cooled in a heat exchanger.

During flight, ram air is the cooling medium, and during operation on the

19) Doc No.: 747-SL-26-020; Issue Date: 17 Mar. 2004; Title: Cargo Compartment False Fire Warnings Due To Moisture.
ground, a fan on the air cycle machine (ACM) cools the air.

As shown in [Figure 6], cool air leaving each of the air conditioning packs flows into a single conditioned plenum chamber, and as necessary, flows to the flight deck, crew rest area, upper deck and cargo compartments through the main distribution manifold.

The temperature controller mixes cool air from the packs with hot air from the engines to generate air at the temperature required by the cabin and then distributes it to each compartment of the airplane.

[Figure 6] Distribution Ducts in the Aircraft

As shown in [Figure 7], air leaving each of the air conditioning packs flows into a plenum chamber and is distributed to the upper deck and main deck cargo compartment through the distribution ducts, and to the lower cargo compartment through diffusers in the ceiling. The air then flows either forward to an overboard valve or aft to outflow valves and is discharged overboard for appropriate airplane pressurization.
The forward equipment racks are cooled by either air conditioning pack air, or by a fan in the forward cargo compartment left sidewall which draws air from the forward cargo compartment for cooling. A second fan in the forward cargo compartment right sidewall exhausts hot air into the forward cargo compartment.

The aft equipment racks are cooled by two lavatory and galley vent fans which draw hot air and exhaust it into the bulk cargo compartment and out through the pressurization outflow valves.

When there is a fire in the forward equipment racks during flight or a pilot puts an equipment cooling control switch in the "OVRD" position, two fans for cooling forward equipment racks stop their operation and the "smoke override valve" is open, thereby exhausting air in the racks overboard.

When the "MAIN DECK ARM" switch is pressed, two of the three air conditioning packs shutdown and airflow to the cargo compartments (main deck
and both lower lobes) is shutoff. One pack continues to operate to provide fresh air to the flight deck and supernumerary area to prevent smoke from entering occupied areas.

When the "CARGO FIRE DEPRESS/DISCH" switch is pressed, two outflow valves open. Through these open valves, air is exhausted to reduce cabin pressure.

1.6.3.2 Fire Warning and Detection System

The fire, smoke, or overheat detection systems give the flight crew visual and/or aural indications of abnormal conditions in the engines, APU, cargo compartments, landing gear, wings, lavatories, crew rest, and E/E compartment. In the cockpit are two speakers sounding fire warnings, two master warning light indicators and an EICAS\(^\text{20}\) screen displaying related messages.

The pilot's overhead panel contains a FIRE/OVHT test button. This button is used to test the fire, overheat, and smoke detection systems for engines, APU, wing leading edge, main deck cargo compartment, and lower cargo compartment.

There is a separate fire loop for each engine nacelle and cowling - two for each engine - to detect any engine fire and overheat condition.

A smoke detector unit is installed in each lavatory to monitor for the presence of smoke.

The main deck cargo compartment on a frighter are divided into a total of 16 fire zones, each of which has two smoke detectors for a total of 32 as shown in [Figure 8]. The forward and aft lower cargo compartments are equipped with

\(^{20}\) Engine indication and crew alerting system (EICAS) is an integrated system providing flight crew with aircraft engines and other systems instrumentation and warnings.
a total of 16 detectors.

[Figure 8] Smoke Detectors in the Main Deck Cargo Compartment

Cargo smoke detection results in the master warning/caution light illuminating, fire bell, and an advisory EICAS message. [Figure 9] shows the smoke detector's basic operating principles.

[Figure 9] Smoke Detector

A smoke detector installed between the supply air duct and exhaust air duct detects smoke in the equipment cooling system, thereby creating an EICAS message for the flight crew.
1.6.4 Weight and Balance

According to Asiana Airlines' loading management procedures, a loadmaster in the cargo department prepares an airplane's weight and balance data by using a computer program and provides such data to flight crew members before departure.

The weight and balance data of AAR991 is as follows:

<table>
<thead>
<tr>
<th></th>
<th>TOW</th>
<th>MTOW</th>
<th>ZFW</th>
<th>MZFW</th>
<th>LDW</th>
<th>MLDW</th>
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</thead>
<tbody>
<tr>
<td></td>
<td>273,471 kg</td>
<td>394,625 kg</td>
<td>224,891 kg</td>
<td>276,691 kg</td>
<td>258,412 kg</td>
<td>302,092 kg</td>
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<tr>
<td>Takeoff Fuel</td>
<td>48,534 kg</td>
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<tr>
<td>Trip Fuel</td>
<td>15,059 kg</td>
<td></td>
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</tr>
<tr>
<td>Cargo Weight</td>
<td>65,937 kg</td>
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</tbody>
</table>

The permissible range of the center of gravity (CG) in accordance with a flight manual, the operating range of CG in accordance with company rules, and the CG in accordance with a flight plan are shown in [Table 2].

(Unit: % MAC)

<table>
<thead>
<tr>
<th>Category</th>
<th>ZFW</th>
<th></th>
<th>TOW</th>
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<tr>
<td></td>
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<td>Fore</td>
<td>Aft</td>
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<tr>
<td>Flight Manual's Permissible Range of CG</td>
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<td>33</td>
<td>11</td>
<td>33</td>
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<tr>
<td>Company's Operating Range of CG</td>
<td>16.1</td>
<td>32.2</td>
<td>16.1</td>
<td>32.2</td>
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<tr>
<td>Flight Plan's CG</td>
<td>27.31</td>
<td></td>
<td>25.98</td>
<td></td>
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</tbody>
</table>

[Table 2] CG Data
1.6.5 ACARS

1.6.5.1 General ACARS Information

The Aircraft Communications Addressing and Reporting System (ACARS) is a digital data-link system that provides data communication between an airplane and ground stations by using radio or satellite communications (HF, VHF, SATCOM) as shown in [Figure 10].

![ACARS Data Flow](image)

[Figure 10] ACARS Data Flow

ACARS replaces voice communication of the airlines’ operation control with data communication. It can reduce flight crew’s workload since specific data can be automatically transmitted if certain conditions are met. Also, it can manually transmit message data at the request of the crew.

Automatically transmitted data is:

- Out, Off, On, In Times: Data is generated due to value changes of the various sensors installed on the aircraft and transmitted shortly after its generation.
• Aircraft Fault Messages: Fault messages from the central maintenance computer (CMC), which are related to EICAS messages, and are sent every minute, but their time stamp has a resolution down to the minute.

• Turbulence and Takeoff Reports: Information from the aircraft condition monitoring system (ACMS)

• Aircraft Position: Information from the flight management computer (FMC)

Manually transmitted data is:
• Estimated time of arrival (ETA) update
• Flight crew identity and payroll
• Flight data such as flight number, departure and arrival airports, and fuel on board
• General text messages

The ACARS Present Leg Fault (PLF) reports are different from the FDR data, and they have the following characteristics:

• An ACARS CMC report may contain maintenance messages and associated EICAS messages. The maintenance messages are time stamped in hours and minutes with the time that the maintenance message was generated by the CMC, but an ACARS CMC report will not include a time stamp for the associated EICAS message. For an EICAS message to be reported, the EICAS message must be correlated to a maintenance message within a specific time window.

• ACARS messages, unlike the FDR data stored at a regular interval, are discontinuous snapshot data generated only when certain conditions are met through the system logic. That is, out of fault data generated from an airplane, only the data subject to certain conditions is converted into messages.
1.6.5.2. ACARS Messages

ACARS messages received from AAR991 include the following three information: aircraft position data; turbulence data; and EICAS fault messages.

Aircraft position data is generated according to a change in waypoint\(^{21}\) as shown in [Table 3], allowing the aircraft position to be traced.

<table>
<thead>
<tr>
<th>Order</th>
<th>Time</th>
<th>Latitude</th>
<th>Longitude</th>
</tr>
</thead>
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<tr>
<td>1</td>
<td>03:07:58</td>
<td>N37.213</td>
<td>E126.369</td>
</tr>
<tr>
<td>2</td>
<td>03:14:26</td>
<td>N36.439</td>
<td>E126.369</td>
</tr>
<tr>
<td>3</td>
<td>03:17:27</td>
<td>N36.237</td>
<td>E126.345</td>
</tr>
<tr>
<td>4</td>
<td>03:21:27</td>
<td>N35.556</td>
<td>E126.312</td>
</tr>
<tr>
<td>5</td>
<td>03:24:20</td>
<td>N35.330</td>
<td>E126.285</td>
</tr>
<tr>
<td>6</td>
<td>03:26:38</td>
<td>N35.153</td>
<td>E126.264</td>
</tr>
<tr>
<td>7</td>
<td>03:53:49</td>
<td>N31.533</td>
<td>E124.588</td>
</tr>
<tr>
<td>8</td>
<td>03:56:58</td>
<td>N31.514</td>
<td>E124.229</td>
</tr>
</tbody>
</table>

[Table 3] Aircraft Positions

Turbulence data is generated when the aircraft vertical acceleration \(G\) is more than 1.3 \(G\) or less than 0.7 \(G\) at more than 50 ft radio altitude from takeoff to landing. Every data is transmitted about 20 seconds after its generation.

As shown in [Table 4], turbulence data was transmitted five times in total. The data was transmitted once at 03:05:09 during takeoff when the aircraft climbed to 120 ft for 20 seconds and then, four times during cruising.

After the pilots reported a fire to SHI ACC at 03:54:23, the aircraft descended by 9,433 ft for 2 minutes and 6 seconds between 03:57:03, second data transmission time, and 03:59:09, fifth final data transmission time. The average descent rate per minute was 4,492 fpm\(^{22}\).

---

\(^{21}\) When passing a waypoint during flight, a message is transmitted.
### Factual Information

#### Aircraft Accident Report

<table>
<thead>
<tr>
<th>Flight Leg</th>
<th>Data Transmission Time</th>
<th>Time</th>
<th>Altitude (ft)</th>
<th>Speed (kt)</th>
<th>G</th>
<th>Heading (deg)</th>
<th>Pitch (deg)</th>
<th>Roll (deg)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Takeoff</td>
<td>03:05:09</td>
<td>03:04:49</td>
<td>211</td>
<td>97</td>
<td>1.03</td>
<td>152</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td></td>
<td></td>
<td>03:05:09</td>
<td>331</td>
<td>172</td>
<td>1.32</td>
<td>152</td>
<td>14</td>
<td>-1</td>
</tr>
<tr>
<td>Cruising</td>
<td>03:57:23</td>
<td>03:57:03</td>
<td>23,478</td>
<td>337</td>
<td>1.04</td>
<td>300</td>
<td>0</td>
<td>10</td>
</tr>
<tr>
<td></td>
<td></td>
<td>03:57:23</td>
<td>22,333</td>
<td>336</td>
<td>1.35</td>
<td>312</td>
<td>-2</td>
<td>18</td>
</tr>
<tr>
<td>Cruising</td>
<td>03:57:43</td>
<td>03:57:23</td>
<td>22,333</td>
<td>336</td>
<td>1.35</td>
<td>312</td>
<td>-2</td>
<td>18</td>
</tr>
<tr>
<td></td>
<td></td>
<td>03:57:43</td>
<td>20,697</td>
<td>345</td>
<td>1.32</td>
<td>328</td>
<td>-5</td>
<td>34</td>
</tr>
<tr>
<td>Cruising</td>
<td>03:58:47</td>
<td>03:58:25</td>
<td>17,690</td>
<td>348</td>
<td>0.91</td>
<td>345</td>
<td>-4</td>
<td>15</td>
</tr>
<tr>
<td></td>
<td></td>
<td>03:58:47</td>
<td>15,490</td>
<td>363</td>
<td>1.33</td>
<td>011</td>
<td>-5</td>
<td>32</td>
</tr>
<tr>
<td>Cruising</td>
<td>03:59:29</td>
<td>03:59:09</td>
<td>14,045</td>
<td>358</td>
<td>1.13</td>
<td>022</td>
<td>0</td>
<td>5</td>
</tr>
<tr>
<td></td>
<td></td>
<td>03:59:29</td>
<td>13,294</td>
<td>351</td>
<td>0.66</td>
<td>026</td>
<td>-3</td>
<td>5</td>
</tr>
</tbody>
</table>

[Table 4] Turbulences

EICAS (FDE\textsuperscript{23}), flight deck effect) messages received by the ground station via ACARS and their levels are summarized in [Table 5], and more details are contained in Appendix 1.

Also, ACARS messages received by Asiana Airlines for about an hour before the crash (03:04:49 - 04:10:50) are found in Appendix 2, along with time-based aircraft status and events.

About 03:59, the EICAS message that the Emergency Locator Transmitter (ELT) was on was displayed but the signal was not received by the Mission Control Center (MCC). More details of the ELT are specified in Section 1.15.2 of this report.

\textsuperscript{22}) \((23,478 - 13,294) \div 146 \text{ (sec)} \times 60 \text{ (sec)}.\)

\textsuperscript{23}) FDE messages displayed on an EICAS in the cockpit require the flight crew's action or reference.
<table>
<thead>
<tr>
<th>Time</th>
<th>FDE Messages</th>
<th>Level -Note-</th>
</tr>
</thead>
<tbody>
<tr>
<td>03:53</td>
<td>EQUIPMENT SMOKE</td>
<td>S</td>
</tr>
<tr>
<td></td>
<td>EQUIP COOLING</td>
<td>C</td>
</tr>
<tr>
<td></td>
<td>CGO DET 11 MN DK</td>
<td>S</td>
</tr>
<tr>
<td>03:54</td>
<td>CGO DET 6, 10 MN DK</td>
<td>S</td>
</tr>
<tr>
<td></td>
<td>CGO DET 7, 16, 5, 4, 3, 8 MN DK</td>
<td>S</td>
</tr>
<tr>
<td>03:56</td>
<td>PACK 2, 3</td>
<td>A</td>
</tr>
<tr>
<td></td>
<td>SATCOM SYSTEM</td>
<td>S</td>
</tr>
<tr>
<td></td>
<td>A/P SINGLE SYS</td>
<td>S</td>
</tr>
<tr>
<td></td>
<td>YAW DAMPER LWR</td>
<td>A</td>
</tr>
<tr>
<td></td>
<td>STAB TRIM, STAB TRIM 2</td>
<td>A</td>
</tr>
<tr>
<td></td>
<td>AUTOPILOT DISC</td>
<td>W</td>
</tr>
<tr>
<td>03:57</td>
<td>DET APU FIRE</td>
<td>A</td>
</tr>
<tr>
<td></td>
<td>FMC LEFT</td>
<td>A</td>
</tr>
<tr>
<td></td>
<td>DOOR ENTRY L5</td>
<td>A</td>
</tr>
<tr>
<td></td>
<td>FLIGHT RCDR SYS</td>
<td>S</td>
</tr>
<tr>
<td>03:58</td>
<td>AUTOTHROT DISC</td>
<td>C</td>
</tr>
<tr>
<td></td>
<td>ELEVATOR FEEL</td>
<td>S</td>
</tr>
<tr>
<td></td>
<td>BTL LOW CARGO A</td>
<td>S</td>
</tr>
<tr>
<td></td>
<td>CGO DET AFT 4</td>
<td>S</td>
</tr>
<tr>
<td>03:59</td>
<td>BAT DISCH APU</td>
<td>A</td>
</tr>
<tr>
<td></td>
<td>SUPRNMRY OXY ON</td>
<td>A</td>
</tr>
<tr>
<td></td>
<td>APU</td>
<td>A</td>
</tr>
<tr>
<td></td>
<td>ELT ON</td>
<td>A</td>
</tr>
<tr>
<td>04:00</td>
<td>YAW DAMPER UPR</td>
<td>S</td>
</tr>
<tr>
<td></td>
<td>RUD RATIO DUAL</td>
<td>A</td>
</tr>
<tr>
<td></td>
<td>FLAPS CONTROL</td>
<td>C</td>
</tr>
</tbody>
</table>

-Note- Message Levels
W Warning: indicates an operational/airplane system condition which requires immediate corrective action.
C Caution: indicates an operational/airplane system condition which requires immediate crew awareness and some prompt compensatory action.
A Advisory: indicates an operational or airplane system condition that requires crew awareness for possible future compensatory action.
S Status: is necessary when determining the dispatchability of the aircraft, and some messages are included in the Minimum Equipment List (MEL).

[Table 5] Select EICAS (FDE) Messages

24) At 18:54:23, pilots declared an emergency and at 18:55:08, notified a main deck cargo fire to the ATC.
25) About 4 times of turbulences were reported from 18:57:03 to 18:59:29.
1.7 Meteorological Information

1.7.1 Precipitation and Temperature of Incheon Airport

Data on precipitation\(^{26}\) and temperature of Incheon Airport in the 27 hours before AAR991’s departure is shown in [Table 6].

<table>
<thead>
<tr>
<th>Time Date</th>
<th>00</th>
<th>01</th>
<th>02</th>
<th>03</th>
<th>04</th>
<th>05</th>
<th>06</th>
<th>07</th>
<th>08</th>
<th>09</th>
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<th>11</th>
<th>12</th>
<th>13</th>
<th>14</th>
<th>15</th>
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<th>18</th>
<th>19</th>
<th>20</th>
<th>21</th>
<th>22</th>
<th>23</th>
</tr>
</thead>
<tbody>
<tr>
<td>27 P</td>
<td>5.0</td>
<td>1.0</td>
<td>-</td>
<td>-</td>
<td>0.5</td>
<td>3.0</td>
<td>22.5</td>
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<td>8.5</td>
<td>22.0</td>
<td>56.5</td>
<td>9.0</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>13.5</td>
<td>22.0</td>
<td>0.0</td>
<td>0.0</td>
<td>2.5</td>
<td>2.0</td>
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</tr>
<tr>
<td>28 P</td>
<td>0.5</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
<td></td>
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<tr>
<td>28 T</td>
<td>25</td>
<td>26</td>
<td>26</td>
<td>26</td>
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<td></td>
</tr>
</tbody>
</table>

Unit: mm, ℃

—Note— - : No precipitation; 0.0: There is precipitation, but less than measurable unit.

[Table 6] Precipitation & Temperature of Incheon Airport in the 27 Hours

1.7.2 Area Weather Condition

Weather observations made by a meteorological satellite from 03:45 until 04:15 on 28 July are shown in [Figure 11]. The exact altitude of cloud is difficult to identify, but the weather conditions over Jeju Island and the accident site indicated that a southwest current of air and a westerly current of air flowed in at the middle and upper levels, respectively. Also, there were no convective cloud\(^{27}\) or other unusual weather phenomena.

\(^{26}\) Data from the Korea Aviation Meteorological Agency in Incheon Airport, and the unit of precipitation is mm.

\(^{27}\) A cloud with heavy rain, turbulence, and hail.
Weather observations made by a weather radar\textsuperscript{28}) from 03:30 until 04:10 on 28 July are shown in [Figure 12], and there was no cloud with rain over Jeju Island and the accident site.

At the time of the accident, two airplanes operated by China Eastern Airline and Asiana Airlines were flying at 33,000 ft on airway A593 and at 37,000 ft on airway B576, respectively. The pilots of the two airplanes stated that over the accident site, there was no turbulence or cloud with rain, and that there were a weak wind and a clear sky.

\textsuperscript{28}) 10 nationwide radars with a surveillance radius of 250 km.
1.7.3 Weather Conditions of Departure and En-route Alternate Airports

A METAR weather report filed when AAR991 took off from Incheon Airport about 03:05 was as follows:

"METAR RKSI 271800Z 20020KT 9999 FEW010 BKN018 OVC080 26/22 Q1007 TEMPO -RA=" (Surface wind 20 kt at 200, Visibility 10 km, Overcast at a middle level, Temperature 26°C, Pressure 1007 mb)

A METAR weather report of Jeju Airport designated as an emergency landing airport by AAR991 after a cargo fire, filed at 04:00 on the day of the accident, was as follows:

"METAR RKPC 271900Z 21009KT 150V300 9999 SCT030 BKN180 29/21 Q1010 NOSIG=" (South-southwest surface wind at 9 kt, Variable from southeast to northwest, Visibility 10 km, Broken at an upper level, Temperature 29°C, Pressure 1010 mb)

Upper wind\(^{29}\) over Jeju Island (observatory location: N33.28° E126.16°) is shown in [Table 7].

<table>
<thead>
<tr>
<th>Observation Time</th>
<th>4,000 ft (agl)</th>
<th>6,000 ft (agl)</th>
<th>10,000 ft (agl)</th>
</tr>
</thead>
<tbody>
<tr>
<td>27 July 21:00</td>
<td>195° at 30 kt</td>
<td>195° at 28 kt</td>
<td>210° at 25 kt</td>
</tr>
<tr>
<td>28 July 09:00</td>
<td>205° at 28 kt</td>
<td>206° at 26 kt</td>
<td>210° at 22 kt</td>
</tr>
</tbody>
</table>

[Table 7] Upper Wind Data

1.8 Aids to Navigation

The radar system of ICN ACC was in normal operation throughout the

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\(^{29}\) Upper wind is observed every 12 hours and was used to calculate the crash position from the last flight track of AAR991 (altitude).
AAR991 flight, and the flight track of AAR991 recorded in the system is contained in Appendix 3.

1.9 Communications

1.9.1 Voice Communications Between the Aircraft and ATCs

Voice communications exchanged between AAR991 and ATCs from takeoff at Incheon Airport to impact were transcribed, and the transcript can be found in Appendix 4.

1.9.2 Direct Line Communications Between ATCs

When AAR991 declared an emergency and diverted to Jeju Airport, three ATCs exchanged its flight data\(^{30}\) via direct telephone line in order for SHI ACC to transfer the control to ICN ACC through HUK ACC, and the following is the main content of their communications:

- At 04:00:01, HUK ACC requested SHI ACC to "transfer the control to ICN ACC at 124.525 MHz."

- At 04:01:35, SHI ACC notified HUK ACC that "altitude was too low\(^{31}\) to contact at 124.525 MHz."

- At 04:01:48, HUK ACC requested SHI ACC to "transfer the control to HUK ACC at 133.6 MHz."

- At 04:03:14, HUK ACC requested ICN ACC to "give an alternative

\(^{30}\) Flight Data: flight number, transponder code, aircraft position and altitude, ATC frequency, emergency situation, etc.

\(^{31}\) About 8,500 ft according to ICN ACC radar data.
frequency because communications were not available at 124.525 MHz."

• At 04:03:17, SHI ACC notified HUK ACC that "altitude was too low to contact at 133.6 MHz, either."

• At 04:03:18, ICN ACC notified HUK ACC that "SHI ACC was requested to use an alternative frequency, 128.37 MHz, to transfer the control."

• At 04:03:42, HUK ACC requested SHI ACC to "transfer the control to ICN ACC at 128.37 MHz."

* SHI ACC did not instruct AAR991 to change its frequency as above, via direct telephone line.

1.9.3 Air Traffic Control Communications Facilities

According to the ATC/pilot communications transcript, when AAR991 declared an emergency due to a cargo fire and diverted to Jeju Airport at 04:00:23, SHI ACC instructed AAR991 to contact ICN ACC at 124.525 MHz in order to transfer the control, but at 04:01:15, AAR991 notified SHI ACC that it was unable to contact ICN ACC. At this time, AAR991's altitude in the ICN ACC radar data was 9,000 ft.

Transceiver antennas operating at 124.525 and 128.375 MHz, two of the frequencies used by ICN ACC to control the aircraft on south and southwest routes of Jeju Island, are located in Seongpanac and Moseulpo on Jeju Island as shown in [Figure 13]. The 124.525 MHz frequency antennas standing 10 m tall are erected on the floor 850 m above sea level, thereby rising 860 m above sea level.
The top of Mt. Halla, 1,950 m above sea level, is located west of the 124.525 MHz transceiver antennas, whereas there are no geographical obstacles west of the 128.375 MHz transceiver antennas.

[Figure 13] 124.525 & 128.375 MHz Transceiver Antennas

1.10 Aerodrome Information

Jeju Airport designated as an en-route alternate airport by AAR991 is operable 24/7 and equipped with airport facilities\(^{32}\) that allow B747-400 airplanes to take off, land, and park.

At 04:00:04, ICN ACC notified JEJ APP in Jeju Airport via direct telephone line that AAR991 would land in Jeju Airport due to an emergency. Accordingly, Jeju Airport Operator prepared for AAR991's emergency landing.

1.11 Flight Recorders

Two flight recorders, flight data recorder (FDR) and cockpit voice recorder

\(^{32}\) Airport facilities consist of basic and support facilities.
(CVR), installed on the accident airplane were not retrieved.

1.11.1 Flight Data Recorder

The FDR installed on the accident airplane was a SSFDR (P/N 980-4700-042, S/N SSFDR-09943) manufactured by Honeywell.

The FDR on the basis of ED-55\(^3\) measures 536 mm by 125 mm by 156 mm and weighs 6.8 kg. It consists of a chassis, the CSMU\(^3\), and the Underwater Locator Beacon (ULB).

The ARAIB recovered the chassis with a severe fire damage but failed to locate the CSMU.

1.11.2 Cockpit Voice Recorder

The CVR installed on the accident airplane was a SSCVR (P/N 980-6022-001, S/N CVR120-07910) manufactured by Honeywell. This CVR on the basis of ED-56a\(^5\) measures 365 mm by 123 mm by 162 mm and weighs 5.9 kg. It consists of a chassis, the CSMU\(^6\) and the ULB, and was not recovered.

1.11.3 Underwater Locator Beacon

\(^3\) ED-55 is a technical standard set by EUROCAE in May 1990. It specifies the Minimum Operational Performance Specification and its testing procedures.

\(^5\) The CSMU is a module to safely protect flight data against external shock or fire. According to the Minimum Operational Performance Specification of ED-55, the module is designed to protect the inner data against impact shock of 3,400 G or 1,100 degrees of fire for at least 30 minutes.

\(^6\) ED-56a is the Minimum Operational Performance Specification developed by EUROCAE in December 1993.

\(^5\) The CSMU is a module to safely protect flight data against external shock or fire. According to the Minimum Operational Performance Specification of ED-55, the module is designed to protect the inner data against impact shock of 3,400 G or 1,100 degrees of fire for at least 30 minutes.
An Underwater Locator Beacon (ULB) emits an ultrasonic pulse of 37.5 KHz at an interval of 0.9 times per second in all quadrants for at least one month when triggered by water immersion, and is fitted to FDR and CVR, respectively. The ULB (model: DK-120) manufactured by Dukane Seacom, Inc. was fitted to the accident airplane. Lithium batteries that have a shelf life of six years were fitted to FDR and CVR on 11 December 2009 and 22 February 2006, respectively, and have never been replaced since then. Batteries are operable at a temperature range between -2.2℃ and 37.8℃.

1.11.4 Search Operations for Flight Recorders

Immediately after being notified of AAR991's accident, the ARAIB conducted search operations in four phases to locate the crash site and retrieve flight recorders. The details of the search operations are contained in Appendix 5.

Despite the operations, no ULB signals enabling the estimating of the flight recorders' position were detected. Accordingly, the ARAIB focused search efforts mainly on the flight recorders but failed to recover them.

1.12 Wreckage and Impact Information

As shown in [Figure 14], the wreckage of AAR991 was distributed in the underwater area 3 km by 4 km, 130 km west of Jeju Airport, in southwest-northeast direction. The black dots in [Figure 14] indicate recovery points of the main pieces of the wreckage.
1.12.1 Accident Site

The depth of the sea where the wreckage is distributed is estimated at 85 m on the west, 87 m in the middle, and 81 m on the east. The average speed of current measured at a sea buoy and the sea floor was about 5 kt and 1 - 2 kt, respectively. The currents at the accident site flowed in a northwesterly direction at high tide and in a southeasterly direction at low tide. The sea floor consisted of mud and sand about 60 cm thick and was generally flat. The average visibility at the sea floor was about 0.5 m. During July and August in 2011, the accident site was hit by seven typhoons37).

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37) Typhoons that influenced the accident site from 12 Jul. 2011 until 5 Sep. 2011: Ma-on (2011-6);
1.12.2 Wreckage Recovery

From 06:00 on 28 July after AAR991 had disappeared from the radar, resources\(^{38}\) from the Coast Guard, the Navy, and the Air Force were dispatched to the accident site and commenced search operations. From 12:00 on 28 July, the Coast Guard started to recover some floating debris and cargo of AAR991 at the accident site.

On 30 July, the ARAIB took over the floating debris\(^{39}\) recovered and temporarily stored it at a safe area in Jeju Airport. Additional ships and airplanes\(^{40}\) for rescuing the pilots and searching for the wreckage were dispatched.

From 1 August, the naval ship was dispatched and searched for the ULB signal.

On 2 August, using a side scan sonar, two search boats of the Japanese salvage company searched for the underwater wreckage and confirmed that the aircraft wreckage was widely distributed on the seabed.

On 17 August, a salvage tug of the Japanese salvage company equipped with recovery equipment\(^{41}\) located the empennage on which the FDR and CVR were presumed to be installed.

On 20 August, the Japanese salvage company tried to recover the wreckage identified as the empennage but to no avail due to a lack of experience of

\(^{38}\) Coast Guard: 5 ships (one 3,000 t, three 1,500 t, one 300 t) and 4 helicopters; Navy: 1 ship and 1 helicopter; and Air Force: 2 helicopters.

\(^{39}\) 869 pieces of debris from the aircraft and cargo in about 60 varieties.

\(^{40}\) 8 ships (Coast Guard: 8, Navy: 2, Korea Hydrographic and Oceanographic Administration: 1) and 3 airplanes (Coast Guard: 2, Navy: 1).

\(^{41}\) A remotely controlled underwater vehicle (working ROV) and a chain sling.
underwater aircraft recovery, deteriorating weather conditions, and difficulty in tying up the underwater wreckage for lifting. Using a remotely operated vehicle (ROV), it picked up three pieces of the aircraft skin.

Until 20 August, the Japanese salvage company recovered three pieces of the aircraft skin, provided coordinates of the wreckage and some images, and then withdrew from the accident site due to the limitations of its underwater recovery ability, and the termination of a tentative contract with Asiana Airlines.

From 6 September until 8, the submarine rescue ship of the Navy recovered three pieces of the aircraft skin located by saturation divers at the site. The portion of the wreckage where flight recorders were installed was recovered, but their rack was gone.

From 27 September until 30 October, the Korean salvage company conducted a recovery operation by using divers and one-boat trawling.

On 29 October, the cockpit was recovered with its upper portion severely compressed, and the bodies of two pilots inside.

During this period, most of the aircraft skin (about 25% of the whole skin and about 10% of the cargo) was recovered by using one-boat trawling. Divers tried to fasten and lift the wreckage presumed to be the rear fuselage, using a large crane but to no avail because it was buried deep in the mud.

The recovered items were moved onto a barge where ARAIB investigators, Asiana Airlines engineers, and Boeing experts assigned a tag number to each item and photographed it for identification, and conducted on-scene investigation. On 2 November, they were moved to a wreckage storage facility near Incheon airport for detailed investigation, then a joint ROK-US investigation\textsuperscript{42} was
conducted at the facility.

From November 2011 until March 2012, the recovery operation was temporarily suspended due to fast currents and strong winds at the accident site.

From 18 April 2012 to 25, a patrol boat affiliated with the former Ministry of Land, Transport and Maritime Affairs, and the Navy resumed search operations to check the movement of the underwater wreckage and pinpoint their exact locations at the accident site, and as a result, added new wreckage coordinates.

From 10 May until 10 June, a private salvage company\(^{43}\) using a pair trawling method recovered 3,421 pieces of the wreckage (about 15% of the aircraft skin and about 5% of the cargo), and the joint ROK-US investigation team determined that a total amount of the recovered wreckage was about 40% of the aircraft skin and about 15% of the cargo.

The ARAIB investigators and Asiana Airlines engineers identified the recovered wreckage and conducted an on-scene investigation. On 18 June, the wreckage was moved to the wreckage storage facility near Incheon Airport, and the second joint ROK-US wreckage investigation\(^{44}\) was carried out.

1.12.3 Wreckage Examination

From 1 August 2012 until 8 September 2012, under the supervision of the ARAIB investigators, investigators from the NTSB, the FAA, and the Boeing Company and engineers from Asiana Airlines examined the initial floating debris recovered by the Coast Guard at a temporary storage facility in Jeju Airport.

\(^{42}\) Investigators from the ARAIB, NTSB, FAA, and Boeing Company, and engineers from Asiana Airlines.
\(^{43}\) A company with experience in dealing with the Air Force aircraft marine accidents in Korea, and in searching and recovering underwater wreckage.
\(^{44}\) Investigators from the ARAIB, NTSB, FAA, and Boeing Company, and engineers from Asiana Airlines.
They identified the debris, and assessed its impact damage, the level of direct fire damage and sooting, etc.

The ARAIB collected samples from the wreckage with severe fire damage and sent them to the National Forensic Service for analysis. The analysis result indicated that there is no possibility of a fire caused by explosives.

On 2 November 2011, the floating debris in Jeju Airport and the initially recovered wreckage were moved to the Incheon wreckage storage facility, and until 20 December, the ARAIB investigators and Asiana Airlines engineers conducted the following tasks: identifying wreckage; documenting the location of wreckage on the aircraft; assessing the level of fire damage and sooting of wreckage; classifying cargo shipments and assessing their fire damage; and photographing small pieces of unidentified wreckage.

From 5 January 2012 until 20 January 2012, at the Incheon wreckage storage facility, the first joint ROK-US investigation\(^{45}\) was conducted in such areas as fuselage/structure, fire, cockpit, and cargo.

The Fire Group conducted a detailed investigation into fire damage for each aircraft location and prepared the first fire map. The Cockpit Group examined the current positions of switches in the cockpit under the microscope. The Cargo Group investigated the overall status of cargo shipments such as whether a fire occurred to them, their pre-accident loading positions, etc. The Fuselage/Structure Group checked the detailed locations of the recovered wreckage against the fuselage diagram and closely examined fire damage and the damaged wreckage. Also, the Group prepared the wreckage map and tagged\(^{46}\) the wreckage.

\(^{45}\) Investigators from the ARAIB, NTSB, FAA, and Boeing Company, and engineers from Asiana Airlines.

\(^{46}\) Tag Numbers: 1 - 173 (initial floating debris); 201 - 225 (wreckage recovered by the Japanese salvage company); 504 - 511 (wreckage recovered by the Navy); 1001 - 1153 (wreckage recovered by the Korean salvage company); and 2000 - 3999 (wreckage tagged by the US investigation team).
From 28 July 2012 until 3 August 2012, at the Incheon wreckage storage facility, the second joint ROK-US investigation was conducted into all the wreckage including one recovered additionally during May and June in 2012. As a result, the wreckage map was prepared as shown in [Figure 15].

Out of all the wreckage, large pieces or those carrying significant implications for the accident investigation were mostly examined and tagged.

As shown in [Figure 16] and [Figure 17], the wreckage items were positioned in relative close proximity to one another in the yard of the Incheon wreckage storage facility in accordance with the level of fire damage, and their levels of damage and trace of fire were examined and documented.
The upper section of the cockpit was extensively pressure formed by direct impact of water, which caused the throttle quadrant, switches, and many levers to sustain mechanical damage.

Cockpit instruments and switches were removed and examined to check their indications and operating states at the time of impact. Light bulb filaments of annunciator lights were examined under magnification to see whether the lights were in operation.
[Figure 18] Cockpit (Throttle Quadrant, Fuel Cutoff Switches, & Others)

As shown in [Figure 18], fuel cutoff switches No. 1 and 2 were in the ON position, whereas No. 3 and 4 in the OFF position, but under magnification, it was confirmed that No. 3 and 4 moved to the OFF position due to impact forces.

Light bulb filaments of annunciator lights removed from the cockpit were examined to see whether the lights were in operation. As a result, some annunciator lights with deformed filaments were identified, but it was confirmed that they were not directly related to the accident, and no anomaly was found during the cockpit wreckage examination.

The details of the cockpit wreckage examination can be found in Appendix 6.

As shown in [Figure 19], the cockpit smoke evacuation shutter was found closed, but a well defined soot trail was discovered on the exterior skin of the shutter in the rear fuselage direction.
Out of the recovered wreckage, sections between fuselage station47) (hereafter referred to as FS) 1700 and FS2400 contained direct fire damage. Yet upper fuselage skins and frames forward of FS1700 were also found to be partly sooted, and some of their plastic material was deformed by heat.

The right wing tip was separated from the wing between wing station (hereafter referred to as WS) 1500 and WS1550. The upper portion of the right wing tip contained compressive buckling tearing, whereas the lower portion exhibited tension failure.

As shown in [Figure 20], blue photo-resist was found on the top surface of the right wing. The top surface of the wing contained multiple black waffle-like markings caused by collisions with electronic components containers48) loaded in position MR, and about 120 electronic components with a diameter of 5 mm, a thickness of 1.2 mm, and a weight of 0.3 g were imbedded in the composite wing upper surfaces.

47) Fuselage stations are numbered in inches from a reference point or the reference datum that is a vertical plane from which measurements fore and aft can be made. The reference point is located 90 inches ahead of the nose of the aircraft, which is FS0. Accordingly, FS1700 is located 1,610 inches from the nose.

48) Black partition boxes in which electronic components are kept.
The forward facing surface of the fuel jettison tube as well as the inside surface of a skin fragment in the right wing fracture at WS1516 also contained black waffle-like markings. No indications of hydro forming were found on the top and bottom surface of the wing.

Blue photo-resist was found on the surface of the right inboard spoiler No. 7, and the main deck cargo floor and the upper portion of the left main deck cargo door also exhibited a large quantity of blue and red photo-resist stains.

As shown in [Figure 21], the left and right winglets\(^49\) were separated from the wings, and their fracture areas sustained damage consistent with overspeed. Blue photo-resist was discovered inside the right winglet fracture area, but no black waffle-like markings or blue photo-resist stains were found on the right winglet, the surface of which was relatively in good condition, with no damage by electronic components.

\(^49\) A winglet attached to the wing tip in an upward angle of 60 degrees raises the aerodynamic efficiency of the wings.
As shown in [Figure 22], the flight control pulley at FS775 showed sooting and discoloration but did not exhibit thermal damage, and the flight control cables attached to the pulley exhibited rust.

As shown in [Figure 23], the LH lower wing skin measuring approximately 40 ft by 8 ft was recovered. It includes portions of two center wing skin panels and three outer wing panels. The skin section spans stringer positions 10 through 23 (from the midspar forward to the front spar), but not all of the stringers remain attached.
As shown in [Figure 24], a forward section of the nose cargo door was separated from the fuselage at FS 160/180, and the radome was missing. The skin demonstrated compressive buckling 360 degrees along the leading edge. The forward pressure bulkhead was hydro formed. Upper portions of both sides of the door, including the hinges, were recovered with the cockpit section.
As shown in [Figure 25], the flight data recorder rack was separated from the mount aft of the upper portion of the L5 door. The upper portion of the frame was thermally damaged, and its interior surface was heavily sooted. The paint of the exterior skin was partially discolored by inner heat.

[Figure 25] Exterior (Left) & Interior (Right) Sides of L5 Door

Portions of the wreckage in the region between FS1740 and FS2360 contained direct thermal damage on the exterior skin as evidenced by melting of internal metal structure and discoloration of the exterior paint. As shown in [Figure 26], the skin panel that extended from FS2180 and FS2360 sustained severe thermal damage as evidenced by twisted and melted stringers and ribs, holes on the surface, and paint discoloration on the exterior of the skin. The skin panel also contained areas which were burned through.
As shown in [Figure 27], the inner insulation materials of the main deck cargo door aft of the left fuselage were burned. Some cargo items were melted and stuck to the upper side of the door hinge, but the aircraft's surface touching the melted cargo items did not exhibit fire damage.

The latch-lock mechanism of the main deck cargo door was in a closed position, and the paint of the exterior skin turned yellow by heat.
As shown in [Figure 28], approximately 80% of the aft pressure bulkhead (APB) at FS2360 was recovered broken into six major pieces. Portions of the wreckage sustained fire damage consisting of sooting, and some fragments of the skin remained after fire. Almost the entire RH side of the bulkhead is accounted for, whereas part of the LH side disappeared.

[Figure 28] Aft Pressure Bulkhead

There is an outboard portion of the LH bulkhead from approximately fuselage stringer S-14L to S-24L missing as well as a smaller outboard LH section from approximately S-1L to S-8L. Fracture surfaces of the bulkhead web are a combination of web tension failures and shear failures.

Some of the radial stiffener fracture surfaces exhibit signs of pure tension failure while others are from bending. Most of the recovered APB pieces roughly maintain their original form with the exception of tears and punctures.
As shown in [Figure 29], the section 48 of the aft fuselage contained no internal sooting or fire damage but did have external soot accumulation on the underside of the left and right skin panels. Most of the damage appeared to have been caused by impact forces during the crash into the sea.

![Section 48 of the Aft Fuselage](image)

[Figure 29] Section 48 of the Aft Fuselage

As shown in [Figure 30], the No. 3 pylon includes the majority of the structure from the rear engine mount bulkhead forward to the forward engine mount bulkhead. The pylon also includes remnants of bleed air ducting, fuel lines, wire bundles and other systems but did not exhibit fire or abnormal damage.
The rear engine mount bulkhead is separated into two pieces, top and bottom, at the production join. The upper portion of the bulkhead remains attached to the upper spar and is bent forward about the upper spar join at approximately a 45 degree angle.

The RH skin forward of the rear engine mount bulkhead is detached from the pylon and deformed inward into the pylon almost to the horizontal position. The LH skin remains attached to the spars. No signs of fire were noted on any of the pylon structure.

As shown in [Figure 31], the left horizontal stabilizer was separated from the empennage. The remaining skin fragments along the upper and lower fracture areas were bent upwards and demonstrated compressive buckling tearing.
The honeycomb panels along the trailing edge of both the top and bottom surface of the stabilizer were slightly hydro formed, and honeycomb panels along the bottom side were intact, whereas four panels along the top side were not present.

The inboard elevator was separated from the stabilizer just aft of the hinge, and the trailing edge of the outboard elevator was damaged. The outboard tip of the stabilizer was fractured at Station 510 and was recovered separately from the stabilizer.

As shown in [Figure 32], the nose landing gear was recovered relatively intact and contained no fire damage.
1.13 Medical and Pathological Information

On 29 October 2010, about 11:00, the bodies of the pilots were recovered at the accident site. On 30 October 2010, about 11:30, professors of the medical school performed an autopsy on the bodies, whose results showed that the cause of death was blunt force injuries due to a plane crash, and toxicology reports indicated no meaningful results.

1.14 Fire

Portions of the aircraft wreckage contained fire damage including sooting. The wreckage has sustained severe damage from FS1700 to the APB, and sooting trails caused by smoke were also found on the exterior of the flight deck's skin.

For the examination of the wreckage, a numbering convention was used to
grade the level of fire damage sustained. This convention is as follows:

- Level 0: No evidence of sooting or thermal damage
- Level 1: Soot evidence
- Level 2: Minor charring and/or paint discoloration from heat
- Level 3: Heavy charring and/or incipient melting
- Level 4: Melted/consumed

1.14.1 Fire Damage of the Airframe

1.14.1.1 Wreckage Between FS1700 and APB

The wreckage between FS1700 and APB sustained the most severe fire damage. Detailed thermal damage maps were generated for these portions of the aircraft. These portions were mostly between the aft main deck cargo door and the L5 door as shown in [Figure 33]. This area can be characterized overall as having been exposed to high temperatures as evidenced by severe thermal damage on the interior structure and discoloration of the paint on the exterior of the aircraft's skin.
1.14.1.2 Wreckage Forward of FS1700 and Aft of APB

The wreckage forward of FS1700 was generally sooted with areas of more severe damage along the upper areas of the aircraft's attic space and crown\(^{50}\). Evidence of sooting was found all the way forward in the main deck cargo compartment on the bottom face of the ceiling liners under the flight deck.

The APB sustained thermal damage originating on the side facing the interior of the main deck cargo compartment. The heavy damage was on the upper section of the bulkhead, with damage also seen on the bottom portion near the APU duct.

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\(^{50}\) Crown is the area above seats in the pressurized crew rest section and the ceiling in the cargo compartment.
The thermal damage map of the APB facing the main deck cargo compartment is shown in [Figure 34], and the colourless portions of the map indicate the wreckage unrecovered.

Portions of the wreckage aft of the APB including the pressure bulkhead facing rear fuselage did not have the evidence of fire damage, but on the exterior of the skin panels on the right and left side of the wreckage aft of the APB were soot trails caused by smoke exiting the outflow valves.

[Figure 34] APB Thermal Damage Map
1.14.1.3 Small Miscellaneous Portions of Wreckage

Many pieces of the wreckage of yet undetermined location within the aircraft were also examined for fire damage. These pieces had a range of damage levels from no fire damage to severe melting.

1.14.1.4 Cargo Control Panels

The main deck cargo control panel from FS510 on the RH side and the nose door control panel showed evidence of sooting.

1.14.1.5 Riser Ducts

Four out of the six riser ducts on AAR991 were recovered. As shown in [Figure 35], all three left riser ducts sustained fire damage which was consistently more severe along the upper glass fiber portions and tapered off towards the bottom. The fire damaged sections were burned such that the resin was consumed leaving only the cloth portion. The remainder of the ducts were undamaged except for sooting on the exterior section. The left forward most riser duct is of significance as it supplies all of the fresh air to the upper deck during a main deck fire.

One of the right riser ducts was recovered, with the upper glass fiber portions separated, and its fire damage was consistent with that of the left ones.

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51) Ducts through which conditioned air from the air conditioning system flows to the ceiling of the aircraft, located between FS800 - 1000.
1.14.1.6 Forward Main Cargo Deck Ceiling Panels

As shown in [Figure 36], portions of the ceiling panels belonging to the area under the flight deck had a layer of soot adhering to the surface. Ceiling panels aft of FS360 were also sooted and had a darker appearance.

1.14.1.7 Upper Deck Interior Panel

As shown in [Figure 37], the upper deck interior panel, part of the lavatory module wall where emergency equipment is installed, exhibited soot accumulation.
1.14.2 Cargo Fire

The cargo configuration of the main deck and lower cargo compartments on AAR991 can be found in [Figure 5]. The main deck cargo compartment was loaded with pallets and one ULD container (at position LL) which was recovered. No evidence of fire damage was found on the inside of the ULD as shown in [Figure 38], but the outside of it was heavily covered in soot.

Films that had been loaded in ULD position MR were recovered with burnt and blackened traces.
There was no fire damage or sooting in the container wreckage located at 44L and 43L of the lower cargo compartment. Edge rails of cargo pallets were found separated from the pallets, and their levels of fire damage are shown in [Table 8], and the serial number of a certain rail could be confirmed as shown in [Figure 39].

<table>
<thead>
<tr>
<th>Location</th>
<th>Levels of Fire Damage</th>
</tr>
</thead>
<tbody>
<tr>
<td>LR</td>
<td>No evidence of fire</td>
</tr>
<tr>
<td>ML</td>
<td>Evidence of burning and sooting</td>
</tr>
<tr>
<td>PR</td>
<td>Evidence of sooting and blue dye splatters</td>
</tr>
<tr>
<td></td>
<td>Cargo net with two strands burnt, the one end</td>
</tr>
<tr>
<td></td>
<td>with blue dye splatters, the other end with</td>
</tr>
<tr>
<td></td>
<td>red dye splatters</td>
</tr>
<tr>
<td>SL</td>
<td>Evidence of sooting and slight melting</td>
</tr>
<tr>
<td>SR</td>
<td>Evidence of sooting and slight melting, some</td>
</tr>
<tr>
<td></td>
<td>portions with severe corrosion</td>
</tr>
<tr>
<td>12P</td>
<td>No evidence of sooting</td>
</tr>
<tr>
<td>22P</td>
<td>No evidence of sooting</td>
</tr>
<tr>
<td>41P</td>
<td>Out of 20 pallets, one pallet and six edge</td>
</tr>
<tr>
<td></td>
<td>rails were recovered with no fire damage</td>
</tr>
</tbody>
</table>

[Table 8] Fire Damage Levels of Edge Rails

Some portions of films loaded at position LL and fabrics loaded at positions CL, 21P, 23P, and 32P were recovered. Films and fabrics showed the evidence of burning and sooting, and burning, respectively. Besides, round-edged rectangle
plastic objects with fire damage, roll films in various sizes, and IC chips of yet undetermined location were recovered.

Recovered debris from the cargoes loaded at positions 11P, 12P, 22P, 31P, 32P, CR, DL, DR, EL, ER, FL, FR, GL, GR, HR, JR, KR, and LL included communications equipment, electronic parts, various reel tapes, computers and their parts, and plastic packaging, but all had no traces of fire damage.

1.14.3 Thermal Damage Map of the Entire Fuselage

Apart from the thermal damage map of the wreckage between FS1700 and APB in [Figure 33], two thermal damage maps at the airplane level - one for the fuselage skin and the other for the fuselage frames - were generated as shown in [Figure 40] and [Figure 41].

Portions of the wreckage forward of FS1700 generally have fire damage consisting of sooting with areas of more severe damage along the upper areas of the aircraft's attic space and crown.
As shown in [Figure 42], among the farthest forward wreckage (FS480 - 700), sooting was found on the fuselage frame at FS500 on the LH side in the area of the main deck cargo compartment. As shown in [Figure 43], sooting was also found on the upper deck floor beams as far forward as FS520.
The farthest forward evidence of thermal heat damage which caused paint discoloration was found on a crown fuselage frame at FS580 on the LH side. This damage is located at a stringer 6.
1.15 Survival Aspects

1.15.1 Search and Rescue

On 28 July 2011, at 03:59:09, ICN ACC received the information from FUK ACC that "AAR991 declared an emergency and requested diversion to Jeju Airport" and then notified JEJ APP of the situation at 04:01.

At 04:03:01, on the radar screen at ICN ACC were displayed a squawk code 7700 informing an emergency and the CST\(^{52}\) code word, and at 04:03, on the radar screen at JEJ APP was displayed a squawk code 7700.

At 04:03:57, ICN ACC received the notification of a cargo fire from KAL886 operating near AAR991.

At 04:10, JEJ APP was notified of the loss of aircraft control and impending emergency descent and ditching by AAR991.

At 04:11:05, the Master Control Report Center (MCRC) of the ROK Air Force declared AAR991 as the flight track of interest, and at 04:12:00, AAR991's track disappeared from the radar screen about 130 km west of Jeju Island.

About 04:12, AAR991's track disappeared from the radar screen of JEJ APP. Jeju Airport prepared for the aircraft's emergency landing, with fire engines ready.

At 04:12:49, ICN ACC inquired of the MCRC about the display of the flight track but was notified that there was no relevant data. Accordingly, at 04:13:00,

\(^{52}\) "CST" appears in the data block when an aircraft's reply to the radar site is not received.
ICN ACC notified the MCRC that AAR991’s track disappeared from the radar screen. About 05:08, the MCRC dispatched one patrol aircraft\(^{53}\) at Gimhae International Airport which is located closest to the accident site.

At 04:15, ICN ACC also inquired of the Coast Guard as to whether distress signal of the ELT was received but confirmed that it was not. The Coast Guard requested by ICN ACC to conduct search and rescue operations at 04:21:00 dispatched two helicopters, which were affiliated with its Jeju Base and Mokpo Base and arrived at the accident site to join search operations about 06:54 and 08:25, respectively.

At 04:30, the Navy was aware of the accident and about 05:38, dispatched one patrol aircraft\(^{54}\), which arrived at the accident site about 06:04. About 09:30, two naval vessels arrived on scene, and on 29 July, so did two naval minesweepers, one at 07:05 and the other at 07:35.

About 06:20, an Air Force patrol plane arrived at the site and searched the area. About 06:25, it notified the MCRC that the floating debris presumed to be the wreckage of the accident aircraft was found on the water about 130 km west of Jeju Airport. About 06:42, the Coast Guard's ship having conducted search operations since the arrival at the site at 06:15 found the floating debris of the aircraft at N33°15'8", E125°01'7".

The Coast Guard conducted search and rescue operations to find missing pilots for about 3 months with the focus on the estimated crash site, an area 17 km in width by 13.5 km in length.

On 29 October 2011, when one-boat trawling was used for wreckage recovery at the accident site, a portion of the cockpit was recovered. On 30 October,

\(^{53}\) A twin-engine, medium-range, maritime patrol aircraft.
\(^{54}\) A four-engine, turbo-prop, antisubmarine aircraft.
when the interior of the cockpit was examined, the bodies of the captain and the first officer were found with a 4-point seat belt fastened on the left and right pilot seat, respectively.

1.15.2 ELT

The fixed ELT can be activated by a switch on the overhead panel or automatically when the deceleration sensing inertia switch senses the impact of 5G and more. 150 seconds after turned ON, it transmits the aircraft information every 50 seconds thereafter. It is in stable operation for at least an hour at temperatures between $-20^\circ C$ and $+55^\circ C$ but is inoperable in the water.

The ELT was manufactured in conformity with the requirements of the COSPAS/SARSAT system\(^{55}\). It operates on 406.025 MHz and is mounted at FS2110, S-4L. The external antenna connected to the ELT is mounted at FS2127.5 forward of the vertical stabilizer. The transmitter, whose serial number is A06V2\(^{56}\), was manufactured by the French ELTA and was installed on the accident airplane on 3 June 2009.

1.16 Tests and Research

In relation to Asiana Airlines' crash accident, Hanseo University in Korea conducted a study on wreckage reconstruction, aircraft fire simulation, and fire cause analysis, and Korea Testing Laboratory (KTL) carried out chemical properties test and analysis of on-board dangerous goods, simulation of cargo loading, and transport condition testing including electrostatic energy-related research and measurements. The results can be found in Appendix 10.

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55) The COSPAS/SARSAT system is an international satellite system coordinated by the US, Russia, etc. to detect alert transmissions.
56) Part No.: 95N6088, Serial No.: 05422257.
1.16.1 Wreckage Reconstruction

The ARAIB carried out wreckage reconstruction to allow investigators to easily access a certain portion of the airframe structure, to have a 3D visual reference, and to examine the distribution of destructive forces in the presumably fire-affected area.

As shown in [Figure 45], the reconstruction focused mainly on Section 46\(^{57}\) with traces of fire damage, including the APB. In other words, 35 pieces of the recovered wreckage from FS1480 to FS2484, about 1/3 the length of the fuselage, were selected and reconstructed.

The reconstructed wreckage was analyzed for physical damage, thermal damage, etc.

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\(^{57}\) Fuselage from the fore cockpit to the rear end is classified as sections 41, 42, 43, 44, 45, and 46.
Before the selected pieces of the wreckage were attached to the aircraft-shaped framework, noncontact 3D measuring equipment was used to generate measurement data for each wreckage. As shown in [Figure 46] and [Figure 47], the accident airplane's wreckage modeling and 3D software were created on the basis of the measurement data.

[Figure 46] Measurement Data for Each Wreckage

[Figure 47] Wreckage Modeling
1.16.2 Chemical Properties Test and Analysis of On-board Dangerous Goods

The procedures for testing properties and storage environment of the dangerous goods (DG) were developed, and according to the procedures, physiochemical properties of the DG on board were tested (for flash point, ignition point, explosiveness, ignition, combustion, etc.).

The KTL developed flash point testing procedures on the basis of UN TDG Test Section 32, ISO 1516, ISO 1523, ISO 2719, ISO 13736, ISO 3679, and ISO 3680, and the Korea MSDS Testing Lab carried out the testing. Also, the KTL developed ignition point testing procedures on the basis of ASTME 659 Standard Test Method for Autoignition Temperature of Liquid Chemical, and the Korea MSDS Testing Lab conducted the testing.

In addition, Hanseo University purchased the same paint as that on board from the manufacturer and tested it for flammable gas leakage. After the university confirmed whether internal and external closure devices of a paint container were held securely, it enclosed the container in a 1 liter-plastic bag, a similar size of the paint container on board, stored it on the ground at room temperature for 2 hours, and measured volatile organic compound (VOC) emissions. The test revealed that flammable gas was detected at room temperature of 18°C, whereas not detected at 5°C. Besides this test, other flammable gas leakage tests\(^{58}\) were conducted as well, using a decompression chamber with a volume of about 280 liters to create two aircraft operation environments, cabin altitude (8,000 ft - 10,000 ft) and cruising altitude (32,000 ft - 34,000 ft)\(^ {59}\). The tests revealed that the VOC was detected at 2.5 parts per million (ppt) at a cruising altitude, whereas not detected at a cabin altitude.

\(^{58}\) On-board dangerous goods - photo-resist/LCD, photo-resist/IC, and paint - were tested for flammable gas leakage. The applicable DG with a measuring device were placed in the decompression chamber that created the environment at an applicable altitude, and VOC emissions were measured.

\(^{59}\) Cabin altitude is the pressure altitude corresponding to the pressure inside the cabin when the aircraft is operated, and cruising altitude is the pressure altitude corresponding to the outboard pressure.
Meanwhile, the KTL examined the minimum ignition energy (MIE) generated when flammable materials among the on-board DG vaporize, through a literature search, and summarized results of testing and research can be found in Appendix 10.

### 1.16.3 Simulation of Cargo Loading and Transport Condition Testing

By developing test procedures according to cargo loading/packaging forms, physical testing through simulations of packaging and loading of the DG (a physical test on the conditions of the cargo loaded in multiple layers or wrapped in a net or plastic wrap) was performed. So was a test of cargo transport conditions through a simulation of the aircraft operating environment.

The electrostatic energy that can be accumulated in the plastic wrap used for fixing and protecting cargo on the pallet from rain was measured. The ARAIB boarded the freighter operated in the flight leg (Seoul/Tianjin) with a similar flight time to that of the accident plane and measured the remaining electrostatic energy accumulated in the wrap. A summary of the measurements can be found in [Table 9]. See Appendix 10, Section 5 for complete results of the electrostatic energy measurements.
[Table 9] Summary of On-board Measurement

### 1.16.4 Aircraft Fire Simulation

Hanseo University carried out aircraft modeling through aircraft structure and design analysis, establishment of the fire simulation environment for aircraft with cargo on board, simulation of the state of the interior of the aircraft in case of fire, and analysis of fire propagation in relation to AAR991. Based on ACARS messages, the university simulated the spread of fire on the assumption that fire initially developed in the pallet in position PR or ML. The development of fire in position PR has sustained more similar thermal damage to that of the thermal damage map than the development of fire in position ML. See Appendix 10, Section 7 for results of the aircraft fire simulation.
1.17 Organizational and Management Information

1.17.1 Asiana Airlines

Asiana Airlines was founded in February 1988 and has its headquarters in Osoe-dong, Gangseo-gu, Seoul. As of the day of the accident, the airline operates 14 domestic and 90 international passenger routes, and 23 cargo routes throughout North America, Europe, Southwest Asia, Australia, China and Japan.

The organizational structure of Asiana Airlines is comprised of 6 divisions including operations and maintenance/engineering divisions, 23 departments, 4 foreign regional divisions, 81 teams, 135 branch offices and 6 sales offices.

As of the day of the accident, the airline's fleet consists of a total of 72 airplanes as follows: 2 B747-400 PAX; 2 B747-400 combi; 4 B747-400SF; 5 B747-400F; 11 B777-200ER; 7 B767-300; 1 B767-300F; 10 A330-300; 11 A320-200; 15 A321-200; 2 A321-100; and 2 B737-400.

1.17.2 Safety Management System of Asiana Airlines

Asiana Airlines has established its safety management system (SMS) in 2008 to manage aviation safety.

The SMS provides safety management framework and logical process in order for safety quality assurance activities taken by each division to be conducted according to purposes.

The safety meetings of the SMS are comprised of the safety policy review board and the safety officers meeting.
The safety policy review board, the company's top decision-making body in relation to safety issues, is presided over by President and attended by the heads of the divisions and the head of the safety management team every Monday morning. Its main agendas are as follows: conclusions from the safety officers meeting in the previous quarter; current status of safety accidents on the ground and future countermeasures; current status of hard landings and safety measures; and other safety-related issues and follow-up measures.

The safety officers meeting is held every quarter, presided by the executives of the safety and security division, and attended by safety officers of each division. The main agendas are as follows: implementation of resolutions of the safety policy review board and discussion about major pending safety issues. In the safety meeting like this, issues requiring cooperation of other divisions and corporate-level decision-making are discussed.

The SMS enables a decision-making process for risk management. In this process, the risk of all hazards in relation to flight operations is contained within an acceptable level; the risk of hazards is assessed in terms of probability and potential consequences of accidents; and the risk is reduced by taking economic feasibility into account.

1.17.3 Flight Crew Training of Asiana Airlines

1.17.3.1 Dangerous Goods Handling Training

In accordance with 「Flight Crew Training Manual of Asiana Airlines」, a professional instructor provided the captain and the FO with the DG handling training for 4 hours during their initial training. The captain and the FO received their most recent refresher training for one hour on 22 July 2010 and 28 October 2010 during their yearly recurrent training, respectively.
The content of the DG handling training is as follows: general principles and framework; limitations; DG list; labelling and marking; recognition of undeclared DG; storage and loading procedures; notification to the captain; regulations on passengers and crew members; and emergency response procedures.

The DG training instructor stated that he had trained the pilots with an emphasis on cargo safety standards for lithium-ion batteries and cargo fire procedures during the first half-yearly type training in 2011 after the fatal UPS crash in the United Arab Emirates on 3 September 2010. Also, he added that he had sent notification to the pilots. The notification was about the summary of SAFO10017 issued by the FAA in relation to the UPS crash and Regulation for Dangerous Goods by Air Transport developed by the Ministry of Land, Infrastructure and Transport (MOLIT).

1.17.3.2 CRM Training

According to 「Flight Crew Training Manual of Asiana Airlines」, the flight crew should complete 21 hours of initial CRM training after hired and 2 hours of recurrent CRM training every year. Also, they should receive 7 hours of joint CRM training every three years along with cabin crew, aircraft mechanics, flight dispatchers, and other personnel with the aim of understanding and cooperating with different fields.

Recently, the captain received his joint CRM training on 17 December 2010, and the FO completed his recurrent CRM training on 10 February 2011.

The pilots in the captain upgrade and instructor designation courses should receive the CRM training suitable for their applicable tasks. In particular, the instructor pilots should be given 4 hours of the recurrent CRM training once a year.
The content of the flight crew initial CRM training is as follows: TEM; culture; decision-making; situational awareness; teamwork; communication; stress and fatigue; command and leadership; automation; checklist and briefing; and monitoring and workload management.

The content of the recurrent CRM training is as follows: selection and review of one subject among the initial CRM curriculum; introduction of CRM techniques and accident prevention programs in foreign countries; air accident case study; and group discussion.

1.17.3.3 Emergency Equipment Training

According to 「Flight Crew Training Manual of Asiana Airlines」, the captain and the FO received 10 hours of initial training and 1 hour of recurrent training once a year, which were dedicated to emergency equipment procedures in response to an emergency situation and other unpredicted situations during operation.

More specifically, the content of the training is as follows: breathing protection equipment and fire suppression training; emergency evacuation training; emergency exit training; fire extinguisher training; oxygen equipment training; flotation device training; ditching training; and participation in and practice of emergency training.

1.17.3.4 Ditching Training

According to 「Flight Crew Training Manual of Asiana Airlines」, the captain and the FO received initial ditching theory training during the basic training after hired and recurrent training during the regular ground training.

After the A320 of US Airways ditched in the Hudson River off midtown
Manhattan in 2009, Asiana Airlines gave emergency ditching training to all flight crew members by using a simulator in the first half of 2009.

The captain and the FO were given the training for emergency ditching due to complete engine shutdown after takeoff in a B747-400 and B767 simulator, respectively.

1.17.3.5 Fire Simulation Training

A B747-400 simulator manufactured by CAE\(^{60}\) on 12 August 1994 was delivered to Asiana Airlines on 4 December 1994. Asiana Airlines contracted an outside training company to train and evaluate its flight crew in a flight simulator.

The flight crew training and evaluation guidelines\(^{61}\) are prepared by Asiana Airlines in accordance with the flight crew training program approved by the Korean government. The company's semiannual recurrent training and evaluation items are developed separately for captain and the FO according to type and distributed in advance to them to prepare themselves for training and evaluation. Simulator instructors of the outside contractor use the guidelines provided by Asiana Airlines to train and evaluate\(^{62}\) the flight crew.

As the simulator is configured as a passenger version of the B747-400, there is no main deck cargo ARM button as shown in [Figure 48], and accordingly, simulator instructors are unable to give a full Fire Main Deck training for B747 freighters. As a result, during briefing before the simulator training, they refer to a cargo plane's panel diagram and the flight crew operations manual.

\(^{60}\) The world's biggest simulator manufacturing company in Montreal, Canada.

\(^{61}\) Asiana Airlines' B747-400 training and evaluation guidelines in the first and second half of 2011 can be found in Appendix 8.

\(^{62}\) The details of B747-400 transition and recurrent training, checks, and fire-related training which were given to AAR991's captain and the FO can be found in Appendix 8.
During the simulator training, the instructors simulate a main deck cargo fire by giving trainees verbal instructions associated with the fire and using the passenger plane's lower cargo deck fire message instead.

![Figure 48] Fire Suppression Panel of Passenger (Left) & Cargo (Right) Plane

1.17.4 Non-normal Procedures for Fire Main Deck

1.17.4.1 Selection of 25,000 ft for Main Deck Cargo Compartment Firefighting Altitude

The Boeing Company has selected the altitude of 25,000 ft for Class E cargo compartment firefighting altitude as optimal based on studies of National Fire Protection Association (NFPA), FAA and other literature available. In establishing the FL250 diversion altitude, the company also assessed other factors such as flight crew physiological tolerance (e.g. decompression sickness, and hypoxia), crew oxygen, and terrain clearance.

NFPA data indicates that the minimum re-ignition energy varies inversely with the square of the pressure and concludes that approximately 4 times the ignition energy is required to rekindle a fire at 25,000 ft in comparison to that of 5,000 ft.
1.17.4.2 Revision of FCOM\textsuperscript{63)}

After the fatal UPS crash in 2010, the Boeing Company revised the "non-normal procedures for Fire Main Deck" in the flight crew operations manual (FCOM) by reinforcing two items in the procedures and issuing the Bulletin AAR-83 on 10 May 2011.

The revised procedures are as follows: first, the main deck cargo fire arm switch must be "ON", then to prevent excessive smoke accumulation on the flight deck, either pack 1 or 3 must be operating, whereas pack 2 control selector must be "OFF"; and second, the aircraft must expedite a climb or descent to 25,000 ft and stay at 25,000 ft as long as possible, and after the descent has been started, the approach and landing must not be delayed.

The "PACK" was newly added to step No. 9 (Do not accomplish the following checklists), so pilots are prohibited from operating packs once landing is initiated.

The QRH's non-normal procedures in relation to AAR991's fire can be found in Appendix 9.

1.17.4.3 QRH Possessed by the Accident Flight Crew

The "QRH" possessed by the accident flight crew on the day of the accident, in which non-normal procedures for Fire Main Deck were specified, were issued on 1 April 2011. Asiana Airlines received the revised non-normal procedures for Fire Main Deck\textsuperscript{64)} valid from 10 May 2011 on 16 May 2011 and distributed them to its flight crew on 1 August 2011 after the accident.

\textsuperscript{63)} The flight crew operations manual (FCOM) issued by the aircraft manufacturer deals with the aircraft system, performance, normal procedures, non-normal procedures, limitations and supplementary procedures.

\textsuperscript{64)} Bulletin AAR-83 issued by the Boeing Company.
Asiana Airlines' staff member in charge of manual distribution stated that, as there is no deadline for distributing the Bulletin, upon receipt, he reviews and reports it to the relevant authorities and then distributes it.

On 12 April 2011, Asiana Airlines posted a plan for revising the procedures for Fire Main Deck along with the main content of such revision on the Intranet flight crew bulletin board. According to log-in records, the captain and the FO read this notice.

1.17.4.4 Implementation of the Non-normal Procedures for Fire Main Deck

In accordance with Asiana Airlines' "FOM," the flight crew should possess their own "POM" and QRH during operation of the aircraft.

The QRH possessed by the flight crew contains the non-normal procedures of passenger, combi, and cargo planes. The combi plane's Fire Main Deck procedures were presented first, followed by the cargo plane's procedures since the passenger plane does not have the non-normal procedures for a main deck cargo fire due to the absence of a main deck cargo compartment.

The B747-400 flight crew should find the applicable non-normal fire procedures coincident with the aircraft's registration mark at the top of the page of the QRH and implement them.

1.17.5 Asiana Airlines' Post-accident Actions

65) FOM deals with regulations on general operations and flight operations. FOM provides policies, guidelines, standards, and procedures regarding general operations and flight operations to Asiana Airlines' staff concerned with air transport business.

66) Manual issued by an aircraft manufacturer with the aim of ensuring the flight crew's quick decision and actions in non-normal situations.

67) The procedures applicable to combi and cargo planes are different from each other. The main difference is that in a combi plane, a designated flight crew member should confirm the presence of smoke or fire, whereas in a cargo plane, a climb or descent to 25,000 ft should be expedited. Refer to Appendix 9 for the Fire Main Deck non-normal procedures of combi and cargo planes.
1.17.5.1 Simulator Session of Fire Main Deck Procedures

After the accident, Asiana Airlines, under the supervision of the ARAIB investigators, conducted two Fire Main Deck demonstrations in the Asiana B747-400 simulator, with Jeju Airport designated as an arrival airport.

☐ First Session (on 4 August 2011)

During the session, Asiana Airlines' B747-400 captain was the left seat PF while the FO was the right seat PM. Investigators of the Operations Group, a captain from the Boeing Company, and Asiana Airlines' persons concerned were present.

The gross weight (GW), ZFW, FOB, and center of gravity (CG) of the aircraft were set as 272,110 kg, 242,670 kg, 29,480 kg, and 24.5%, respectively. The winds were established as 220/25 kt aloft.

The session began when the instructor announced event by stating "Fire Main Deck" at a location 125 nm (230 km)\(^{68}\) southwest of Jeju Airport. There were no aural or visual alerts in the cockpit since the simulator supported only a passenger plane.

The flight crew implemented the Fire Main Deck procedures in the QRH. After landing, using the ILS approach, at runway 06\(^{69}\) of Jeju Airport, they ran the evacuation checklist.

During this procedure, the captain failed to use speedbrakes for expedited descents and experienced difficulty adjusting his oxygen mask harness.

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\(^{68}\) A point close to where AAR991 was aware of a fire.

\(^{69}\) Refer to Appendix 7 for the ILS approach chart for runway 06 in Jeju Airport.
The FO failed to select 100% oxygen on his O2 mask since he did not confirm the position of O2 supply currently set while donning the mask. He also experienced difficulty setting his respective communication panel, which led to a delay in the execution of the Fire Main Deck checklist.

The aircraft began to achieve its landing configuration and standard speed 19.5 nm (36 km) from the landing point.

From the declaration of a main deck cargo fire to touchdown, it took 31 minutes.

□ Second Session (on 17 September 2012)

The second session simulated the LOFT in which the aircraft made an emergency landing at Jeju Airport. Asiana Airlines' B747-400 captain was the left seat PF while the FO was the right seat PM. Investigators of the Operations Group and Asiana Airlines' persons concerned were present.

The GW, FOB, and CG of the aircraft were set as 272,160 kg, 29,480 kg, and 24%, respectively.

The aircraft was located 120 nm (222 km) southwest of Jeju Airport. When a main deck cargo fire was declared at 34,000 ft and 300 kt with no wind, the flight crew implemented the applicable procedures in the QRH, increased speed up to Vmo,70) and descended to 25,000 ft.

The TOD point at 25,000 ft was set as a point 55 nm (102 km) from Jeju Airport. Using the speedbrakes to the maximum, the aircraft descended to the MSA at the maximum sink rate at 360 kt.

70) Vmo (Maximum Operating Speed): this speed limit may not be deliberately exceeded in any regime of flight (climb, cruise, or descent).
As the aircraft reached 3,000 ft approximately 18 nm (33 km) from Jeju Airport, it decreased to Vref. As speed reduced, the aircraft achieved landing configuration of gear down and flap 30 and then made the ILS landing at runway 06. After touchdown, the flight crew ran the evacuation checklist on the runway. It took approximately 12 minutes from descent at 25,000 ft to touchdown and took approximately 10 nm (19 km) to achieve landing configuration at 360 kt.

Over a year after the accident, Asiana Airlines provided all B747-400 pilots with the LOFT, on the presumption of AAR991's main deck cargo fire, during which they made an emergency landing at Jeju Airport.

1.17.5.2 Flight Crew Training in Dangerous Goods and Cargo Loading

After the event, Asiana Airlines provided its B747 and B767 flight crew with training for a better understanding of cargo.

The company offered a two-day training course nine times in total. On the first day of training, types of cargo shipments and their loading procedures, and general and practical information on cargo including DG were taught, and on the second day, trainees visited Incheon Airport Asiana Cargo Service Office and observed the whole process from cargo acceptance to loading.

1.17.5.3 Revision of Freighter Operating Procedures

As of 31 December 2012 (Rev. 10), Asiana Airlines newly added "Chapter 9 Cargo" to "POM" to bring B747-400 freighter operating procedures together from scattered regulations and establish specific procedures for various in-flight situations including false cargo fire warning. Also, the company required its B747-400 pilots to apply the revised POM during cargo flight.
The added content are as follows: main terms; items to be confirmed before flight; DG; special cargo; cargo compartment classification; false cargo fire warning; emergency response guidance; on-board weight and balance system; life raft; decompression door; emergency escape device; and miscellaneous.

1.17.5.4 Plan for Installing CCTVs on B747-400 Freighters

As shown in [Figure 49], according to Asiana Airlines' data, in 2013, the company started installing CCTVs, which enable the flight crew to monitor a fire situation in the cockpit, in cargo compartments of a total of 12 B747-400 airplanes including freighters to be delivered after the AAR 991 accident. As of July 2015, a total of 8 CCTVs have been installed, and the installation will be completed by 2016.

This fire surveillance camera system is comprised of a monochrome camera in a main deck cargo compartment, an LCD monitor in the cockpit, a video server, and related software. In case of a fire in the cargo compartment, the flight crew will be provided with video imagery of fire along with an aural alert as shown in [Figure 50].

[Figure 49] Installation Locations of CCTVs
1.17.6 Cargo Handling Training of Asiana Airlines

The cargo handling manager of Asiana Airlines stated that, in accordance with DG training regulations specified in the ICAO Technical Instructions for the Safe Transport of Dangerous Goods by Air, IATA dangerous goods regulations, and MOLIT Regulation for Dangerous Goods by Air Transport, Asiana Airlines' employee responsible for DG acceptance shall receive DG training suitable for Duty Category 6\(^\text{71}\) in the DG training institutions approved by the ICAO, IATA, or MOLIT.

Training for Duty Category 6 includes the following curriculum: general principles and systems of DG handling; limitations; general obligations of shippers; DG classification; DG list, packaging requirements; packaging specifications; labelling and marking; DG shipment documents and relevant documents; acceptance procedures; recognition of undeclared DG; DG storage and loading procedures; notice to captains; regulations on passengers and crew members; and emergency response procedures. Among DG training courses, training for Duty Category 6 has the longest training hours and the most training subjects. Initial and recurrent DG training courses for Duty Category 6 take 40

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\(^{71}\) Duty Category 6: training for employees of airlines or ground handling companies which accept dangerous goods.
and 24 hours, respectively. Within 24 months after initial training, recurrent training is offered. Trainees are subjected to tests to check their understanding of course material. A score of 80% is considered passing. Also, their training records are stored per each branch office for at least three years.

In addition, to ensure the safe transport of DG, Asiana Airlines also requires its airport cargo service employees, apart from its DG acceptance staff, to complete Duty Category 6 DG training and then perform cargo handling services including DG handling on site.

Basically, loadmasters must complete DG training, and weight and balance training by freighter types72). They also must receive DG training for Duty Category 6.

Weight and balance training by freighter types consists of revised weight and balance procedures and revisions, and practice of weighing and balancing. After the completion of training, only those who passed a qualification test given by the cargo service team can obtain a loadmaster certificate of the applicable type. Initial and recurrent weight and balance training courses take 40 and 16 hours, which are minimum training hours, respectively. The certificate is valid for three years after the issue date. Loadmasters should complete recurrent training and pass a re-qualification test before the expiry date to maintain their qualification.

The loadmaster of AAR991 completed a 40-hour DG training and a 24-hour weight and balance training.

1.17.6.1 Training of Cargo Handlers

The cargo handling manager of Asiana Airlines stated that, in accordance with

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72) B747-400F and B767.
the ICAO Technical Instructions for the Safe Transport of Dangerous Goods by Air, IATA dangerous goods regulations, and MOLIT Regulation for Dangerous Goods by Air Transport, employees of Asiana Airport, a company offering ground handling services\(^{73}\) to Asiana Airlines, completed training suitable for Duty Categories 7/8\(^{74}\). Under the regulations, the training program shall consist of 4 hours of initial training and 2 hours of recurrent training within 24 months after the completion of the initial training, but Asiana Airport offers recurrent training annually to enhance DG safety management.

In addition, Asiana Airport's cargo handlers are given in-house duty training according to their given duties, twice a year for 2 hours each (one in the first half year and the other in the second half year). After the completion of the training, they begin to perform their duties such as handling, storing, and loading of cargo, consignment, and mail.

Cargo handlers of AAR991 completed DG training and in-house duty training.

1.17.7 Safety Inspection of Asiana Airlines by MOLIT

The Office of Civil Aviation under MOLIT is responsible for supervising the commercial aircraft registered in Korea. As of the day of the accident, there is a total of 47 air safety inspectors consisting of professionals in each specialty: 10 inspectors responsible for supervising international air transport operators; and 37 inspectors responsible for supervising domestic air transport operators and small air transport operators and for certifying aircraft maintenance organizations.

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\(^{73}\) Guidance for port entry and departure of the aircraft, loading management and power support, provision of aircraft operation information, services in relation to boarding, entry, and departure of passengers and crew members, equipment rental, and aircraft cleaning.

\(^{74}\) Duty Category 7: training for employees of airlines or ground handling companies which accept general cargo, exclusive of dangerous goods.

Duty Category 8: training for employees of airlines or ground handling companies which are involved in handling, storing, and loading of general cargo, consignment, and mail.
A total of 10 inspectors, consisting of 6 operations inspectors and 4 airworthiness inspectors, are responsible for international air transport operators. They issue the AOC to them and perform an on-scene inspection. Inspectors in charge of Asiana Airlines consist of 1 operations inspector and 1 airworthiness inspector. In November 2012, MOLIT increased the number of the inspectors to 17\(^75\) to ensure seamless safety inspection activities in response to the reduced inspection time caused by a rapid increase in the number of low cost carriers.

1.17.7.1 Aviation Safety Management System

According to MOLIT's "aviation safety regulations," once air transport operators receive the AOC and begin operations, they are subjected to year-round aviation safety inspection. MOLIT applied systematic inspection methods to aviation safety inspection. In addition, to manage unsafe factors repetitively and with emphasis, the Ministry has divided year-round safety inspection activities into three categories, which are regular inspection, concentrated inspection, and potential risk inspection, and conducted them.

Regular inspection means essential inspection and scheduled inspection which are regularly performed by aviation safety inspectors according to MOLIT's annual inspection plan. For this inspection, a detailed monthly inspection plan is established based on the inspection checklist by area specified in the "Manual for Aviation Safety Inspector."

In accordance with the "Manual for Aviation Safety Inspector", concerns identified during the regular inspection are addressed in the following three ways: correction action in case of violation of various standards and procedures; improvement recommendations for suggesting safety enhancement measures; and on-site correction in case of minor factors which have no direct influence on

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\(^75\) 17 inspectors: 6 (operations), 6 (airworthiness), 2 (cabin), 2 (flight dispatch), 1 (DG).
safety and can be corrected for a short period of time.

According to MOLIT's aviation safety inspection records, from January 2010 to the day of the accident in July 2011, 279 times of regular inspection were performed on Asiana Airlines, and during this period, a total of 75 concerns were identified and then were addressed by 18 corrective actions, 50 improvement recommendations, and 7 on-site corrections. Asiana Airlines completed all these 75 activities, which were not related, however, to this accident, and its percentage of concerns was at an equivalent level of other Korean airlines.

On the basis of a separate inspection plan, concentrated inspection is performed on concerns which require intensive and extensive verification or are repetitively identified by the analysis/review of regular inspection results. A separate team conducts this inspection to come up with findings and prepares the countermeasures by analyzing them.

On the basis of a separate inspection plan, potential risk inspection is performed to identify potential risk factors and then recommend improvement measures to operators when there is a need to reassess problems with operators' safety management system in the event of frequent cancelations, malfunctions, and serious incidents.

In December 2010, MOLIT performed concentrated inspection on the SMS and operations sectors. As a result, the following safety concerns were notified in writing to Asiana Airlines, and related improvement actions were taken.

- Improvement recommendations about 7 SMS operation-related safety concerns identified as inadequately addressed although Asiana Airlines was performing safety activities such as safety target management, hazard
identification and management, etc. according to the SMS manual approved by the government
- Improvement recommendations about 8 safety concerns in relation to inadequate implementation of operations quality management, improper follow-up measures of the FOQA, etc.

In April 2011, potential risk inspection of Asiana Airlines was performed to ensure safe operations by checking whether the airline prepared and implemented countermeasures against incidents and whether it acted on improvement recommendations. As a result, the following safety concerns were notified in writing to Asiana Airlines, and related improvement actions were taken.

- According to a result of checking the implementation of business improvement directives (15 cases), SMS improvement directives (7) and operations improvement directives (8) were being implemented, whereas safety enhancement directives (4) including general inspection of B747-400 wings were already implemented.

1.17.7.2 Post-accident Safety Measures

The aviation safety inspector of MOLIT stated that the Ministry took the following post-accident safety measures: "Special Inspection"; "General Inspection of the Fire Detection System and the Reinforcement of Pilot Training"; and "Aircraft Fire Prevention Measures."

○ Special Inspection

After the accident, MOLIT conducted a special inspection of Asiana Airlines from 16 to 19 August to check the conditions of the air cargo and DG transport management, the compliance with DG transport standards, etc. As a result of the
inspection, a total of 3 improvement recommendations were made as follows: strengthen DG training for a cargo handling contractor's employees; improve the management of the DG manual; and enhance the quality control of air cargo containers.

- Inadequate DG training for a cargo handling contractor's employees: Those handling dangerous goods were supposed to receive proper job training according to their given duties (12 types) such as transport, ground handling services, etc. but they performed their duties after given a different type of DG handling training.
- Inadequate quality control of air cargo containers: The maintenance of containers, pallets, and nets is outsourced for repair, but institutional mechanisms for maintenance quality control were unsatisfactory.

General Inspection of the Fire Detection System and the Reinforcement of Pilot Training

On 14 August 2011, Korean Airlines' B747-400 cargo airplane made an emergency landing at Incheon Airport due to a fire warning during the landing phase. The on-scene investigation revealed that it was a false fire warning because a smoke detector detected, as smoke, vapor caused by the inflow of moist external air. As a result, MOLIT prepared the following safety measures to ensure safe operations of the national airplanes.

- Conduct general inspection of the normal operation of the fire protection and suppression systems of B747 airplanes as well as all type freighters
- Train pilots on response procedures referenced in the QRH, etc. in the
event of a fire warning

- Establish measures to improve cargo loading procedures so that the inflow of outside moisture can be minimized

**Aircraft Fire Prevention Measures**

In December 2011, before the investigation conclusion of the ARAIB comes out, MOLIT prepared preemptive safety measures in areas likely to be the causes of a fire, thereby reinforcing prevention activities.

- Enhance air cargo safety supervision
- Establish a DG safety management system
- Reinforce aircraft fire prevention activities
- Reinforce inspection of the conditions of aircraft maintenance support

### 1.18 Additional Information

#### 1.18.1 Classification of the Cargo Compartment

In accordance with the Korean Airworthiness Standards 25.857, the cargo compartment is classified into either A, B, C or E classes, and the requirements of the compartments of each class are as follows:

- **Class A.** A Class A cargo or baggage compartment is one in which-- (1) The presence of a fire would be easily discovered by a crew member while at his station; and (2) Each part of the compartment is easily accessible in flight.

- **Class B.** A Class B cargo or baggage compartment is one in which-- (1) There is sufficient access in flight to enable a crew member to effectively reach any part of the compartment with the contents of a hand fire extinguisher; (2)
When the access provisions are being used, no hazardous quantity of smoke, flames, or extinguishing agent will enter any compartment occupied by the crew or passengers; and (3) There is a separate approved smoke detector or fire detector system to give warning at the pilot or flight engineer station.

○ Class C. A Class C cargo or baggage compartment is one not meeting the requirements for either a Class A or B compartment but in which-- (1) There is a separate approved smoke detector or fire detector system to give warning at the pilot or flight engineer station; (2) There is an approved built-in fire extinguishing or suppression system controllable from the cockpit; (3) There are means to exclude hazardous quantities of smoke, flames, or extinguishing agent from any compartment occupied by the crew or passengers; and (4) There are means to control ventilation and drafts within the compartment so that the extinguishing agent used can control any fire that may start within the compartment.

○ Class E. A Class E cargo compartment is one on airplanes used only for the carriage of cargo and in which-- (1) There is a separate approved smoke or fire detector system to give warning at the pilot or flight engineer station; (2) There are means to shut off the ventilating airflow to or within the compartment, and the controls for these means are accessible to the flight crew in the crew compartment; (3) There are means to exclude hazardous quantities of smoke, flames, or noxious gases from the flight crew compartment; and (4) The required crew emergency exits are accessible under any cargo loading condition.

The lower cargo compartment of AAR991 is a C-class cargo compartment, and the main deck is an E-class cargo compartment.

1.18.2 Cargo Loaded on AAR 991
1.18.2.1 Cargo Unloading and Loading History of AAR991

On 28 July 2011 at 00:05 before leaving for Shanghai, AAR991 arrived at Incheon Airport as flight AAR786 (Frankfurt-Incheon) and unloaded the whole cargo.

From 01:00 to 02:02 on 28 July 2011, 58,265.8 kg of cargo, which is 60 cases by master airwaybill, was loaded on 30 pallets and 5 containers at Incheon Airport. As shown in [Figure 5], 35 positions including 24 in the main deck and 11 in the lower cargo compartment were used.

At positions of main deck, CL, CR, DL, DR, EL, ER, FL, FR, GL, GR, HL, HR, JL, JR, KL, KR, LR, ML, MR, PR, RR, SL and SR were loaded Code M (318 cm × 244 cm) pallets, and at position LL was loaded a Code M container. Positions A1, A2, B1, PL, RL and T were empty.

At position 11P of the forward lower cargo compartment was loaded a Code A (318 cm × 224 cm) container, and at positions 12P, 21P, 22P and 23P were loaded Code M pallets.

At positions 31P, 32P and 41P of the aft lower cargo compartment were loaded Code M pallets, and at positions 43L, 43R and 44L were loaded AKE (153 cm × 156 cm) containers. Position 44R was empty.

1.18.2.2 Cargo Manifest for Incheon Departing Cargo

The total weight of Incheon departing cargo was 39,331 kg by 48 AWBs, and the cargo acceptance time at Asiana Airlines' export storage area was from 27 July at 10:11 through 28 July at 00:06. For security check during acceptance, X-ray screening and explosive trace detection were conducted.
The total weight of cargo transshipped to AAR991 at Incheon Airport was 18,934.8 kg by 12 AWBs as shown in [Table 10], and the weight by departure point is as follows:

<table>
<thead>
<tr>
<th>Departure Point</th>
<th>Flight No.</th>
<th>Arrival Date &amp; Time</th>
<th>Weight (kg)</th>
<th>Remarks</th>
</tr>
</thead>
<tbody>
<tr>
<td>Osaka</td>
<td>AAR191</td>
<td>27 July 20:15</td>
<td>258.6</td>
<td>DG</td>
</tr>
<tr>
<td>Fukuoka</td>
<td>AAR131</td>
<td>27 July 13:10</td>
<td>1,024.9</td>
<td></td>
</tr>
<tr>
<td></td>
<td>AAR133</td>
<td>27 July 20:40</td>
<td>128.3</td>
<td></td>
</tr>
<tr>
<td>Delhi</td>
<td>AAR768</td>
<td>27 July 12:00</td>
<td>145.0</td>
<td></td>
</tr>
<tr>
<td>Manila</td>
<td>AAR704</td>
<td>27 July 05:00</td>
<td>931.0</td>
<td></td>
</tr>
<tr>
<td></td>
<td>AAR702</td>
<td>27 July 17:45</td>
<td>21.0</td>
<td></td>
</tr>
<tr>
<td>Frankfurt</td>
<td>AAR542</td>
<td>27 July 12:20</td>
<td>865.0</td>
<td></td>
</tr>
<tr>
<td>Los Angeles</td>
<td>AAR2831</td>
<td>27 July 07:50</td>
<td>1,285.0</td>
<td></td>
</tr>
<tr>
<td></td>
<td>AAR965</td>
<td>26 July 05:25</td>
<td>11,201.0</td>
<td></td>
</tr>
<tr>
<td>San Francisco</td>
<td>AAR2831</td>
<td>27 July 07:50</td>
<td>3.0</td>
<td>DG</td>
</tr>
<tr>
<td>Seattle</td>
<td>AAR2377</td>
<td>27 July 11:30</td>
<td>3,072.0</td>
<td></td>
</tr>
</tbody>
</table>

[Table 10] Cargo Transshipped at Incheon Airport

As shown in [Table 11], from 27 July at 17:00 through 28 July at 00:30, Asiana Airlines classified cargo according to the assigned master airwaybill numbers and loaded it on the ULDs. When loading the ULDs on the aircraft, the company matched the serial number assigned to each ULD with the applicable position in the cargo compartments according to its load plan.
<table>
<thead>
<tr>
<th>Loading Order</th>
<th>ULD</th>
<th>Serial No.</th>
<th>Package (No.)</th>
<th>Weight (kg)</th>
<th>Main Content</th>
<th>Port of Loading/Remarks</th>
</tr>
</thead>
<tbody>
<tr>
<td>8</td>
<td>KR</td>
<td>PMC13317OZ</td>
<td>103</td>
<td>2,925</td>
<td>CKD LIGHTUNIT SET, LEAD FRAME, LED PKG, SLF INDUCTOR, MOULD PARTS, PCB, CABLE</td>
<td></td>
</tr>
<tr>
<td>9</td>
<td>LR</td>
<td>PMC15592OZ</td>
<td>5</td>
<td>3,134</td>
<td>FRUIT (CHERRY)</td>
<td>Seattle, US</td>
</tr>
<tr>
<td>10</td>
<td>MR</td>
<td>PMC15223OZ</td>
<td>68</td>
<td>3,494</td>
<td>LED, ELBOW FITTING, ADHESIVE PLASTIC, SEMICONDUCTOR DEVICE PART, SUITABLE FOR MANUFACTURING PRINTED CIRCU, LABEL, FACING HEAD UNIT</td>
<td></td>
</tr>
<tr>
<td>11</td>
<td>SR</td>
<td>PMC14489OZ</td>
<td>18</td>
<td>1,520</td>
<td>IC, T R PACKAGE, EZ CLEAN, SILICON, COMPRESSOR</td>
<td></td>
</tr>
<tr>
<td>12</td>
<td>SL</td>
<td>PMC14841OZ</td>
<td>40</td>
<td>2,480</td>
<td>HARD DISK DRIVE FOR PLAY STATION, DIFFUSION FILM, EITAXIAL WAFER, CASE POLE SPACER BOTOM, BRAZE FILLER PASTE, MAS FLOW EQUIPMENT</td>
<td></td>
</tr>
<tr>
<td>13</td>
<td>RR</td>
<td>PMC15301OZ</td>
<td>24</td>
<td>1,260</td>
<td>TFT DISPLAY GLAS SCREEN NEC RELAYS, EITAXIAL WAFER, CASE POLE SPACER BOTOM, BRAZW FILLER PASTE, MASS FLOW EQUIPMENT, DIE ATTACH FILM</td>
<td></td>
</tr>
<tr>
<td>14</td>
<td>CL</td>
<td>PMC12988OZ</td>
<td>22</td>
<td>1,370</td>
<td>FABRIC, IC DRIVER SOURCE</td>
<td></td>
</tr>
<tr>
<td>15</td>
<td>DL</td>
<td>PMC11437OZ</td>
<td>6</td>
<td>1,590</td>
<td>LED BACKLIGHT UNIT</td>
<td></td>
</tr>
<tr>
<td>16</td>
<td>EL</td>
<td>PMC12174OZ</td>
<td>54</td>
<td>1,975</td>
<td>LEAD FRAME, SLF INDUCTOR, MOULD PARTS</td>
<td></td>
</tr>
<tr>
<td>17</td>
<td>FL</td>
<td>PMC12854OZ</td>
<td>18</td>
<td>2,495</td>
<td>NETWORKING EQUIPMENT</td>
<td>LA, US</td>
</tr>
<tr>
<td>18</td>
<td>GL</td>
<td>PMC15528OZ</td>
<td>19</td>
<td>2,000</td>
<td>CHIP ON WAFER, ELECTRICAL GOODS, IC, SILICON</td>
<td></td>
</tr>
<tr>
<td>19</td>
<td>HL</td>
<td>PMC11340OZ</td>
<td>3</td>
<td>1,454</td>
<td>BRAKE HOSEFITTING, BOLT</td>
<td></td>
</tr>
<tr>
<td>20</td>
<td>JL</td>
<td>PMC14695OZ</td>
<td>40</td>
<td>1,878</td>
<td>TRANSFER ROLLER, COMPUTER, PLATE, ANTTENA PART, PCB SOURCE, CKD BACKLIGHTUNIT, SECURITY PRODUCT</td>
<td></td>
</tr>
<tr>
<td>21</td>
<td>KL</td>
<td>PMC12355OZ</td>
<td>13</td>
<td>3,050</td>
<td>SEMICONDUCTOR, WAFER, TRANSFER, CYLINDER DIA 125MM QUINTEC, ELECTRODE FOR CCFL</td>
<td></td>
</tr>
<tr>
<td>22</td>
<td>LL</td>
<td>AMA08668OZ</td>
<td>260</td>
<td>2,990</td>
<td>PHOTOMASK, IC</td>
<td></td>
</tr>
<tr>
<td>23</td>
<td>PR</td>
<td>PMC13389OZ</td>
<td>65</td>
<td>1,575</td>
<td>LITHIUM-ION BATTERY, PAINT, AMINES LIQUID CORROSIVE, AUTOMOTIVE PART, PHOTO COLOR RESIST, FLAMMABLE LIQUID</td>
<td>DG Loaded</td>
</tr>
<tr>
<td>24</td>
<td>ML</td>
<td>PMC11978OZ</td>
<td>161</td>
<td>1,790</td>
<td>FLAMMABLE LIQUID, PCB, CMOS, DG</td>
<td>DG Loaded</td>
</tr>
</tbody>
</table>
## Table 11 Cargo Manifest of AAR991

<table>
<thead>
<tr>
<th>Loading Order</th>
<th>ULD</th>
<th>Packages (No.)</th>
<th>Weight (kg)</th>
<th>Main Content</th>
<th>Port of Loading/Remarks</th>
</tr>
</thead>
<tbody>
<tr>
<td>Order of Loading Cargo on the Lower Deck</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>23P</td>
<td>PMC13363OZ</td>
<td>60</td>
<td>1,730 SHAFT SUB ASSYETC, IC DRIVER SOURCE, WOVEN FABRIC</td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>22P</td>
<td>PMC15460OZ</td>
<td>8</td>
<td>1,680 DENSE LOADER, EITAXIAL WAFER TFT DISPLAY GLASS SCREEN, CASE POLE SPACER B o t o m, BRAZE FILLER PASTE MASS FLOW EQUIPMENT</td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>21P</td>
<td>PMC12799OZ</td>
<td>24</td>
<td>1,182 IC DRIVER SOURCE, CLEANING DISK, MULTI LCD INSPECTION EQUIPMENT, FILM GUIDE, TEXTILE FABRICS WOVEN</td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>11P</td>
<td>AAP06606OZ</td>
<td>150</td>
<td>1,545 PHOTOMASK, HYNIX MEMORY CHIP, MASK, CIS WAFER</td>
<td></td>
</tr>
<tr>
<td>5</td>
<td>12P</td>
<td>PMC15494OZ</td>
<td>4</td>
<td>2,584 POLARIZING FILM</td>
<td></td>
</tr>
<tr>
<td>6</td>
<td>31P</td>
<td>PMC15520OZ</td>
<td>5</td>
<td>1,910 POLARIZING FILM</td>
<td></td>
</tr>
<tr>
<td>7</td>
<td>32P</td>
<td>PMC13821OZ</td>
<td>36</td>
<td>2,415 AUTO PARTS SEAL, COMPUTER PARTS, SAFEELIA PIT EM150 (PRODUCT NAME), BOBBIN ASSEMBLY, TEXTILE FABRICS, WOVEN FABRIC, SATELLITE RADIO PART</td>
<td></td>
</tr>
<tr>
<td>8</td>
<td>41P</td>
<td>PMC12697OZ</td>
<td>19</td>
<td>2,650 PMC PALLET STACK (PMC OZ) 10699, 11508, 12617, 13173, T3473, 13853, 14126, 14384, 14771, 14864, 15104, 15161, 15455, 15497, 15520, 15845, 15860, 15917, 16136</td>
<td></td>
</tr>
<tr>
<td>9</td>
<td>43L</td>
<td>AKE20493OZ</td>
<td>36</td>
<td>363 MEMORY, SYSTEM LSI</td>
<td></td>
</tr>
<tr>
<td>10</td>
<td>43R</td>
<td>AKE28149OZ</td>
<td>15</td>
<td>363 IC, SYSTEM LSI</td>
<td></td>
</tr>
<tr>
<td>11</td>
<td>44L</td>
<td>AKE21128OZ</td>
<td>18</td>
<td>440 EXPRESS CARGO</td>
<td></td>
</tr>
<tr>
<td>Total Weight of Cargo</td>
<td>65,938</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

### 1.18.3 Dangerous Goods

As shown in [Table 12], dangerous goods loaded on the accident flight were products of 6 companies covered under 8 master airwaybills. All of these shipments were loaded on the main cargo deck. Two of them, photo-resist/IC,
were located on the pallets situated in positions ML and PR, and the remaining 5 shipments were located on the pallet situated in position PR. Both positions ML and PR were adjacent to the main deck side cargo door. The dangerous goods included flammable liquids, corrosive liquids, and lithium-ion batteries.

<table>
<thead>
<tr>
<th>Dangerous Goods</th>
<th>AWB No. 988</th>
<th>Port of Departure</th>
<th>Total weight (kg)</th>
<th>Net Q'ty*</th>
<th>Item Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lithium-ion batteries</td>
<td>-63857393</td>
<td>Osaka, Japan</td>
<td>258.6</td>
<td>243.6 kg</td>
<td>-Lithium-ion battery for hybrid automobile</td>
</tr>
<tr>
<td>Photo-Resist/IC</td>
<td>-68738121</td>
<td>Incheon</td>
<td>114</td>
<td>41.58 L</td>
<td>-Sensitizing solution for raising the sensitivity of semiconductor</td>
</tr>
<tr>
<td></td>
<td>-68738110</td>
<td></td>
<td>386</td>
<td>166.32 L</td>
<td></td>
</tr>
<tr>
<td></td>
<td>-68738132</td>
<td></td>
<td>621</td>
<td>272.16 L</td>
<td></td>
</tr>
<tr>
<td>Photo-Resist/LCD</td>
<td>-68693542</td>
<td>Incheon</td>
<td>679</td>
<td>477 L</td>
<td>-Liquid synthetic resin for coating LCD panel</td>
</tr>
<tr>
<td>Amines Liquid Corrosive N.O.S.</td>
<td>-68119586</td>
<td>Incheon</td>
<td>8</td>
<td>5 L</td>
<td>-Anti-static agent for preventing static electricity</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>-Mixed liquid for preventing dust from attaching to paint and impurities from attaching to various products</td>
</tr>
<tr>
<td>Paint</td>
<td>-68527056</td>
<td>Incheon</td>
<td>22</td>
<td>12 L</td>
<td>-Paint for damp proof insulation of electronic circuit</td>
</tr>
<tr>
<td>Inspection Seal Lacquer</td>
<td>-68019571</td>
<td>San Francisco, US</td>
<td>3</td>
<td>0.236 L</td>
<td>-Seal lacquer for preventing loosening of bolt/nut</td>
</tr>
</tbody>
</table>

* Net weight or volume of the dangerous goods before packed.

[Table 12] Dangerous Goods Loaded on AAR991

1.18.3.1 Lithium-ion Batteries

A lithium-ion battery is a secondary battery\(^{77}\), which uses a lithium salt in an organic solvent, consisting of positive and negative electrodes, thin film, electrolyte, and a container. The positive electrode is a metal oxide, and the negative one is made from carbon. They are used to coat a thin film of aluminum and copper, respectively, thereby forming electrode plates after being dried. According to a metal oxide, lithium-ion batteries are categorized into LCO (Co), NCM (Ni, Cd, Mn), NCA (Ni, Co, Al), LMO (Ni, Mn), and LFP (Ni, Fe, P).

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\(^{77}\) Electric energy storage device which can recharge and discharge repetitively.
Lithium-ion batteries shipped onboard the accident airplane were regulated as Class 9\textsuperscript{78}) UN3480, Packing Group II, dangerous goods. They were in either a 6-cell or 12-cell configuration for use in hybrid electric vehicles. The individual cells were rated at 24.4 - 24.8 Ah at 3.65 volts and 89.1 - 90.5 Wh. The shipment contained a total of 18 lithium-ion batteries, including 15 of the 12-cell configuration and 3 of the 6-cell configuration.

As shown in [Figure 51], 12-cell batteries were packed 1 per box in 15 fiberboard boxes, whereas 6-cell batteries, 2 per box in 2 fiberboard boxes, and the remaining one was packed individually, so there was a total of 17 fiberboard boxes. The entire shipment was prepared on a single pallet wrapped in plastic and loaded at the main deck PR position.

\textbf{[Figure 51]} 12-Cell (Left) & 6-Cell (Right) Lithium-ion Batteries

\textbf{[Figure 52]} 1-Cell Battery

\textsuperscript{78}) Class 9 is classified by ICAO as miscellaneous dangerous substances and articles including lithium-ion batteries, dry ice, etc.
[Figure 52] above shows a 1-cell battery measuring 148×91×26.5 mm and weighing 0.69 kg. The manufacturer stated, in case of a battery fire, it can be extinguished by carbon dioxide, nitrogen, water, and powder extinguishant (ABC extinguishant).

1.18.3.1.1 Results of Testing Lithium-ion Batteries by the Manufacturer

The lithium-ion battery manufacturer provided data in relation to the testing of 50 cells produced between 2 March and 14 May 2009 according to the method and standards prescribed in the "UN Recommendations for Transport of Dangerous Goods."

- The manufacturer's test report indicated the cells were subjected to an altitude simulation test, thermal test, vibration test, shock test, external short-circuit test, impact test, overcharge test, and forced discharge test, and that they passed all of them.

In addition, one of the lithium cells produced from each lot79) was extracted randomly to conduct tests such as nail penetration, submergence, and contact with chemical substances, and all the tests showed no exceptions that would lead to thermal runaway or fire.

The nail penetration test simulates a worst case failure by short-circuiting the battery at 10% and 100% state-of-charge (SOC). Based on a risk assessment from this testing regime, the manufacturer has adopted 10% SOC as the standard for all of its lithium-ion battery shipments.

1.18.3.1.2 Manufacturer's Inspection Before Packing

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79) Product unit of a specific number produced in one batch.
The manufacturer stated that each battery produced is subjected to quality assurance inspections before packed for shipment, and added that cells and stacks loaded onboard the accident aircraft all passed them.

- Cell inspection items are visual inspection, insulation film condition inspection, internal short-circuit inspection, and physical characteristics inspection.
- Stack inspection items are size inspection, weight inspection, and visual inspection.

1.18.3.1.3 Packing Container

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

The packing containers used for the lithium-ion battery shipment were specification 4G/Y40 fiberboard boxes. The packing weight limit for each box used for Packing Group II materials, such as lithium-ion batteries, was 40 kg.

The manufacturer stated the reason for packing at or below 40% of the packing weight limit was that the safety margin was taken into consideration. Under the ICAO Technical Instructions for the Safe Transport of Dangerous Goods by Air, the lithium-ion per package quantity limitation for cargo aircraft is 35 kg.

1.18.3.1.4 Packing and Shipping

The produced batteries have the terminals covered with insulating material to prevent external short-circuit in transit and are packed as shown in [Figure 53].
The polyethylene wrapping has a melting point of 122 ℃.

![Figure 53] Batteries Wrapped in Plastic

The lithium-ion batteries were wrapped with polyethylene and secured with fiberboard inner packaging material fit for the shape of the battery. A sheet of impact-resistant bubble wrap was placed in the top of the box and closed to complete the packaging.

The manufacturer stated that the product is kept in a separate place with temperatures between 20 - 30 ℃ before shipping, that humidity does not affect battery performance, and that there had been no abnormal cases during sea, land, and air transport of the lithium-ion batteries. [Figure 54] shows the final packaging of lithium-ion battery shipment in a production plant.

![Figure 54] Final Packaging of Lithium-ion Battery Shipment
1.18.3.2 Photo-Resist/IC

This product is used for integrated circuit (IC) manufacturing and is regulated as Class 3 UN1993, Packing Group III, flammable liquid. As shown in [Figure 55], transparent photo-resist solution was contained in either a purple- or yellow-labeled glass container. The dangerous goods declaration indicates that packaging was in accordance with ICAO TI Packing Instruction 366.

![Purple & Yellow-Labeled Containers](image)

The main component in product is propylene glycol monomethyl ether acetate (PGMEA), which makes up 50 or more percentage of its weight.

The product is stored and transported between 0 and 10°C. The safety of the product is not affected by temperatures that exceed 10°C, but the quality of the product is compromised and no longer marketable. The manufacturer said that it is not necessary to maintain the aircraft cargo compartment at a specific temperature since the product is packed so as to maintain optimum temperature until destination.

The MSDS\textsuperscript{80)} indicates the following: the flash point\textsuperscript{81)} of the product is 4

\textsuperscript{80) Material safety data sheets (MSDS) conform to the United Nations' Globally Harmonized System of}
2°C; high-temperature heat, sparks, and flames should be avoided during handling; explosion proof facilities should be used; and acrid smoke and poisonous gases are generated if the product is exposed to high temperatures or during fire.

The shipment included a total of 127 brown glass containers (1 gallon per container). These containers were covered with black plastic bags. Four (82) of these glass containers were placed in one UN specification fiberboard box into form-fitted Styrofoam blocks (providing 360° bracing and maintaining temperature) with blue ice and a digital temperature recorder to keep the product cold. There was a total of 32 fiberboard boxes packaged in such a way.

The manufacturer handled the process from packaging to loading the product onto a transport vehicle. Yet its person in charge of DG packaging was not aware of the dangerous goods handling procedures and just understood that the product should be safely handled in a special custom-made box (UN specification) to be protected from damage in transit.

The manufacturer contracted the third-party dangerous goods handling agent approved by the Korean government on 20 June 2011 to transport the boxes by land, and the agent completed the shipper's declaration for dangerous goods without opening any of the boxes.

They were loaded on pallets at positions ML and PR. Five overpacks (83) made by binding 29 small packaging boxes were loaded at ML, and one overpack made by binding three small packaging boxes was loaded at PR.

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Classification and labelling of Chemicals. The MSDS outlines the dangers, composition, safe handling, and disposal of hazardous chemicals.
81) A flash point is the lowest temperature at which a product can vaporize to form an ignitable mixture in air.
82) Three glass containers were contained in one fiberboard box.
83) Repacking with wood or strong protective material for protection or transport convenience.
1.18.3.3 Photo-Resist/LCD

This product is a highly flammable liquid and is regulated as Class 3 UN1866, Packing Group III, flammable liquid. The dangerous goods declaration indicates that packaging was in accordance with ICAO TI Packing Instruction 355. The main component in product is propylene glycol monomethyl ether acetate (PGMEA), which makes up 50 - 60% of its weight, and is similar to the aforementioned photo-resist solution.

The MSDS indicates that the flash point of the product is 43 - 47°C and that the product may explode in the case of heating. Photo-resist is used for LCD manufacturing, and it is either a bright blue or bright red liquid, designated by the "B" or the "R" in the product name. The integrity of the product is sensitive to temperature and light.

The product was contained in 53 brown plastic 10-liter containers, each of which was filled with 9 liters of a blue or red liquid. As shown in [Figure 56], the containers were each enclosed in clear plastic bags and were packed 2 per 1 fiberboard box inside Styrofoam inserts with blue ice to keep the product cold. There was a total of 27 fiberboard boxes. The manufacturer packed two digital temperature recorders\(^ {84}\) with each bulk shipment to ensure safe transportation and prevent the product from being compromised.

These 27 boxes were contained within three\(^ {85}\) fiberboard box overpacks and loaded on a pallet at position PR.

These plastic containers are made of high-density polyethylene with a polyethylene screw cap that has a Teflon coated gasket. They were subjected to

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84) This temperature gauge can check only the highest temperature inside of the box to confirm the marketability of the product.
85) Ten fiberboard boxes each packed into two overpacks and seven fiberboard boxes packed into one overpack.
a 12-hour inverted leak test, a 120 cm high drop test, and a 20 Kpa pressure test for 5 minutes.

![Figure 56] Photo-Resist & Internal Packaging of Each Package in Shipment

This product is stored at 5°C in the manufacturer's facility and transported in a refrigerated truck to a dangerous goods handling agent. The safety of this product is not affected by temperatures that exceed 5°C, but the quality of the product is compromised and no longer marketable.

The manufacturer's person in charge stated that they have not had any leaking containers in 8 years of shipping this product, and that no containers had been returned due to a defective product.

1.18.3.4 Amines Liquid Corrosive N.O.S.

This product is a corrosive liquid and is regulated as Class 8 UN2735, Packing Group III, corrosive material. The dangerous goods declaration indicates that packaging was in accordance with ICAO TI Packing Instruction 856. The main component is ethoxylated alkylamines, which makes up 90% of its weight. Its flash point is greater than 100°C.
The MSDS indicates that the product has no special risks of flammability or explosion. It is a clear colorless liquid.

The product was supplied to a domestic company by a French company, and was repackaged and transported through a cargo agent. The cargo agent classified the product, selected packaging materials, and completed the shipper's declaration for dangerous goods. The cargo agent packed dangerous goods every three months on behalf of the domestic company. The agent's person concerned stated that he checked the plastic containers for leakage prior to further packaging activities, and that they have not had any product in an unsatisfactory condition, i.e. a leaking container.

This shipment consisted of one 5-liter plastic container. This container was placed into a plastic bag which was then tied closed, and as shown in [Figure 57], Styrofoam sheets were form fitted around the container within the fiberboard box with "Corrosive" labels affixed. The shipment was loaded at ULD position PR.

[Figure 57] Exemplar Final Packaging of Amines
1.18.3.5 Paint

This product is provided by a Japanese supplier to a domestic company which supplies it to the Asian region through a distribution company. It is regulated as Class 3 UN1263, Packing Group II, flammable liquid. The dangerous goods declaration indicates that packaging was in accordance with ICAO TI Packing Instruction 364. The main component in product is Ethylcyclohexane, which makes up 50 - 60% of its weight.

The MSDS indicates that it has a flash point of -1°C and that vapor may form an explosive mixture in air, exceeding -1°C. It is a blue transparent liquid. The product should be stored at temperatures below 35°C (below 25°C according to the AWB).

The shipment included a total of 12 metal containers of product (open or close by screwing the metal lid), each with 1 liter of product. As shown in [Figure 58], the containers were packed 12 per box inside Styrofoam inserts.

[Figure 58] Exemplar (Left) & Final (Right) Packaging of Paint

The products were packed in one UN specification 4G fiberboard box and overpacked. The shipment was loaded on a pallet and transported to a dangerous goods handling agent. The agent visually inspected the shipment on the pallet.
for damage and attached "flammable" labels, and completed the shipper's declaration for dangerous goods. The entire shipment was loaded at ULD position PR.

1.18.3.6 Lacquer for Seal Inspection

This product is a colored paste and is regulated as Class 3 UN1263, Packing Group III, flammable liquid. The dangerous goods declaration indicates that packaging was in accordance with ICAO TI Packing Instruction Y344. The main component in product is ethanol, which makes up 30 - 60% of its weight. It has a flash point of 42.8°C.

As shown in [Figure 59], the shipment included a total of 16 plastic tubes of product, approximately 15 grams per tube, and the total amount of product was 0.236 liters. The tubes of the product were packed in one fiberboard box with "flammable" labels affixed. The shipment was located on a pallet in ULD position PR.

[Figure 59] Final Packaging of Torque Seal Shipment & the Product

1.18.4 Statements of the Cargo Handlers

The Cargo Group interviewed the Asiana loadmaster and 9 Asiana employees
who handled the dangerous goods shipments and obtained written statements, the content of which is as follows:

As part of Asiana's cargo shipment acceptance process, all of these shipments were x-rayed at the Asiana Airlines cargo terminal of Incheon Airport, with the exception of the lithium-ion batteries which departed Kansai International Airport in Japan and the lacquer which departed San Francisco International Airport in the US.

Out of the dangerous goods in [Table 12], the photo-resist solutions\(^{86}\) of the two companies described in 1.18.3 were temporarily stored in the cool room at the Asiana facility prior to being loaded onto the two pallets. The lithium-ion batteries\(^{87}\) and three dangerous goods\(^{88}\) including paint and lacquer were stored in Asiana's temporary DG storage area which is a permanent area for storing the dangerous goods in isolation from other general cargo. This area is also used to temporarily store the dangerous goods shipments in transit or for export, prior to being loaded onto pallets.

On 27 July 2011, about 22:05, the dangerous goods were collected for placement on two pallets. Asiana Airlines' employee in charge of handling transit cargo inspected packaging, labelling, marking, and related documents of the lithium-ion battery shipment. Then, the shipment was brought to the build-up area\(^{89}\) in the warehouse.

After loaded on a pallet, the shipment is normally wrapped in plastic twice, but at the time, it was done so three times due to rain forecast. Around 23:30, the build-up of the two pallets was completed. The loadmaster then signed for

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86) MAWB No.: 988-68738110 (2), 988-68738132 (3), 988-68693542 (3), and 988-68738121 (1).
87) MAWB No.: 988-63857393 (1).
88) MAWB No.: 988-68119586 (1), 988-68527056 (1), and 988-68019571 (1).
89) A build-up area does not mean a specially designated separate area, being a place in the warehouse where loading of export cargo is carried out.
the dangerous goods shipment, and the two dangerous goods shipment pallets were weighed and loaded.

Neither the loadmaster nor any of the nine cargo handlers noted any damage, leakage, or other problems with the dangerous goods shipments during the cargo checks in their statements.

The CCTV images on the left in [Figure 60] and [Figure 61] show the two dangerous goods pallets, PMC11978OZ and PMC13389OZ, which were being transported to be loaded into ULD positions ML and PR, respectively, on 28 July, about 00:47. The images on the right in [Figure 60] and [Figure 61] show the simulations of the build-ups of the two dangerous goods pallets, which were created based on the Asiana cargo handlers' recollection of package positioning on the pallets.

The two pallets of dangerous goods were loaded onto the airplane between around 01:00 and 02:00 on 28 July 2011. At about 02:15, the captain of AAR991 was then informed of the nature of the dangerous goods shipments onboard by the loadmaster, and was escorted to the two dangerous goods pallets in ULD positions ML and PR.

[Figure 60] CCTV Image (Left) & Simulation of Build-up (Right) of Pallet PMC11978OZ (ULD Position ML)
[Figure 61] CCTV Image (Left) & Simulation of Build-up (Right) of Pallet PMC13389OZ (ULD Position PR)

At approximately 02:30, the captain signed the Notification to Captain for special load (NOTOC\(^{90}\)), weight & balance sheet, load manifest, and cargo loading check list.

1.18.5 Maintenance and Repair of Cargo Container/Equipment

The maintenance records for the ULDs that were loaded on the accident airplane were reviewed. The records cover any maintenance issues that arose over the past year. No uncorrected defects were noted. All reported damage had been repaired in accordance with the supplier's instructions.

On 11 August 2011, the Cargo Group visited Asiana's cargo facility at Incheon Airport. During the visit, the conditions of approximately 20 ULDs were checked while observing cargo loading on a 747-400SF (HL7414) airplane that is similar to the accident aircraft. Approximately 20 ULDs were checked and found

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\(^{90}\) A document that notifies the captain of dangerous goods and other special load (animals/DG, etc.) among all shipments at the cargo departure airport. NOTOC lists the location and quantity of cargo, type of packaging, and procedures to follow in the event of an emergency, which are in accordance with international standards (Technical Instructions for the Safe Transport of Dangerous Goods By Air by ICAO, Part 7, 4.1).
to be all serviceable.

Some of the containers had visible repairs. The pallet nets were all found to be serviceable and properly installed.

Approximately 25 ULDs in the Asiana warehouse were checked, and all were serviceable. So were two AKE containers in the warehouse.

Asiana Airlines installs a thick protective plastic sheet under flammable liquid cargo, in addition to the two sheets of thinner plastic used to cover the palletized loads, as a means of preventing any possible leakage and also for security reasons.

1.18.6 Cargo Handling System

The main deck cargo handling system of the accident airplane, which consists of drive units, conveyance, and restraints, was manufactured by Telair International and was installed under an FAA issued Supplemental Type Certificate (STC).

The Cargo Group checked the maintenance records for the main deck and lower cargo handling systems for the accident airplane. These maintenance records covered repair history for the last two years. Review of these records revealed only normal maintenance of the systems.

On 11 August 2011, the Cargo Group visited Asiana's cargo facility at Incheon Airport. During the visit, the group checked the conditions of the cargo handling system on B747-400SF (HL7414), which was found to be serviceable.

1.18.7 Dangerous Goods Handling Procedures
Asiana Airlines' cargo handling procedures conform to international and domestic standards. All air cargo procedures are documented in the Asiana Cargo Service Operation Procedure in its current revision. More specifically, standards of the DG, transport documents, cargo handling and loading, and dealing with accidents are referenced in Chapter 9 of this manual.

In addition to the aforementioned procedures, Asiana Cargo at its Incheon Airport facility has additional guidance in the form of an "Additional Dangerous Goods Handling Procedures to IATA Dangerous Goods Regulations (DGR)", last revised in August 2011. This guidance also includes specific procedures utilized by Asiana Cargo acceptance personnel to prevent the acceptance of undeclared dangerous goods.

Cargo agents intending to offer dangerous goods shipments at Asiana Cargo's Incheon facility are required to register with the air carrier as a "Dangerous Goods Handling Agent" by submitting IATA Dangerous Goods Regulations (DGR) training completion documentation for personnel involved with preparing documentation and inspecting dangerous goods shipments, prior to offering to Asiana Cargo.

As of the day of the accident, Asiana Cargo has a roster of 96 freight forwarder/cargo agent entities approved to offer dangerous goods cargo at its Incheon facility.

All dangerous goods must be tendered loose to be visually examined. Asiana Cargo dangerous goods specialists, using the DG acceptance checklist made by Asiana Airlines on the basis of IATA DGR, carry out DG acceptance inspection. More specifically, they inspect documentation, packaging conditions, marking, and labelling of the DG in accordance with the checklist.
Since the dangerous goods need to be isolated due to their different characteristics from those of general cargo, an employee is separately allocated for access control. During acceptance/release of the dangerous goods, the external conditions of the dangerous goods packaging are checked while the records of acceptance/release are maintained. To prevent a leakage during transport of liquid dangerous goods, a company regulation requires the shipments to be overpacked.

The dangerous goods are barred from being loaded onto a bulk cargo compartment where ULDs are not used. After the dangerous goods are loaded, a checker and a loadmaster separately prepare and sign their own dangerous goods field checklist for confirming the following: packaging conditions when loaded; dangerous goods recognition tags; regulations on DG segregation; damage; documentation; compliance with loading regulations; and preparation of NOTOC. The dangerous goods recognition tags for DG shipments in positions ML and PR contain such information as DG class, UN number, weight, and exclusive transportation by freighter. These tags are hung on the pallet nets instead of being affixed.

### 1.18.8 Interview with Asiana Airlines Flight Crew and Others

From 4 August 2011 through 11, the Operations Group investigators, a captain from the Boeing Company, and Asiana Airlines' persons concerned carried out interviews with a total of 15 people including a simulator instructor and pilot examiner, captain, first officer, flight dispatcher, emergency equipment ground school instructor, dangerous goods instructor, and line mechanic.

The following is the summaries of the interviews about Asiana flight crew's fire-related training, etc.

- Simulator Instructor, etc.
Boeing contract instructors teach Asiana Airlines' procedures as well as evaluate trainees, and must have a Korean pilot license. They are also required to ride the cockpit jump seat biannually.

Asiana Airlines' simulator is configured as a B747-400 passenger aircraft, mirroring HL7418. There is no Fire Main Deck non-normal malfunction option on the instructor panel, and the overhead panel switch does not have the cargo depressurization option.

Instructors use a schematic from Asiana FCOM to simulate the Fire Main Deck scenario. The instructor has students point to the switch they would be pushing to activate the main deck depressurization.

**B747-400 Captains**

According to the statements of B747-400 captains, Fire Lower Deck procedures were included in the simulator training syllabus in the second half of 2011.

When asked about when was the last Fire Main Deck training, two captains answered they did not remember. During the Fire Main Deck training, when the instructor gives the situation, pilots follow the QRH checklist and "imagine" that the simulator is a cargo airplane at time of the scheduled fire because the Asiana simulator is a passenger configuration. Before entering the simulator, the instructor discusses the cargo fire with trainees and teaches them three buttons for the Fire Main Deck in the briefing room. In the simulator, the instructor sets the situation (cargo fire), and messages then come up for the "lower cargo fire", but not the main deck. Pilots follow the Fire Main Deck checklist and don the

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91) Fire simulation artificially made by the instructor in the back seat.
92) The accident flight crew’s simulator training in the second half of 2011 was scheduled after the accident.
O2 mask. The 25,000 feet level off in the fire main deck checklist is a procedure, and depressurization results in a lack of oxygen.

Asiana’s O2 masks are all full face masks. One of the captains was trained on O2 masks from Boeing when he first received his B747-400 training. O2 masks are trained at Asiana in ground school by use of hood for PBE training instead of the actual airplane O2 masks. During initial ground and recurrent training, they are learned from textbooks. During preflight, 100 percent and normal switches on the O2 mask module are checked, and so are the emergency knob and O2 flow pressure.

Captains received information on the dangers of lithium-ion batteries and in-flight fire in ground school, and several relevant notices have been posted on the Intranet. The last notice one captain remembered was the one about a call for caution in dealing with lithium-ion batteries.

In the simulator, instructors instruct pilots to don O2 masks[^93].

When a captain operates a cargo airplane, he checks with NOTOC and cargo loading, then walks around to inspect the dangerous goods after the cargo is loaded.

**B747-400 First Officer**

He said captains conduct walkarounds on the aircraft while first officers check the cockpit. When he had his last trip with the captain of the accident airplane, the captain walked around the aircraft and checked the main deck, as required. He stated that captains check the security of cargo and ceiling clearance (2 inches) during their walkarounds.

[^93]: One pilot stated that sometimes he would practice donning the mask but it was not required during simulator training, and that it would depend on the instructor.
He said dangerous goods are also checked based on NOTOC, and that crew members should be aware of where they are loaded.

○ **B747-400 Chief Pilot**

He said since you cannot practice Fire Main Deck in a simulator, Boeing instructors inform trainees of a Fire Main Deck situation and have them imagine it. They help them note the differences by using FCOM.

He said training changed after the fatal UPS 6 crash in 2010 to include "cargo fire" in the training syllabus.

○ **B747 Flight Dispatcher**

When asked why the flight was carrying extra fuel (tankering94)), he said it was normal when flying to China since fuel was expensive there and it was cheaper to carry it.

○ **Manager of B747-400 Training Program**

He made the simulator profiles as well as LOFT scenarios and ground school schedules as per flight crew training regulation (FCTR). He develops the draft program, then sends it to Boeing for review. When the review process is completed after two months of discussion over the content, the final program is finally made.

The subject of Lower Cargo Deck Fire was integrated into the recurrent simulator training in the second half of the year due to the idea of the UPS 6 accident in 2010.

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94) Policy of loading extra fuel for the next flight at the airport where fuel price is low.
○ Line Mechanic

After the accident airplane arrived at Incheon Airport, he saw the cargo being off-loaded and found nothing unusual. He did not know if the cargo contained dangerous goods and did not see any damaged cargo. He did some checks in the main deck when the aircraft was empty, but there was no damage to the main deck, let alone fluid on the floors.

He ran a transition checklist on the aircraft between flights. He said there were no defect items, and that the weather was clear with no rain during ground inspection.

○ Emergency Equipment Ground School Instructor

Pilots receive emergency equipment training once each year, which is delivered through PowerPoint presentations and videos, and they practice with a real life jacket, PBE, and fire extinguisher. The emergency exit door and raft, and emergency survival equipment are trained every year. Fire extinguisher training is just "pretend" and not with a live fire. Emergency evacuation training is carried out every three years.

○ Dangerous Goods Instructor

He said an Emergency Response Drill Guide indicating crisis response for captains is kept in the cockpit, along with NOTOC. Additional information about the dangerous goods on the aircraft comes from the shipper's declaration.

He stated that in 2010, Asiana pilots received a lot of lithium-ion battery-related training, including the dissemination of the UPS 6 accident in 2010.
2. Analysis

2.1 ACARS CMC Messages

Among the ACARS CMC messages received from AAR991, maintenance messages in relation to FDE messages were interpreted according to the maintenance manual. This interpretation, which can be found in Appendix 1, consists of the following: time a related maintenance message first became active; maintenance message number; message content; intermittence; activity; related FDE message and number; and FDE level. It also describes required conditions for a message, meaning of a message, and content of a related FDE message.

Analysis of the ACARS messages received by the ground station revealed that, at 03:53:XX, the first fault messages were detected in fire zone 11 at the aft main deck compartment and the E/E compartment.

The FDE message, "CGO DET 11 MN DK," was generated in relation to the maintenance message, "CARGO FIRE MAIN DECK ZONE-11 LOOP-A FAIL." This LOOP-A FAIL message can appear when the following conditions are met: ① The zone 11A detector was in alarm for at least 8 seconds without the Zone 11B detector being in alarm; ② The 11A detector failed to pass a "disagree" test from the zone 11 AFOLTS card; and ③ The wire from the zone 11A detector to the AFOLTS was open circuit when a "disagree" test was performed. Because this fault was correlated to "CGO DET 11 MN DK" and not to "MD CGO 11 LP A," the zone 11B detector was in alarm or faulted within 20

95) Levels: Warning, Caution, Advisory, Status.
96) XX indicates that seconds are unknown.
97) They are eight printed circuit cards installed in the E/E compartment, which offer the interpretation of the fire detected signal, system function inspection, fire alarm output, fire detection system's error direction, etc.
98) "MD CGO 11 LP A" was not generated since loop A in the zone 11 was not faulted. In other words, it is assumed that fire was detected.
seconds of the zone 11A detector.

The above message would be consistent with zone 11A and zone 11B detectors being in alarm (detecting smoke) more than 8 seconds but less than 20 seconds apart. In other words, two detectors in zone 11 detected smoke almost at the same time, which, the ARAIB assumes, indicates that there was an in-flight fire near the zone 11 detectors.

The E/E compartment is cooled by a suction fan which draws air from the forward lower lobe left cheek and an exhaust fan which emits air that became hot after passing through the E/E compartment. "EQUIP COOLING" is an EICAS Caution level FDE message that informs the pilots of a problem with the E/E compartment cooling system. One of the several ways this message is generated is when the "EQUIPMENT SMOKE" message, which indicates smoke is detected within the E/E compartment, is displayed for more than 3 seconds.

Subsequently, at 03:54:XX, CGO DET 6 MN DK and CGO DET 10 MN DK messages were displayed, followed by CGO DET 3, 4, 5, 7, 8, and 16 MN DK messages at 03:55:XX. The ARAIB assumes that these messages indicate an in-flight fire, like CGO DET 11 MN DK message.

At 03:56:XX, three FDE messages - PACK 2, PACK 3, and SATCOM - were displayed, which indicates the pilots implemented the Fire Main Deck procedures in the QRH.

At 03:56:XX, the autopilot was disconnected.

From 03:57:23 to 03:59:29, AAR991 descended from 22,700 ft to 13,400 ft. Turbulence data was transmitted four times in total at 03:57:23, 03:57:43, 03:57:43, 03:57:23.
03:58:47,\textsuperscript{(101)} and 03:59:29,\textsuperscript{(102)} According to weather data and the statements of the pilots who flew over the accident site, there were a weak wind and a clear sky with no cloud accompanied by turbulence or rain over the accident site. Thus, the ARAIB assumes that these four turbulences resulted from the fire's rapid propagation.

After 03:57, the wire running at both upper section near the scene of a fire or under the main deck cargo floor was likely short or open circuit due to the fire. FDE messages associated with system faults are generated by the signal sent through the wire to the EIUs and CMC.

Since the wire, when damaged, is likely to be short or open circuit, faulty signals can be sent to the CMC or EIUs, thereby generating FDE messages. Thus, many of the FDE messages transmitted via ACARS cannot be seen necessarily consistent with actual situations. For example, the message "ELT ON" is generated when the pilots turn on the ELT or when it automatically activates with the impact of 5G and more. Although AAR991 flew for more than 10 minutes after the message was generated, however, its distress signal was not received by the ground stations. Thus, the ARAIB assumes that the message did not mirror an actual situation.

In addition, messages, "DET APU FIRE," "BAT DISCH APU," and "APU" are generated when there is a fault with a fire detector, battery discharge, and a fault with a duct, respectively. The APU was irrelevant to the main deck cargo fire due to the APB and APU firewall, and wreckage examination did not find any evidence of fire. Thus, the ARAIB assumes that the messages generated after 03:57 did not likely reflect actual situations.

From 04:00 until the crash, ACARS messages were not received at all. The

\textsuperscript{101)} 03:58:47 - altitude 16,000 ft, speed 454 kt, heading 344°.
\textsuperscript{102)} 03:59:29 - altitude 13,400 ft, speed 453 kt, heading 011°.
ACARS messages are transmitted via SATCOM and VHF3. The SATCOM system was not in operation at 03:56 when the pilots implemented fire suppression procedures in response to a cargo fire, and thus, the reasons why the messages stopped being transmitted after 04:00 were as follows: ① ACARS MU was so damaged that the messages could not be generated; ② the pilots selected VHF3 to use for voice communications; and ③ VHF3 was inoperable.

According to Asiana's FOM 13.5.2.2 (Data Communications Network Maintaining Procedures), VHF3 shall not be used for voice communications with ATCs in normal times since the use of VHF3 during the operation of the ACARS will stop ACARS messages from being transmitted. Therefore, it is determined that the pilots did not use VHF3 for voice communications. It is likely that the ACARS computer was not powered or damaged.

2.2 Operation Issues

2.2.1 Awareness of Fire and Decision to Divert

At 03:53:XX when ACARS messages, CGO DET 11 MN DK, EQUIPMENT SMOKE, and EQUIP COOLING, were generated, AAR991 was cruising at 477 kt at an altitude of 34,000 ft on a heading of 202°. At 03:54:23, while flying 219°R/125 nm (231 km) from Jeju Airport and 075°R/165 nm (305 km) from Pudong Airport, the airplane declared an emergency due to a main deck cargo fire and requested a descent to 10,000 ft. At 03:55:08, AAR991 notified its intention to divert to Jeju Airport to SHI ACC.

At 03:54:37, SHI ACC gave AAR991 a descent clearance and instructed it to turn at its discretion. ARR991 started descending about 03:54:59, about 1 minute and 59 seconds\(^{(103)}\) (maximum time difference) after 03:53:XX when the first

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\(^{(103)}\) As EICAS fault messages are time stamped in hours and minutes, seconds are not provided. Therefore, there is a time error of maximum - 60 seconds when an EICAS fault message and its
ACARS message was generated. The airplane started turning right for diversion about 03:56:12\(^{104}\) when flying at 28,200 ft, about 3 minutes 12 seconds (maximum time difference) after 03:53:XX. It continued to descend at a steep angle\(^{105}\) from 34,000 ft\(^{106}\) to 8,200 ft for about 6 minutes and 55 seconds.

### 2.2.2 History of Flight Control Based on ACARS Messages

At 03:53:XX, when AAR991 was cruising at 477 kt at an altitude of 34,000 ft on a heading of 202°, ACARS messages, CGO DET 11 MN DK, EQUIPMENT SMOKE, and EQUIP COOLING, were generated, followed by many other messages. About 03:54:59, the airplane started descending from 34,000 ft.

[Figure 62] shows AAR991's vertical flight track, altitude, speed, heading, and major ATC/pilot communications. The FDE message CGO DET 11 MN DK, which indicates that smoke was detected in zone 11 of the main deck cargo compartment, is transmitted when it is correlated to the CMC fault message.

The ARAIB concludes that the EICAS message "FIRE MAIN DECK AFT" must have been displayed in the cockpit, but this message was not transmitted to the ground via ACARS since it was not correlated to the fault message.

At 03:56:XX,\(^{107}\) AAR991 was descending from 28,200 ft to 23,900 ft. At this time, ACARS messages, PACK 2 and PACK 3, were generated by the

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\(^{104}\) Heading 258°.

\(^{105}\) Sink rate/min: about 3,700 fpm/5,600 fpm/3,900 fpm/4,900 fpm/3,500 fpm/2,100 fpm/2,290 fpm.

\(^{106}\) ICN ATC radar data on AAR991 is as follows: 34,000 ft (03:54:48) - 30,300 ft (03:55:48) - 24,700 ft (03:56:48) - 20,800 ft (03:57:48) - 15,900 ft (03:58:48) - 12,400 ft (03:59:48) - 10,300 ft (04:00:48) - 8,200 ft (04:01:43).

\(^{107}\) 03:56 - PACK 2, PACK 3, >AUTOPILOT DISC, FLAP SYS MONITOR, >NO AUTOLAND, >YAW DAMPER LWR, >STAB TRIM 2, F/D BAR BIAS, SATCOM DATA, STAB TRIM, SATCOM SYSTEM, NO AUTOLAND, >SATCOM, >NO LAND 3 (03:56:00 - altitude 28,200 ft, speed 470 kt, heading 258°).
pilot's implementing Fire Main Deck procedures, along with STAB TRIM, F/D BAR BIAS, and AUTOPilot DISC, which indicates a fault with stabilizer trim, disappearance of flight director's guidance, and autopilot disconnection, respectively. Therefore, the pilot was likely flying the airplane manually.

At 03:57:XX, 108) AAR991 was descending from 23,900 ft to 19,100 ft. ACARS messages generated at this time indicate a fault with door L5, inoperative APU fire detection, bottle low, stabilizer auto trim/cutout, EIU disagree, incapability of autolanding, and a fault with left FMC and FDR.

At 03:58:XX, 109) AAR991 was descending from 19,100 ft to 14,900 ft. ACARS messages generated at this time indicate smoke detected in the lower cargo compartment, cargo bottle discharge/low, and a fault with FMC and elevator feel computer. The ARAIB concludes that the message "FIRE CARGO AFT" must have been displayed in the cockpit, but it was not transmitted to the ground via ACARS since it was not correlated to the fault message.

It is also concluded that the reason why AAR991's speed momentarily increased to a maximum ground speed of 494 kt at 03:58:29 was that AAR991's transition from automatic throttle control to manual one had resulted in the airplane's failure to maintain speed.

At 03:59:XX, 110) AAR991 was descending from 14,900 ft to 11,900 ft. ACARS messages generated at this time indicate APU battery discharge, a fault with APU, and operation of supernumerary oxygen and ELT.

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108) 03:57 - >DET FIRE APU, >BOTTLE LOW APU, STAB AUTO TRIM, EIU DISAGREE, FMC LEFT, FMC LEFT, DOOR ENTRY L5, FLIGHT RCDR SYS, STAB AUTO CUTOUT, APU FIRE LOOP B, BOTTLE LOW APU, APU FIRE LOOP A, NO LAND 3 (03:57:00 - altitude 23,900 ft, speed 478 kt, heading 279°).
109) 03:58 - >AUTOTHROT DISC, >CGO BTL DISCH, >FMC MESSAGE, ELEVATOR FEEL, BTL LOW CARGO A, CARGO DET AFT 4 (03:58:00 - altitude 19,100 ft, speed 481 kt, heading 328°).
110) 03:59 - >BAT DISCH APU, SUPRNMRY OXY ON, APU, >ELT ON (03:59:00 - altitude 14,900 ft, speed 451 kt, heading 352°).
At 04:00:XX, AAR991 was descending from 11,900 ft to 9,800 ft. ACARS messages generated at this time indicate a fault with flaps control and rudder control such as upper yaw damper and rudder ratio dual. The messages were not transmitted any more after 04:00:XX.

[Figure 62] Vertical Flight Track Including Altitude, Speed & Heading

111) 04:00 - YAW DAMPER UPR, RUD RATIO DUAL, FLAPS CONTROL, >YAW DAMPER UPR (04:00:00 - altitude 11,900 ft, speed 437 kt, heading 027°).
2.2.3 History of Flight after the Transmission of ACARS Messages

AAR991 that was descending reached an altitude of 8,200 ft\footnote{112) Ground speed 404 kt, heading 033°.} at 04:01:43 and started climbing. After this, the airplane's altitude, ground speed, and heading changed inconsistently until its flight track disappeared from the radar screen about 04:10:50. AAR991's transponder code\footnote{113) A transponder is an electronic device that produces a response when it receives a radio-frequency interrogation from the radar on the ground, providing information on the aircraft's location, altitude, speed and situation to the air traffic controller.} was set to 7700 indicating emergency as the airplane climbed to 8,500 ft about 04:03:01\footnote{114) Ground speed 410 kt, heading 027°.}.

AAR991 given SHI ACC's instruction to fly heading 045 at 03:59:50 turned right and left repetitively about 7 times until crash, with a heading range between 004 and 045.

When AAR991 informed KAL886 that it was flying direct to Jeju heading 030 at 04:03:29, KAL886 informed AAR991 that SHI ACC gave it heading 045. As Jeju Airport was located 110 nm (204 km) from AAR991 on a heading of 058°, AAR991 deviated about 28° to the left from the route to Jeju Airport. Contributing to this deviation of 28° may be smoke in the cockpit, communications issue, compromised controls, and a defect in the navigation system.

At 04:05:32, KAL886 relayed the message of ICN ACC, "Maintain heading 060, radar vector for final, and descend to 7,000 ft." At this time, AAR991 was flying at 10,300 ft on a heading of 031°, but later turned left to 010°, right to 045°, and again left to 005°, which indicates the airplane's loss of directional control. AAR991 failed to reach an advised heading of 060° until crash.

Between 04:01:43 and 04:09:18\footnote{115) Altitude 14,600 ft, 409 kt, heading 019°.}, AAR991 was descending from 14,600 ft
to 8,200 ft, during which the airplane went up and down about 5 times, and its ground speed (GS) continued to change from 384 kt to 453 kt. After reaching 14,600 ft, as shown in [Table 13], AAR991 continued to descend to 4,000 ft, at which its flight track disappeared from the radar screen of ICN ACC and the MCRC.

<table>
<thead>
<tr>
<th>Radar</th>
<th>Time</th>
<th>Alt (ft)</th>
<th>Speed (kt)</th>
<th>Descent Rate (fpm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>ICN ACC</td>
<td>04:09:18.305</td>
<td>14,600</td>
<td>409.35</td>
<td>1,020</td>
</tr>
<tr>
<td></td>
<td>04:09:30.061</td>
<td>14,400</td>
<td>401.88</td>
<td>5,099</td>
</tr>
<tr>
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<td>04:09:41.828</td>
<td>13,400</td>
<td>395.51</td>
<td>6,120</td>
</tr>
<tr>
<td></td>
<td>04:09:53.592</td>
<td>12,200</td>
<td>404.74</td>
<td>3,047</td>
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<tr>
<td></td>
<td>04:10:05.405</td>
<td>11,600</td>
<td>411.33</td>
<td>2,044</td>
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<td>04:10:17.146</td>
<td>11,200</td>
<td>424.07</td>
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<td>04:10:28.993</td>
<td>9,600</td>
<td>429.57</td>
<td></td>
</tr>
<tr>
<td>MCRC</td>
<td>04:10:25.000</td>
<td>9,600</td>
<td>-</td>
<td>20,667</td>
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<tr>
<td></td>
<td>04:10:50.000</td>
<td>4,000</td>
<td>-</td>
<td></td>
</tr>
</tbody>
</table>

[Table 13] Descent Record Between 14,600 ft & Track Disappearance

At 04:06:32, the captain stated, "Ah… we are now that rudder control is not working and seems to be fired… (jamming)." At 04:07:34, he said, "We have to open the hatch, hatch." It is assumed that, at this time, rudder was not operational, and that smoke caused by fire was propagated into the cockpit. At 04:09:47, the captain stated, "Rudder control… flight control, all are not working," which indicates that all control surfaces including rudder were compromised.

At 04:10:15, the FO stated, "Altitude control is not available due to heavy vibration, going to ditch… ah," which was AAR991's last communication record.
As shown in [Table 13], AAR991 was crashing as evidenced by its descent rates, 8,103 fpm between 11,200 ft and 9,600 ft, 20,667 fpm between 9,600 ft and 6,500 ft, and 9,375 fpm between 6,500 ft and 4,000 ft.

2.2.4 Fire-related Non-normal Procedures

The ARAIB assumes that, as many messages influencing flight control were generated due to rapid fire spreading, AAR991 most likely implemented various kinds of non-normal procedures. Four turbulence messages likely indicate that fire got more serious, and AAR991 likely exhibited irregular vertical and horizontal flight tracks due to a flight control failure after reaching 8,200 ft at 04:01:43. Therefore, the size and condition of fire was at a serious level that required inevitable ditching.

As fire rapidly spread, AAR991 had to implement various kinds of QRH procedures. It is assumed, based on ACARS message CGO DET 11 MN DK at 03:53, emergency declaration due to a main deck cargo fire at 03:54:23, and ACARS messages PACK 2 and PACK 3 at 03:56, that AAR991 first implemented non-normal procedures in the Fire Main Deck checklist.

It is likely, based on ACARS messages EQUIPMENT SMOKE and EQUIPMENT COOLING at 03:53, that AAR991 needed to implement non-normal procedures in the Equipment Cooling checklist.

At 03:57, many messages in relation to the APU fire system (APU FIRE LOOP A, APU FIRE LOOP B, DET FIRE APU, >BOTTLE LOW APU) were generated.

It is likely, based on ACARS messages CARGO DET AFT 4, >CGO BTL DISCH, and BTL LOW CARGO A at 03:58 and ATC/pilot communications
"Aft, cargo aft, fire cargo aft," that AAR991 implemented non-normal procedures in the FIRE CARGO AFT checklist.

It is likely, based on a well defined soot trail discovered on the exterior skin of the smoke evacuation shutter in the rear fuselage direction and on the captain's statement at 04:07:34, "We have to open the hatch, hatch" that, due to the entry of smoke and fumes into the cockpit, the flight crew had to implement non-normal procedures in the Smoke Fire or Fumes, or Smoke or Fumes Removal checklist.

At 04:10:06, the FO informed JEJ ACC that inevitable ditching was imminent, stating, "We have heavy vibration on the airplane, may need to make an emergency landing, emergency ditching."

2.2.5 QRH and Fire Fighting Altitude 25,000 ft

At 03:54:23, AAR991 declared an emergency due to a main deck cargo fire, requested SHI ACC to clear a descent to 10,000 ft, then obtained a descent clearance, and at 03:54:59, started descending from 34,000 ft. AAR991 likely implemented non-normal procedures in the Fire Main Deck checklist when it was first aware of the occurrence of fire, but did not maintain 25,000 ft116) selected by Boeing as a main deck cargo compartment firefighting altitude.

[Figure 63] shows B747 freighter's non-normal procedures in the Fire Main Deck checklist issued on 1 April 2011 and distributed to the flight crew. PACK 2, PACK 3, and SATCOM SYSTEM messages generated by executing step No. 4 of the procedures were transmitted at 03:56:XX. Step No. 7 of the procedures specifies that the aircraft should climb or descend to 25,000 ft when conditions

116) The fire suppression system for a Class E cargo compartment is, instead of using the extinguishing agent, to stay at 25,000 ft and depressurize the cabin in order to decrease psi to that of the ambient air at 25,000 ft and reduce oxygen, thereby containing fire propagation.
and terrain allow, but AAR991 passed 25,000 ft about 03:56:33\(^{117}\) and continued to descend. SHI ACC asked AAR991 whether it needed to descend to 10,000 ft (3,000 meters) when the airplane was passing about 22,000 ft about 03:57:36, and the FO responded that AAR991 would descend to 10,000 ft and return to Jeju. Later, AAR991 passed 10,000 ft and continued to descend to 8,200 ft about 04:01:42.

Boeing's Bulletin AAR-83 issued on 10 May 2011 was not distributed to the flight crew, but the revised content was disseminated beforehand on the Intranet.

\(^{117}\) Ground speed 473 kt, heading 269°.
8.32


**FIRE MAIN DECK**

**FIRE MN DK AFT, FWD, MID**

**Condition:** Smoke is detected in the main deck cargo area(s).

1. Don the oxygen masks.
2. Establish crew communications.
3. SUPRMNY OXY switch ................. ON
4. MAIN Deck CARGO FIRE
   ARM switch ................ Confirm .... ARMED
   HL7413 - HL7415, HL7419, HL7420, HL7436 - HL7616
   SATCOM will shut down to prevent overheating.
   Two packs are automatically shut down and the associated PACK messages are shown.

Select the pack control selectors that have the PACK messages shown.

5. PACK control selectors .......... One pack on, two packs OFF

**Warning!** Either pack 1 or 3 must be operating to prevent excessive smoke accumulation on the flight deck.

6. CARGO FIRE
   DEPRES/DISCH switch ............. Push and hold for 1 second

[Figure 63] Freighter's Fire Main Deck NNC (1 April 2011)
FIRE MAIN DECK continued

7. Climb or descend to 25,000 feet when conditions and terrain allow.

8. Plan to land at the nearest suitable airport.

9. Do not accomplish the following checklists:
   - CABIN ALTITUDE or Rapid Depressurization
   - TEMP ZONE
   - TRIM AIR OFF

10. Checklist Complete Except Deferred Items

Continued on next page

[Figure 63] Freighter's Fire Main Deck NNC (1 April 2011) (continued)
Deferred Items

Descent Checklist
Recall ................................................... Checked
Autobrake ............................................. ___
Landing data .................. VREF___, Minimums___
Approach briefing ................. Completed

Approach Checklist
Altimeters ............................................ ___

Warning! Inform ground personnel not to open the cargo door until all supernumeraries and crew have exited the airplane and fire fighting equipment is nearby.

Landing Checklist
Speedbrake ........................................... Armed
Landing gear ................................. DOWN
Flaps ................................................... ___

[Figure 63] Freighter's Fire Main Deck NNC (1 April 2011) (continued)
[Figure 64] compares part of the different non-normal procedures in the Fire Main Deck checklist before and after revision. Step No. 7 in the revised procedures on the right emphasizes 25,000 ft for fire suppression by advising the flight crew to "expedite a climb or descent to 25,000 ft when condition and terrain allow, plan to stay at 25,000 ft as long as possible, and do not delay the approach and landing after the descent has been started."

On the other hand, step No. 7 in the unrevised procedures on the left that were distributed to AAR991 did not emphasize 25,000 ft but in effect instructs the flight crew to maintain 25,000 ft by advising them to "climb or descend to 25,000 ft when conditions and terrain allow." It is likely that AAR991’s flight crew interpreted "when conditions and terrain allow" as conditional or determined that fire was a situation where conditions and terrain do not allow.

[Figure 64] Unrevised (Left) & Revised (Right) Fire Main Deck NNCs
It is also likely that AAR991 failed to stay at 25,000 ft, fire suppression altitude, because the flight crew implemented a combi plane's non-normal procedures in the Fire Main Deck checklist and/or descended intentionally after interpreting fire as serious.

2.2.5.1 Basis for the 25,000 ft Requirement and Result of Non-compliance

The Boeing Company has selected the altitude of 25,000 ft for Class E cargo compartment firefighting altitude as optimal based on studies of the NFPA and other literature of many institutes. The purpose of firefighting at 25,000 ft is to suppress the fire, thereby increasing time available to continue flying to a safe landing location. As a result, the fire may not be extinguished at 25,000 ft and could rekindle and spread during the descent as an increase in oxygen and atmospheric pressure occurs.

Accordingly, the flight crew should not delay landing at the nearest suitable airport for the purpose of suppressing fire at 25,000 ft. If fire broke out at the TOD point, they should descend to make a rapid landing instead of staying at 25,000 ft for fire suppression.

Boeing's B747 manuals for the flight crew failed to specify the basis for the 25,000 ft requirement, the effect and concept of fire suppression at 25,000 ft, and when to descend from 25,000 ft.

If the flight crew implement non-normal procedures in a combi plane's Fire Main Deck checklist, time to start depressurization will become relatively later because the designated crewmember must first verify the presence of smoke or fire before starting the procedures. In addition, if the airplane descends below 25,000 ft, cabin pressure and oxygen will relatively increase according to altitude difference, and the effect of fire suppression will reduce, thereby resulting in the
spread of fire.

It is not confirmed that the reason for AAR991's leaving 25,000 ft was that the flight crew mistakenly implemented a combi plane's non-normal procedures in the Fire Main Deck checklist or that the flight crew descended intentionally in full consideration of the condition of fire. AAR991's late action to suppress fire (depressurization) and loss of opportunity to suppress fire at 25,000 ft likely contributed to the spread of fire, based on the theory that the minimum re-ignition energy varies inversely with the square of the pressure.

Judging from the size and condition of AAR991's fire, there is a possibility that, even if AAR991 had suppressed a main deck cargo fire by maintaining 25,000 ft, the fire would not have been extinguished until the TOD point for Jeju Airport, and that, in this case, as an increase in oxygen during the descent had resulted in the spread of fire, the outcome of this accident would not have changed.

In case that the airplane descends from 25,000 ft at IAS 271 kt, AAR991's TOD point will be located about 69 nm from Jeju Airport, which takes about 14 minutes from TOD point to landing. In case of a descent at IAS 360 kt, the TOD point, from which it takes about 10 minutes to land, will be located about 57 nm from Jeju Airport.

In case that the airplane descends at IAS 271 kt (TAS 392 kt, GS 405 kt), it can maintain 25,000 ft for about 10.5 minutes, for which fire can be

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118) B747 FCTM page 7.6 Rapid Descent "When the aircraft's structural damage is presented or expected, restrict speed to less than the current one." : AAR991 near SADLI (altitude 34,000 ft, wind 270/13, HDG 266°), AAR991 during return (G/S 465 kt - tail wind 13 kt = TAS 452 kt = IAS 271 kt/M0.78).

119) Data was generated by using Boeing Performance Software (BPS) and Boeing INFLT/REPORT program. Aircraft Weight 260,952.144 kg (575,301 lb = Takeoff Weight 602,901 lb - Trip Fuel until SADLI 27,600 lb), 34,000 ft (SADLI): Ambient Temperature -37°C/34.6°F, Wind 270/13 kt, 25,000 ft (SADLI): Ambient Temperature -16°C/3.2°F, Wind 230/13 kt.

120) AAR991 reached 25,000 ft, 140 nm (258 km) from Jeju Airport on a heading of 225°
suppressed between 25,000 ft and the TOD point for Jeju Airport. In case that the airplane descends at IAS 360 kt (TAS 511 kt, GS 524 kt), it can maintain 25,000 ft for about 9.504 minutes.\footnote{AAR991 can maintain 25,000 ft for about 9.504 minutes (83\times60/524) since the distance between the point reaching 25,000 ft and the TOD point is 83 nm (140-57).}

### 2.2.5.2 Possibility of Implementing a Combi Plane's Fire Main Deck Non-normal Procedures

Asiana Airlines has four kinds of B747 airplanes (PAX, COMBI, FREIGHTER, SF), and their non-normal procedures are specified in one QRH, which might cause the flight crew to delay and/or make a mistake while selecting applicable procedures in the QRH.

When referring to a freighter's Fire Main Deck non-normal procedures in the B747 QRH, there is a possibility that the flight crew selected a combi plane's procedures in [Figure 67] that were filed right before a freighter's procedures because they failed to check AAR991’s registration mark (HL7604) or by mistake. The basis for this assumption is as follows:

First, a combi plane's Fire Main Deck non-normal procedures do not contain the 25,000 ft requirement, unlike those of a freighter, since its main deck cargo compartment is not a Class E cargo compartment.

Second, a freighter's Fire Main Deck depressurization procedure was delayed. When a main deck cargo fire arm switch is armed, PACK 2 and 3 ACARS messages are generated. At 03:53:XX, CGO DET 11 MN DK ACARS message was generated, followed by PACK 2 and 3 ACARS messages at 03:56:XX.\footnote{03:56:00 - altitude 29,300 ft.} [Figure 65]\footnote{N31.8425/E124.529166667}, the airplane can maintain 25,000 ft for about 9.504 minutes (83\times60/524) since the distance between the point reaching 25,000 ft and the TOD point is 83 nm (140-57).
about 2 minutes\textsuperscript{124) later in comparison to Boeing pilots' implementation of the non-normal procedures, which indicates that AAR991's Fire Main Deck depressurization procedure was delayed for about 2 minutes. Step No. 1 of a combi plane's Fire Main Deck non-normal procedures is to "instruct the designated crewmember\textsuperscript{125) to verify the presence of smoke or fire." If the captain\textsuperscript{126) personally verified the presence of fire and continued to implement a combi plane's Fire Main Deck non-normal procedures, the generation of PACK 2 & 3 ACARS messages would be delayed for the time required for fire verification, which explains the time difference of PACK 2 & 3 messages between timeline above and below as shown in [Figure 65].

\textsuperscript{123) As shown in [Figure 65], data above timeline is based on communications records of AAR991’s flight crew and ACARS data. Data below timeline is based on the times calculated and averaged when two Boeing pilots performed the QRH non-normal procedures in a B747 simulator without knowing what emergency they were going to respond to. Data in tan shadow are messages to be expected according to the implementation of the QRH non-normal procedures.
\textsuperscript{124) Minimum 1 minute to maximum 3 minutes, considering a time error of an EICAS fault message.
\textsuperscript{125) The designated crewmember normally means a flight attendant, other than flight crew on duty.
\textsuperscript{126) The FO took control of early radio communications with SHI ACC at 03:51:15 until 03:55:54 when the captain resumed control.
Third, as shown in [Figure 66], AAR991's flight crew failed to turn on the supernumerary oxygen switch,\(^\text{127}\) which is specified in non-normal procedures in a freighter's Fire Main Deck checklist, but not in a combi plane's.\(^\text{128}\) Detailed examination\(^\text{129}\) of AAR991's cockpit wreckage revealed that a frangible wire\(^\text{130}\) of the switch guard did not fracture as shown in [Figure 66], and that the supernumerary oxygen switch was in the NORM\(^\text{131}\) position.

\(^{127}\) The supernumerary oxygen system supplies oxygen from an oxygen storage cylinder to service units located in the cabin and lavatory. Supernumerary oxygen masks are contained in service units. Except the captain and the FO, there was no other occupant on AAR991 who could use supernumerary oxygen in the cabin.

\(^{128}\) It was not confirmed whether a TRIM AIR switch specified in a combi plane's non-normal checklist had been in the OFF position or whether a Landing Altitude switch had been in the MAN position. Cockpit wreckage examination of a TRIM AIR switch revealed that the filaments of the two bulbs each had one major portion loose within the glass enclosure, that no distortion of the major features or of the localized coils was seen, and that the lower two positions had plastic plugs installed.

\(^{129}\) Refer to Appendix 6 Detailed Examination of Cockpit Wreckage.

\(^{130}\) The supernumerary oxygen switch in the NORM position was covered with the guard connected to a frangible wire that provides protection against careless movement. Therefore, the guard should be open to move the supernumerary oxygen switch to the ON position, which fractures a frangible wire.

\(^{131}\) When cabin pressure decreases to an equivalent of 14,000 ft altitude with the supernumerary oxygen switch in the NORM position, the supernumerary oxygen system is automatically operated.
Also, if the flight crew had implemented a freighter's Fire Main Deck non-normal procedures in a specified order, SUPRNMRY OXY ON ACARS message should have been generated earlier than PACK 2 & 3 messages, but it was generated 3 minutes after them, at 03:59:XX. The supernumerary oxygen system is automatically operated when cabin pressure decreases to an equivalent of 14,000 ft altitude even without the cockpit's supernumerary oxygen switch in the ON position. According to Boeing's data, SUPRNMRY OXY ON ACARS message is generated about 2 to 3 minutes after the initiation of depressurization (push of CARGO FIRE DEPRES/DISCH switch for 1 sec.).

132) The SUPRNMRY OXY switch must be ON right before a procedure, "MAIN Deck CARGO FIRE ARM switch - Confirm ARMED" accompanied by associated PACK 2 & 3 advisory messages.
133) This message is generated when the supernumerary oxygen switch on the cockpit overhead panel is in the ON position or when cabin pressure exceeds 8.7±.2 psia.
134) Altitude 14,900 ft, ground speed 451 kt, heading 352°.
135) When cabin pressure decreases to an equivalent of 14,000 ft altitude, system operation is initiated by the barometric pressure switch according to aerodynamics principles.
136) It takes about 1 minute for AAR991's cabin pressure altitude (~6,000 ft) to reach 14,000 ft, at which the supernumerary oxygen system is automatically operated, plus it takes about 1 to 2 minutes for the system to respond and for the CMC and EICAS messages to correlate with each other and generate maintenance messages. As a result, it takes about 2 to 3 minutes for ACARS messages to be generated after the initiation of depressurization.
137) According to Boeing's data, cabin pressure altitude increases by 9,000 ft/min until reaching 20,000 ft, and afterward, by 2,500 ft/min until reaching 23,900 ft.
**Condition:** Smoke is detected in the main deck cargo area.

1. Instruct the designated crewmember to verify presence of smoke or fire.

2. Choose one:
   - Presence of smoke or fire is **verified**:
     - **Go to step 3**
   - Presence of smoke or fire is **not** verified:
     A crewmember must monitor the cargo compartment for the rest of the flight.

3. **MAIN Deck CARGO FIRE**
   - **ARM switch** . . . . . . . . . . . . . . . . Confirm . . . . . ARMD
     - Pack 3 will shut down.

4. **PACK 3 control selector** . . . . . . . . . . . OFF

5. **PACK 1 and 2 control selectors** . . . . . . . One pack on, one pack OFF

6. **CARGO FIRE DISCH switch** . . . . . Push and hold for 1 second
   - 90 minutes of fire suppression are available.

7. **TRIM AIR switch** . . . . . . . . . . . . . . . . . . . . . . Off

[Figure 67] Combi Plane's Fire Main Deck NNC (1 April 2011)
8.30

ASIAN AIRLINES


▼FIRE MAIN DECK continued▼

8 Choose one:

Airplane is **at or below** 8,000 feet:

▲▲Go to step 11

Airplane is **above** 8,000 feet:

▲▲Go to step 9

9 LDG ALT switch ........................ MAN

10 LDG ALT selector ....................... Set between 8000 8500

11 Plan to land at the nearest suitable airport

12 Do **not** accomplish the following checklists:

LANDING ALT
TEMP ZONE
TRIM AIR OFF

13 Checklist Complete Except Deferred Items

Deferred Items

Before descent

LDG ALT switch ........................ AUTO

Descent Checklist

Recall ................................. Checked

Autobrake .......................... ___

Landing data ......................... VREF___, Minimums___

▼ Continued on next page ▼

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[Figure 67] Combi Plane's Fire Main Deck NNC (1 April 2011) (continued)
Approach briefing ........................ Completed

Approach Checklist
Altimeters ........................................ __

Warning! Inform ground personnel not to open the cargo door until all passengers and crew have exited the airplane and fire fighting equipment is nearby.

Landing Checklist
Speedbrake ................................. Armed
Landing gear ................................. DOWN
Flaps ............................................. ___  ■ ■ ■ ■

[Figure 67] Combi Plane's Fire Main Deck NNC (1 April 2011) (continued)
2.2.5.3 Possibility of the Flight Crew's Intentional Descent

The display of FDE messages at 03:53:XX likely required AAR991's flight crew to implement Fire Main Deck and EQUIPMENT COOLING non-normal procedures. The display of BTL LOW CARGO A message at 03:58:XX probably required the flight crew to implement Fire Cargo Aft non-normal procedures. Also, there is a possibility that Smoke Fire or Fumes, or Smoke or Fumes Removal procedures had to be applied since smoke or fumes entered the cockpit.

In AAR991's EQUIPMENT COOLING and Fire Cargo Aft non-normal checklists, there is no requirement for maintaining 25,000 ft, unlike the Fire Main Deck checklist. Also, step No. 8 in the Smoke or Fumes Removal checklist instructs the flight crew to "start a descent and level off at the lowest safe altitude" or 8,500 ft, which is higher.

On AAR991, the rapid spread of fire resulted in failures in many systems and the loss of flight control. Turbulence data from the ACMS was transmitted four times from 03:57:23 at 22,700 ft to 03:59:29 at 13,400 ft, which could be an indicator that the fire got more serious.

The possibility can therefore not be excluded that AAR991 made an intentional descent below 25,000 ft in advance after fully considering the following: the flight crew simultaneously had to implement multiple complex non-normal procedures requiring them to maintain different altitudes; there was a future possibility of ditching due to a spreading and worsening fire; and Jeju Airport was not far from the airplane.

138) Refer to Appendix 9 for non-normal procedures in the checklists of Fire Cargo Aft, Smoke Fire or Fumes, and Smoke or Fumes Removal.
139) Mt. Halla is 6,398 ft tall, and the radar minimum altitude of the accident site is 8,000 ft.
Meanwhile, AAR991's implementation of depressurization procedures for suppressing a main deck cargo fire was delayed for about 2 (1 - 3) minutes, judging from ACARS messages, PACK 2 & 3 at 03:56:XX and SUPRNMRY OXY ON at 03:59, as shown in [Figure 65].

According to Asiana Airlines' POM, under a non-normal situation, the captain should be in charge of flight control\footnote{Asiana Airlines' B747 POM 4.1.2: Basic principles in case of non-normal situations - the captain should be in charge of flight control and maintain a proper flight path and configuration.} and instruct the FO to implement non-normal procedures, then take control of communications\footnote{Asiana Airlines' B747 POM 2.3.3.4 Communications.} with ATCs while the FO implements the QRH procedures. Yet, after 03:53 when EICAS fault messages were generated, the FO took control of communications for about 1 minute and 31 seconds between the declaration of a cargo fire and the captain's resumption of communications at 03:55:54. If the captain had not implemented the QRH procedures during this time, implementing the applicable procedures would have been delayed. In addition, it is likely that it took additional time for the flight crew to determine the emergency situation, refer to the QRH for applicable procedures, and don oxygen masks.

\subsection*{2.2.6 Ditching}

According to the aircraft accident report on the fatal UPS B747 crash in 2010, the Transportation Safety Board (TSB) of Canada studied 15 fire-related aircraft accidents that had occurred between 1967 and 1998, which showed that the time elapsed between the occurrence of an in-flight fire and ditching, emergency landing, or crash was 5 to 35 minutes, and that the average flight time was 17 minutes. In recent accidents involving a B747 main deck cargo fire, it took 19 minutes for South African Airways flight 295 to recognize a fire until its flight track disappeared, and 28 minutes for UPS flight 6 to lose flight control in 2010.
As for AAR991, about 15 minutes 47 seconds (04:09:47) after the generation of the EICAS fault message about 03:53, the captain said to JEJ ACC, "Rudder control… flight control, all are not working," and it took 17 minutes and 50 seconds for AAR991 to disappear from the radar screen at 04:10:50 when the airplane was flying at 4,000 ft, located at N33°15'12" E124°59'34", 139 km (263°/75 nm) west of Jeju Airport.

On the day of the accident, the time of moonrise and civil twilight\(^\text{142}\) was 02:58 and 05:22, respectively. The expected time of sunrise was 05:50, and AAR991 disappeared 1 hour and 40 minutes before sunrise, when the intensity of illumination\(^\text{143}\) was so low that it was difficult for AAR991 to visually check the surface of the sea and make an emergency ditching.

Judging by the FO's statement at 04:10:15, "Altitude control is not available due to heavy vibration, going to ditch… ah," AAR991 failed to attempt an emergency ditching and crashed.

After a main deck cargo fire was detected at 03:53:XX, AAR991 descended to 34,000 ft at 03:54:59 and reached 25,000 ft at 03:56:33. It took the maximum 3 minutes and 33 seconds and about 1 minute and 34 seconds for AAR991 to reach 25,000 ft from the detection of a fire and from the initiation of a descent, respectively. It takes about 10 to 14 minutes for AAR991 to make an emergency ditching from 25,000 ft, and thus, if AAR991 with fire damage had immediately descended and attempted an emergency ditching as soon as a fire had been detected, it could have made a ditching before 04:09:47, when the captain had reported the loss of flight control.

\(^{142}\) Civil twilight is defined when the sun is 6° below the horizon, and lasts for about 30 minutes after sunset or before sunrise, This is the limit at which twilight illumination is sufficient for people to carry on activities without artificial illumination although the sun is below the horizon.

\(^{143}\) 28 July 2011 (27 of the lunar calendar) ☿ about 04:00 - illuminated friction of the moon's disk 8.2% [from last quarter to crescent (29~30)], clear surface illumination 11.02 mlux ☿ about 05:00 - illuminated friction of the moon's disk 8.0%, clear surface illumination 58.04 mlux.
Checklist instructions\(^{144}\) for B747 QRH non-normal checklists stated, "In some multiple failure situations, the flight crew may need to combine the elements of more than one checklist. In all situations, the captain must assess the situations and use good judgement to determine the safest course of action. … It must be stressed that for smoke that continues or a fire that cannot be positively confirmed to be completely extinguished, the earliest possible descent, landing, and evacuation must be done. If a smoke, fire or fumes situation becomes uncontrollable, the flight crew should consider an immediate landing. … However, in a severe situation, the flight crew should consider an overweight landing, a tailwind landing, an off-airport landing, or a ditching."

B747 non-normal checklists for AAR991’s fire can be summarized as follows: the flight crew should first rapidly and accurately implement depressurization procedures for a main deck cargo fire, maintain 25,000 ft, and attempt to suppress fire until the TOD point for Jeju Airport. Also, the flight crew should check the current condition of a fire, including whether a fire is suppressed, extinguished, or spread, and if a fire is determined to be uncontrollable, they should make an early descent in consideration of ditching.

Currently, it is difficult for the flight crew to decide to make a ditching for the following reasons: they cannot accurately check the condition of a cargo fire, including whether it is suppressed, extinguished, or spread; they cannot determine whether a fire can be contained; and they cannot predict or determine when to lose flight control or whether it is possible to fly to a diversion airport.

Maintaining 25,000 ft for suppressing a main deck cargo fire has been emphasized, whereas it takes about 10 to 14 minutes to make a ditching from 25,000 ft. In this regard, it is necessary to come up with countermeasures against the possibility of missing a time window for ditching as a last resort.

\(^{144}\) Chapter CI (Checklist Instructions), page CI.2.2 - CI.2.3.
Therefore, the ARAIB concludes that the aircraft system should be improved to enable the flight crew in the cockpit, who become aware of an uncontrollable fire, to accurately determine the size and condition of the fire so that they can make a timely decision to descend from 25,000 ft and make a ditching.

In addition, Boeing's B747 manuals for the flight crew should contain specific information on the basis for the 25,000 ft requirement, its effect and concept of fire suppression, and when to descend from 25,000 ft.

2.2.7 Recurrent Training-Evaluation and Improvements to a Simulator

As Asiana Airlines' B747 simulator is configured as a passenger plane, it cannot simulate Fire Main Deck on a freighter. The main content of the revised Fire Main Deck non-normal checklists with the emphasis on maintaining 25,000 ft was disseminated on the company's Intranet, and it was not confirmed whether AAR991's captain and the FO were given their Fire Main Deck training in the simulator.

Asiana Airlines' recurrent simulation training syllabus and evaluation items are notified in advance to the flight crew, and with no change of their content, training and evaluation are conducted, which allows the flight crew to study them in advance and improve the effect of the training. Yet, this kind of pre-notification has also a negative influence on the flight crew's ability to judge and respond to unexpected situations and the effect of the CRM training.

As Asiana Airlines has no B747 freighter simulator, training subjects that cannot be simulated as the same as on a B747 freighter are difficult to be selected as recurrent training subjects, and thus, they are less trained. Also, the subjects that were not incorporated in training and evaluation are given a lower priority on the flight crew's usual study list.
Asiana Airlines should improve its management method of recurrent training and evaluation in order for the flight crew to properly judge and respond to unexpected complex non-normal situations like this accident.

In addition, the company should modify its simulator configured as a passenger version of the B747 so that its flight crew can be realistically trained on non-normal procedures of a combi, cargo, and special cargo plane.

Also, Asiana Airlines should provide a consistent and enhanced simulation training to the flight crew so that they can rapidly don their oxygen masks and do the non-normal checklists in a real-life situation, with their tasks allocated according to regulations.

2.3 ATC and Communications

According to the analysis of AAR991's ATC/pilot communications transcript, while diverting to Jeju Airport due to an emergency after communicating with SHI ACC in ICN flight information region (FIR), AAR991 had to exchange flight information via HUK ACC since there was no direct telephone line between SHI ACC and ICN ACC. As a result, a more rapid information exchange could not be made when the emergency occurred.

After the occurrence of the emergency, AAR991 attempted to communicate with ICN ACC on 124.525 MHz around 10,000 ft but to no avail. Though, instead of using a frequency of 128.375 MHz, AAR991 continued to communicate on 124.525 MHz, in a difficult and complicated way, via other airplanes flying at a higher altitude.

As aforementioned in Section 1.9.3 of this report, AAR991 entered a communication dead zone while descending from 34,000 ft to 10,000 ft because
of the location and height of the 124.525 MHz transceiver antennas used for communication with ICN ACC, thereby failing to communicate with ICN ACC.

Unlike the 124.525 MHz transceiver antennas, there seems to be no communication obstacles\(^\text{145)}\) between AAR991 and the transceiver for 128.375 MHz used by the ICN ACC south sector, and it is thus assumed that if AAR991 had used 128.375 MHz while flying around 10,000 ft, it could have communicated with ICN ACC.

Therefore, the ARAIB concludes that the use of frequency 128.375 MHz should be contained in the Aeronautical Information Publication (AIP)\(^\text{146)}\) to allow airplanes flying at a low altitude in the western zone south of "Jeju VORTAC" on airway A593 and B576 to communicate with ATCs on that frequency, and that this change should be disseminated to SHI ACC and HUK ACC for cooperation.

2.4 Fire

2.4.1 Initial Fire Location

Locations of cargo positions, smoke sampling ports connected to smoke detectors, and fire zones are shown in [Figure 68]. Smoke sampling ports are attached to the ceiling, and if air sample through the ports contains smoke, smoke detectors detect it. Two detectors per zone are installed on the left of the fuselage.

The main deck cargo compartment consists of three fire zones: FWD fire zone 1 - 5; MID fire zone 6 - 9; and AFT fire zone 10 - 16. If smoke is

\(^\text{145)}\) Inspection and official confirmation are needed during a future scheduled flight inspection.
\(^\text{146)}\) Korea's AIP valid at the time of the accident did not contain frequency 128.375 MHz as an ATC frequency for airways A593 and B576.
generated, it enters smoke sampling ports in each fire zone. Smoke detectors in fire zones 10, 11, and 13 detect smoke over cargo positions L, M, and P, respectively. Smoke detectors in fire zone 12 detect smoke by a smoke sampling port installed near the main deck side cargo door.

Fire zone 10 encompasses a cargo position L, which consists of LR on the right and LL on the left based on the nose. Cherries, and IC plates and memories were loaded in cargo positions LR and LL, respectively, but with no flammable materials.

Fire zone 11 encompasses a cargo position M, which consists of MR on the right and ML on the left based on the nose. LED, valves, semiconductor components, viscous clay, and labels were located on the pallet in position MR, with no flammable or self-ignition materials.

[Figure 68] Smoke Sampling Ports, Fire Zones, and Cargo Positions
Flammable liquid (Photo-Resist/IC), printed circuit boards (PCB), complementary metal oxide semiconductor (CMOS), and IC connectors were located on the pallet in position ML. Flammable liquid was Photo-Resist/IC classified as dangerous goods by the ICAO "Technical Instructions for the Safe Transport of Dangerous Goods by Air" and specified in NOTOC.

Fire zone 13 encompasses a cargo position P, which consists of PR on the right and PL on the left based on the nose. Position PL located aft of position ML and near main deck side cargo door was empty. Lithium-ion batteries, paint, Amines liquid corrosive, photo-resist, flammable liquid, and automotive parts were located on the pallet in position PR. All shipments except automotive parts were classified as dangerous goods by the ICAO "Technical Instructions for the Safe Transport of Dangerous Goods by Air" and specified in NOTOC.

Among shipments in the aft cargo compartment, those that can self-ignite or have flammability are located in fire zones 11 and 13. According to the ATC/pilot communications transcript, a fire occurred in the aft main deck cargo compartment, and based on the analysis of ACARS messages, a fire occurred first in the aft fire zones rather than others. Because smoke was initially detected in fire zones 11 and 13 and structural fire damage occurred in the region of pallet locations ML and PR, the ARAIB concludes that the origin of the fire was in or around the pallets where dangerous goods had been loaded onto the aircraft.

2.4.2 Time of Fire Occurrence

FDE messages transmitted via ACARS are not time stamped, and their time of generation thus can be estimated by maintenance messages correlated to them, which are time stamped in hours and minutes.
Among fire-related ACARS messages received by the ground station, FDE message "CGO DET 11 MN DK" was the first generated at between 03:53:01 and 03:53:59, and maintenance message "CARGO FIRE MAIN DECK ZONE-11 LOOP A FAIL" correlated to this message was generated at 03:53.

If the message "CARGO FIRE MAIN DECK ZONE-11 LOOP A FAIL" is correlated to "MD CGO 11 LP A," it indicates a fault with the zone 11A detector, but as the message is correlated to "CGO DET 11 MN DK," the zone 11B detector was in alarm or faulted within 20 seconds of the zone 11A detector. In other words, "CGO DET 11 MN DK" would be consistent with zone 11A and zone 11B detectors detecting smoke (being in alarm) more than 8 seconds but less than 20 seconds apart. Therefore, the ARAIB concludes that a fire occurred on the airplane when the above message was displayed.

FDE messages with no correlation with maintenance messages are not transmitted to the ground station via ACARS. Therefore, FDE messages, FIRE MAIN DECK, FIRE MN DK FWD, FIRE MN DK MID, or FIRE MN DK AFT, were not transmitted to the ground because they were not correlated to maintenance messages. In other words, this means that all fire-related FDE messages were not transmitted to the ground. It is assumed that a fire occurred on the airplane before the generation of the message "CGO DET 11 MN DK."

The ARAIB concludes based on the ATC/pilot communications transcript that, when the FO communicated with SHI ACC at 03:52:51, a fire did not occur or he did not recognize the occurrence of a fire, for he did not mention it, and that a fire broke out at between 03:52:51 and the time when "CGO DET 11 MN DK" was generated (03:53 - 03:54).
2.4.3 Cause of Fire

The ARAIB reviewed the accident plane's maintenance records from 5 months before the accident to the day of the accident in order to see whether a fire had occurred due to a short-circuited wire, but found no defect with wires that could have ignited a fire.

Based on the ATC/pilot communications transcript and ACARS messages, it is assumed that a fire occurred first on cargo shipments, including flammable materials, located in positions ML or PR in the aft main deck cargo compartment, but physical evidence of the cause of the fire was not found. There were flammable materials in position ML, and flammable materials and lithium-ion batteries in position PR. Flammable materials can be ignited if the cargo compartment is within flammability limits147) due to a certain factor and an ignition source like electrostatic energy exists, and lithium-ion batteries can be self-ignited if exposed to high temperature from external sources. Therefore, the ignition possibility of these two was studied.

2.4.3.1 Ignition Possibility of Volatile Flammable Materials

The ARAIB measured the amount of electrostatic energy that could be accumulated in the plastic wrap used for bundling pallet-loads of products together prior to loading since the Board concludes that electrostatic energy could play a role as an ignition source. As shown in [Figure 69] comparing electrostatic energy with the MIEs, the amount of electrostatic energy varied from a minimum 0.138 mJ to a maximum 0.412 mJ, with the average of 0.264 mJ. The plastic wrap was used to fix or protect cargo from rain.

147) Flammability limits (explosive limits) are normally expressed in terms of volume percentage (%) of combustible gas among mixtures of dispersed combustible materials and air. The highest concentration and the lowest concentration of a gas in air capable of producing a flash of fire are referred to as the upper flammable limit and the lower flammable limit, respectively.
The ARAIB boarded the freighter with a similar flight pattern to that of the accident airplane and verified whether electrostatic energy was generated during flight. When pallets were loaded on the airplane, they discharged all the electrostatic energy that had been charged up on the ground and accumulated in the plastic wrap as they had the same electrical potential as that of the airplane. Electrostatic energy accumulated on eight pallets was measured 1 hour to 1 hour and 20 minutes after boarding.

As shown in [Table 9], 1 hour and 20 minutes after boarding, electrostatic energy was not found on seven pallets except for a pallet in position GL, which measured 0.23 mJ. This result revealed that friction was generated in the plastic wrap, and that static electricity could be built up although the aircraft was electrically bonded to prevent its accumulation.

Paint in position PR provides moisture-proof insulating coating used for manufacturing mobile phones. According to its MSDS, it is regulated as Class 3
UN1263, Packing Group II, flammable liquid that should be packed in a metal container, it has a flash point of -1°C, and vapor may form an explosive mixture in air, exceeding -1°C. The product can be exploded when heated. Its chemical composition and the MIEs are shown in [Table 14].

<table>
<thead>
<tr>
<th>Molecule</th>
<th>Molecular Formula</th>
<th>MIE (mJ)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ethane</td>
<td>( C_2H_6 )</td>
<td>0.26</td>
</tr>
<tr>
<td>Methane</td>
<td>( CH_4 )</td>
<td>0.28</td>
</tr>
<tr>
<td>Butanol</td>
<td>( C_4H_{10}O )</td>
<td>0.26</td>
</tr>
<tr>
<td>Methanol</td>
<td>( CH_3O )</td>
<td>0.14</td>
</tr>
<tr>
<td>Methylcyclohexane</td>
<td>( C_7H_{14} )</td>
<td>0.27</td>
</tr>
</tbody>
</table>

[Table 14] Paint's Chemical Composition & MIE

The product should be stored at temperatures between -5°C and 25°C, but was stored in the temporary DG storage area with a temperature of more than 26°C for more than 6 hours between its acceptance and loading.

According to the results of wreckage reconstruction study, and testing and analysis in relation to Asiana Airlines' crash accident, a container of the product, tightly closed by internal and external closure devices and inserted in the enclosed plastic bag, was left for 2 hours at room temperature of 18°C, and its volatile organic compound (VOC) emissions were measured, then detected. However, the flammable gas leakage test revealed that VOCs were not detected at a cabin altitude (8,000 ft), environment where the fire occurred on the event aircraft.

In addition, it is confirmed that the product could be ignited by a spark at room temperature, and that comparison of the MIEs of paint's flammable molecules and electrostatic energy measurements revealed that the product, if the surroundings are within flammable limits, could be ignited even by electrostatic energy.
Therefore, if paint is exposed to room temperature of more than 25°C for over 6 hours, it can emit VOCs. It is assumed that the product, if the surroundings including VOCs are within flammable limits, could be ignited by electrostatic energy. However, it is difficult to conclude, judging from the testing result that VOCs were not detected at a cabin altitude, that paint was ignited. The MIEs of gases emitted by the product when evaporating can be found in [Table 14]. The MIEs of methanol and ethanebutanol were less than an average of electrostatic energy that can be accumulated in the plastic, 0.264 mJ, whereas the MIEs of methane and methylcyclohexane were 0.28 mJ and 0.27 mJ, respectively, which were almost similar to an average of or less than the maximum of electrostatic energy.

2.4.3.2 Ignition Possibility of Lithium-ion Batteries

Lithium-ion batteries in position PR, manufactured by Company A, were in either a 6-cell or 12-cell configuration for use in hybrid electric vehicles. The ARAIB paid a visit to the manufacturer and obtained detailed information on lithium-ion battery cell's design, production quality management, safety test, packaging, and shipment. Also, the Board examined a sample of the battery that had been loaded on the accident airplane and packaging materials, but failed to acquire the data that could prove the ignition possibility of the batteries in normal conditions of transport.

Since an in-flight fire on UPS Airlines flight 1307 occurred on 7 February 2006, 36 aircraft serious incidents involving batteries and battery-operated devices have been reported, and they were involved with smoke, fire, extreme heat or explosion. Among them, 24 serious incidents, of which 15 were involved with fire, were related to lithium-ion batteries, and the rest 12 serious incidents, of which 8 were involved with fire, were related to lithium metal batteries.
On 3 September 2010, UPS Airlines flight 6, a Boeing 747-400F, with lithium-ion batteries on board, developed an in-flight fire. The first of the eight causes of the accident is as follows: "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."

According to the MSDS of a lithium-ion battery, if the battery has been subject to fire, mechanical damage, disassembly, and electrical stress caused by an abuse, its cell case could rupture in the worst case, which could cause internal hazardous materials to be released. Also, if exposed to excessive heat due to a fire, the battery has the potential to release flammable vapors. Proper extinguishing media are water, CO2, nitrogen, dry chemical and foam. When handled, the battery should avoid extreme fire or heat, water or seawater, strong oxidizers, severe mechanical damage, and terminals' short circuit. It should also be stored in a cool, dry area away from direct sunlight. The MSDS indicates that if exposed to an external short circuit, crushes, modification, or high temperature above 100°C, the battery could release heat and self-ignite.

The lithium cell undergoes a chemical reaction once it is heated to the point of thermal runaway. This chemical reaction generates very high temperatures and pressures within the cell. A cell in thermal runaway can reach 1100°F. The 1100°F temperature is very close to the melting point of aircraft aluminum, 935°F to 1180°F. A large shipment of lithium cells could generate enough heat to potentially damage the structure of the aircraft.\textsuperscript{148}

Restricting shipment of lithium-ion cells to Class C cargo compartments would largely mitigate but may not eliminate the hazard. The Halon 1301 fire

\textsuperscript{148} Excerpt from DOT/FAA/AR-10/31, Fire Protection for the Shipment of Lithium Batteries in Aircraft Cargo Compartments.
suppression system in Class C cargo compartments has been shown to effectively suppress the open fire associated with the burning electrolyte.

The battery manufacturer argues that tests revealed that lithium-ion batteries were safe, but the tests conducted by the manufacturer did not show all anomalous cases. As major manufacturers went into competition for cost reduction and high capacity\(^{149}\) battery, accidents involving lithium-ion batteries' ignition or explosion have occurred. Recalls in response to ignition and explosion of lithium-ion battery-operated computers\(^{150}\) are shown in [Table 15].

### Table 15: Recalls in Response to Ignition & Explosion of Lithium-ion Battery-operated Computers

<table>
<thead>
<tr>
<th>Time</th>
<th>Computer Manufacturer</th>
<th>No. of Recall</th>
<th>Battery Manufacturer</th>
<th>Damage</th>
</tr>
</thead>
<tbody>
<tr>
<td>2009 - 2011</td>
<td>HP</td>
<td>300,000</td>
<td>Nondisclosure</td>
<td>Nondisclosure</td>
</tr>
<tr>
<td>Oct. 2008</td>
<td>HP, Dell</td>
<td>600,000</td>
<td>Sony</td>
<td>Nondisclosure</td>
</tr>
<tr>
<td>Aug. 2007</td>
<td>Nokia</td>
<td>46,000,000</td>
<td>Panasonic</td>
<td>80 bil ¥</td>
</tr>
<tr>
<td>Mar. 2007</td>
<td>Lenovo</td>
<td>Nondisclosure</td>
<td>Sanyo</td>
<td>Nondisclosure</td>
</tr>
<tr>
<td>Dec. 2006</td>
<td>Mitsubishi</td>
<td>1,300,000</td>
<td>Sanyo</td>
<td>2 bil ¥</td>
</tr>
<tr>
<td>2005 - 2006</td>
<td>9 Manuf. including Dell</td>
<td>9,660,000</td>
<td>Sony</td>
<td>51 bil ¥</td>
</tr>
<tr>
<td>Oct. 2005</td>
<td>HP</td>
<td>135,000</td>
<td>Sony</td>
<td>Nondisclosure</td>
</tr>
<tr>
<td>May 2005</td>
<td>Apple</td>
<td>128,000</td>
<td>LG Chem</td>
<td>Nondisclosure</td>
</tr>
<tr>
<td>Aug. 2004</td>
<td>Apple</td>
<td>28,000</td>
<td>LG Chem</td>
<td>Nondisclosure</td>
</tr>
</tbody>
</table>

[Table 15] Recalls in Response to Ignition & Explosion of Lithium-ion Battery-operated Computers

In the ICAO DGP-WG meeting held in Montreal, Canada, from 6 to 10

\(^{149}\) Safety issues were raised when the electrode board's thickness and density are increased, and the separator diaphragm's thickness is reduced in order to insert more electrodes storing energy into a standardized container.

\(^{150}\) Excerpt from the article, “Trend Analysis and Prediction of Lithium-ion Battery Materials Technology” published by the Korea Development Bank.
February 2012, the Korea Electrotechnology Research Institute, which participated in the meeting with the Korean panel, explained the results of a lithium-ion battery safety test, arguing that a ban on air transportation of lithium-ion batteries and a proposal to reinforce related regulations were unreasonable.

2.4.4 Fire Propagation and In-flight Breakup

A fire developed on the aft main deck in or near fire zone 11 or 13 where palletized DG were loaded, and in about 3 to 4 minutes after smoke detection, smoke spread rapidly throughout the main deck cargo compartment.

Smoke was detected in fire zone 11, and so was it in E/E compartment through a suction fan used for cooling the E/E compartment. Melting from intense heat was found along the crown area in positions ML and PR in fire zones 11 and 13, respectively, where flammable materials were loaded. This area located between FS1700 and APB sustained the most severe fire damage.

The ARAIB concludes that smoke and flames spread to the forward and aft of the aircraft along the crown area. Judging by the fact that a well defined soot trail was discovered on the exterior skin of the cockpit smoke evacuation shutter in the rear fuselage direction, and that portions of the ceiling panels belonging to the area under the flight deck and ceiling panels aft of FS360 were sooted, smoke entered the flight deck. Thus, the Board concludes that the flight crew operated the shutter to get rid of smoke.

Among the wreckage with sooting, the farthest forward wreckage was the fuselage frame at FS500 on the LH side in the area of the main deck cargo compartment. The farthest forward evidence of thermal heat damage which caused paint discoloration was found on a crown fuselage frame at FS580 on the LH side. This damage is located at a stringer 6.
Forward portions of the wreckage generally have fire damage consisting of sooting with areas of more severe damage along the upper areas of the aircraft's attic space and crown. The wreckage between FS1700 and APB, where the pallets on positions ML and PR in fire zones 11 and 13 are located, sustained the most severe fire damage. The crown in this area was melted from intense heat.

At position ML between FS1658 and FS1784 were loaded flammable materials, and at position PR between FS1784 and FS1910 were loaded lithium-ion batteries. The fuselage wreckage on the LH side of ML and on the RH side of PR was not recovered. The ARAIB concludes that the wreckage could not be recovered since the aircraft shattered into many pieces due to dangerous goods' explosive energy.

Of the recovered wreckage, that of positions PL and RL aft of ML sustained 2 to 3 levels of fire damage since these positions were empty, whereas that of positions RR and SR aft of PR sustained 4 level of fire damage since combustibles including electronic components were loaded on these positions, which indicates that the right rear fuselage sustained one or two higher levels of fire damage than the left one. Analysis of the thermal damage maps of the recovered wreckage revealed that the fire spread rapidly due to dangerous goods at positions ML and PR.

Portions of the wreckage aft of APB did not have the evidence of fire damage, but on the exterior of the skin panels on the right and left side of the wreckage aft of the APB were long soot trails caused by smoke exiting the outflow valves, which indicates that the valves were at full open positions after the fire occurred. For the outflow valves to fully open, the flight crew must press the main deck cargo ARM button. The ARAIB thus concludes that the flight crew pressed it after becoming aware of the fire.
Blue photo-resist and paint were found on the top surface of the right wing. The top surface of the wing contained multiple black waffle-like markings caused by collisions with electronic components containers loaded at position MR forward of PR. As shown in [Figure 70], electronic components with a diameter of 5 mm in the containers were imbedded in the composite wing upper surfaces. They, made of metal, are glass-to-metal seals used for photoelectronic materials.

![Figure 70] Glass-to-Metal Seals

At position PR were loaded dangerous goods such as lithium-ion batteries, flammable liquids, Amines liquid corrosive N.O.S., paint, and blue photo-resist/LCD. At position MR forward of PR were loaded electronic components used as glass-to-metal seals in [Figure 70]. Dangerous goods at position PR were located across the main deck side cargo door, on the RH side of the fuselage.

The ARAIB concludes that powerful "fire energy" was produced to the extent that photo-resist/LCD and paint in position PR splattered on the top surface of the right wing, about 30 meters from PR, and that electronic components in position MR, shown in [Figure 70], were imbedded in the composite wing upper surfaces. The Board also concludes that this energy was generated by fire-induced explosion of flammable materials and lithium-ion batteries.
Thermal heat damage was mainly found along the crown area that was melted from intense heat. The flight control pulleys and cables did not exhibit thermal deformation or damage since they belonged to the forward section of the aircraft, which was under relatively little influence of heat. Although flight control components that ran along the crown area in the aft section of the aircraft were not retrieved, however, they likely sustained severe thermal damage, considering [Figure 40] Thermal Damage Map - Fuselage Frames.

While burning, photo-resist loaded in position ML generates about 24,000 kJ/kg, which means that the heat release from burning 1,007 kg of photo-resist is about 24,168 MJ or 22.9 mega British Thermal Unit (BTU).\(^{151}\)

Meanwhile, the heat release from burning about 793 kg of photo-resist in position PR is about 19,032 MJ or 18.04 mega BTU. At position PR were also loaded 22 kg of paint, the heat release from which is estimated at about 1 mega BTU and thus, the total is 19 mega BTU for cargo position PR.

The ARAIB concludes that a rapid increase in thermal energy caused some portions of the fuselage to separate from the airplane, evidenced by the fact that shipments loaded inside the main deck cargo compartment were imbedded on the exterior surface of the wing.

### 2.4.5 Analysis of an In-flight Breakup Through 3D Wreckage Reconstruction

As shown in [Figure 71], the ARAIB carried out 3D wreckage reconstruction. The aircraft-shaped framework was made between FS1741 and FS2658, about 1/3 the length of the fuselage, and the selected pieces of the wreckage were attached to the framework.

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\(^{151}\) The British Thermal Unit (BTU) is the amount of energy needed to cool or heat one pound of water by one degree Fahrenheit. 1 kcal = 3.968 BTU.
[Figure 71] 3D Wreckage Reconstruction

[Figure 72] shows certain portions of the reconstructed wreckage. The upper image in [Figure 72] contains a yellow circle in which there is a fracture line between two pieces of the wreckage. Color on both sides of the line that should have been the same is apparently different. The left piece of the wreckage is heavily sooted, whereas the right one does not exhibit sooting, which indicates that a fire lasted even after the separation of the wreckage. In other words, the left piece of the wreckage was attached to the fuselage while the fire progressed, whereas the right one separated from the fuselage.

The bottom image in [Figure 72] shows a yellow circle in which stress is observed along a fracture line between two pieces of the wreckage at FS2180. The left piece of the wreckage could stand outward force because it was attached to the fuselage frame, whereas the skin of the right piece was bent outward due to energy on the inside. In other words, the skin along the wreckage sheared off in midair due to energy on the inside of the airplane.
2.5 Survival Aspects

2.5.1 Rescue and Search

On 28 July 2011, about 03:54, AAR991's pilots reported a cargo fire to SHI
ACC, and 4 minutes later, about 03:59, the ACARS message "ELT ON" was transmitted, but the distress signal was not received by the authorities concerned. According to Section 2.1 ACARS CMC Messages, the message "ELT ON" is generated when the pilots turn on the ELT or when it automatically activates with the impact of 5G and more.

Although AAR991 flew for more than 10 minutes after the message was generated, however, its distress signal was not received by the ground stations. Thus, it is assumed that the message did not likely mirror an actual situation, and when AAR991 crashed into the international waters about 130 km west of Jeju Airport, the signal was not also received. The ELT installed on AAR991 is inoperable in the water.

Therefore, the ARAIB concludes that a current ELT installed on airplanes flying over maritime areas needs to be newly improved to float to the surface and operate, be operable in the water or broadcast the GPS location so that the location of missing pilots and airplanes can be rapidly and accurately identified.

Agencies concerned including the Coast Guard conducted large-scale search and rescue operations to find missing pilots for about 3 months with the focus on the estimated crash site, an area 17 km in width by 13.5 km in length, but to no avail. On 29 October 2011, a Korean salvage company that was carrying out wreckage recovery operations at the accident site, using one-boat trawling, recovered a portion of the cockpit. On 30 October, when the interior of the cockpit was examined, the bodies of the captain and the FO were found.

2.5.2 Search for FDR and CVR

Investigators from the ARAIB and Taiwanese and Singaporean investigation authorities, and agencies concerned (Asiana Airlines, Korean Navy and Coast
Guard) together used their sonars to listen for the ultrasonic signal emitted by the FDR in order to recover the FDR and CVR throughout four phases of search operations from the time of the crash until 28 August 2011 but to no avail.

To ensure a thorough accident investigation, the FDR and CVR should be retrieved, but as the airplane crashed into the sea, it could not be located although a lot of personnel, equipment, time, and costs (approximately $14 million) were injected.

From 18 to 25 April 2012, the ARAIB in cooperation with the former Ministry of Land, Transport and Maritime Affairs and the Navy checked the movement of the underwater wreckage to pinpoint their exact locations at the accident site, and as a result, added new wreckage coordinates to search for the FDR and CVR. From 10 May until 10 June 2012, a private salvage company carried out a second-phase search operation using a pair trawling method, and on 16 May, recovered the chassis with a severe fire damage, as shown in [Figure 73].

[Figure 73] FDR's Chassis
According to the results of fire damage analysis, the location where the FDR and CVR were installed (FS2300, aft of L5 door) sustained a level 2 fire damage (minor charring and/or paint discoloration from heat).

The flight data recorder rack was separated from the frame aft of the upper portion of the L5 door. The upper portion of the frame was thermally damaged, and its interior surface was heavily sooted. Judging by this evidence and the chassis' fire damage including sooting, the ARAIB assumes that the ULB fitted to the CSMU must have exceeded its operable temperature between -2.2 and 37.8°C or must have been burned in a fire, thereby becoming inoperable.

In addition, the depth of the sea where AAR991 had crashed was estimated at 81 to 87 meters. The sea floor, generally flat, consisted of mud and sand about 60 cm thick, but the currents flowed fast, at 2 - 4 m/sec, and the average visibility at the sea floor was just 0.5 meters. If the CSMU is buried here, it will be all the more difficult for a diver to find it with the naked eye, and the ULB signal will be much weaker.

On 1 June 2009, Air France flight 447, an Airbus A330-200, crashed into the Atlantic Ocean while flying en route from Brazil to France. After this accident, the difficulties of retrieving the flight recorders (costly and long lasting search) were encountered, and thus, the ICAO Flight Data Recovery Working Group is looking into new technology to safeguard flight data and/or to facilitate the localization and recovery of on-board recorders. The Working Group has studied the feasibility of the following measures, some of which were incorporated in Annex 6: ① extend from 30 to 90 days the regulatory transmission time for ULBs installed on flight recorders on airplanes; ② make it mandatory for airplanes to be equipped with an additional ULB capable of transmitting on a low frequency (between 8.5 and 9.5 kHz); ③ make it mandatory for airplanes to regularly transmit basic flight parameters via ACARS; and ④ implement
deployable recorders.

Therefore, the ARAIB concludes that based on new technologies currently studied, technological research and development should be carried out to resolve problems with aircraft location tracking for identifying the location of the crashed aircraft and rescuing missing pilots because the ULB and chassis, vulnerable to heat and impact, can be easily separated from the CSMU and because the ULB signal will get much weaker if the sea floor consists of thick mud and sand like AAR991's accident site.

2.6 Cargo

2.6.1 Cargo Loading

From 01:00 to 02:02 on 28 July 2011, 58,265.8 kg of cargo (30 pallets, 5 containers), which is 60 cases by master airwaybill, was loaded at Incheon Airport, and 35 positions including 24 in the main deck (Class E) and 11 in the lower cargo (Class C) compartments were used. At positions of main deck assumed to be the origin of a fire, CL, CR, DL, DR, EL, ER, FL, FR, GL, GR, HL, HR, JL, JR, KL, KR, LR, ML, MR, PR, RR, SL and SR were loaded Code M (318 cm × 244 cm) pallets, and at position LL was loaded a Code M container. Positions A1, A2, B1, PL, RL and T were empty.

The total weight of Incheon departing cargo was 39,331 kg by 48 AWBs, and the cargo acceptance time at Asiana Airlines' export storage area was from 27 July at 10:11 through 28 July at 00:06. For security check during acceptance, X-ray screening and explosive trace detection were conducted. The total weight of cargo transshipped to AAR991 at Incheon Airport was 18,934 kg by 12 AWBs, and departure points were eight airports abroad.
Asiana Airlines classified cargo according to the assigned master airwaybill numbers and loaded it on the ULDs (pallets and containers). When loading the ULDs on the aircraft, the company matched the serial number assigned to each ULD with the applicable position in the cargo compartments according to its load plan. The ARAIB concludes that although all the dangerous goods were loaded together on two pallets for convenience in transportation, regulations on DG segregation was not violated, and found no evidence that Asiana Airlines' cargo loading was carried out in violation of the company's current regulations.

2.6.2 Dangerous Goods Acceptance

Cargo agents intending to transport the dangerous goods by air through Asiana Cargo's Incheon facility are required to register with the air carrier as a "Dangerous Goods Handling Agent." For registration, the Agent should submit certificates of DG Category 6 qualification and employment held by one of its personnel to Asiana Airlines and get its permission, thereby obtaining qualifications for offering the dangerous goods. This Dangerous Goods Handling Agent certification system requiring a certified DG handling employee was adopted only by Asiana Airlines at the time of the accident in 2011. To meet the requirements specified in "MOLIT Regulation for Dangerous Goods by Air Transport, Article 12 (Training Syllabus, etc.)," Dangerous Goods Handling Agents shall hire an employee who received DG training (including radioactive substance training) at least for more than 40 hours in the DG training institutions approved by the Minister of MOLIT and obtained a certificate.

The dangerous goods reserved only by a bonded goods caretaker (holder of a DG Category 6 qualification certificate) from the office separately located inside a cargo warehouse are accepted and inspected. Specifically, they were accepted only after master airwaybills prepared by shipper, shipper's DG declaration, packaging, marking and labelling were inspected according to the latest checklist.
attached to the newest DGR Appendix issued by IATA. The ARAIB found no evidence that Asiana Airlines accepted the dangerous goods in violation of the company's current regulations.

Also, it is concluded that Asiana Airlines has adequately managed the dangerous goods at airports in that, apart from the checklist attached to the IATA DGR Appendix, a loadmaster and a checker separately ran their own dangerous goods field checklist so that marking, labelling, external conditions of the packaging, compliance with This Side Up label, proper fixing, and conditions of DG labels affixed to ULDs could be reinspected.

2.6.3 Dangerous Goods Storage

The dangerous goods waiting to be loaded for air transportation are stored in a temporary DG storage area prepared separately in a cargo warehouse and exclusively managed by employees (holder of a DG Category 6 qualification certificate) of Asiana Airport, a company offering cargo handling services to Asiana Airlines. In other words, the dangerous goods waiting to be loaded on aircraft are always stored in a temporary DG storage area in isolation from other general cargo.

Asiana Airport employees store the dangerous goods in accordance with marking, labelling, and regulations on DG segregation (MOLIT Regulation for Dangerous Goods by Air Transport, Article 177) prescribing that the dangerous goods that have a dangerous chemical reaction to each other should be segregated.

The ARAIB found no evidence that the dangerous goods were stored in violation of Asiana Airlines' current regulations since the temporary DG storage area was furnished with DG-related agencies' latest contact information, DG
labelling chart, DG segregation chart, dangerous area warning markings, disposable gloves, steel drum, protective gloves, waste plastic bags, power absorbent, detergent, plastic shovels, and first-aid kit, in accordance with MOLIT Regulation for Dangerous Goods by Air Transport, Appendix 23.

### 2.6.4 Lithium-ion Battery Build-up and Loading

Lithium-ion batteries shipped onboard the accident airplane were regulated as Class 9 UN3480, Packing Group II, dangerous goods. They were in either a 6-cell or 12-cell configuration for use in hybrid electric vehicles. The individual cells were rated at 24.4 - 24.8 Ah at 3.65 volts and 89.1 - 90.5 Wh. The shipment contained a total of 18 lithium-ion batteries, including 15 of the 12-cell configuration and 3 of the 6-cell one.

According to the statement of the dangerous goods handling agent, fifteen 12-cell batteries were packed 1 per box in 15 fiberboard boxes, whereas three 6-cell batteries in 2 fiberboard boxes, with 2 per box and the remaining one per box. The batteries have the terminals covered with insulating material to prevent external short-circuit in transit, and they are wrapped with polyethylene that has a melting point of 122°C and secured with fiberboard inner packaging material fit for the shape of the battery. A sheet of impact-resistant bubble wrap was placed in the top of the box and closed to complete the packaging.

One box can be packed with two 6-cell batteries or one 12-cell battery. Since the weight of two 6-cell batteries and one 12-cell battery is approximately 16 kg and 14 kg, respectively, the ratio of 14 - 16 kg of the battery weight to 40 kg of the box's packing weight limit as a percentage is 40% or less.

The manufacturer's testing of lithium-ion batteries met the method and standards prescribed in the UN Manual of Tests and Criteria, Part III, subsection
38.3 of "UN Recommendations for Transport of Dangerous Goods." The batteries were shipped in appropriate packing materials that were manufactured to the UN standard for Packing Group II.

DG loading was performed in accordance with "MOLIT Regulation for Dangerous Goods by Air Transport, Article 180," IATA DGR, and ICAO T.I. MOLIT Regulation for Dangerous Goods by Air Transport, Article 180 (Loading and Fixing) specifies that DG packages and overpacks bearing the "Cargo Aircraft Only" label should be loaded according to one of the following methods: ① loaded in a Class C cargo compartment; ② loaded on ULDs equipped with the fire detection and extinguishing system approved by the Minister of MOLIT and in compliance with certification requirements of a Class C cargo compartment; and ③ easily confirmed and accessed by crewmembers, related personnel or authorized personnel during flight or in case of emergency, and segregated from other shipments if the dangerous goods' size and weight are within the allowable range. The ARAIB found no evidence that the dangerous goods were loaded in violation of Asiana Airlines' current regulations since the dangerous goods in a Class E cargo compartment were located near the aisle of the main deck cargo compartment accessible by the flight crew in accordance with the current laws and regulations.

Yet the ARAIB recommends that, for safer transportation of dangerous goods, flammable dangerous goods (Class 3) and lithium batteries (Class 9) bearing the "Cargo Aircraft Only" label 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) be loaded in a separate ULD and segregated from other flammable dangerous goods (Class 3).

2.6.5 Flammable Liquid Build-up and Loading
2.6.5.1 Photo-Resist/IC

This product is regulated as Class 3 UN1993, Packing Group III, flammable liquid. Transparent photo-resist solution in either a purple- or yellow-labeled glass container was loaded on pallets at positions ML and PR. Packaging was in accordance with ICAO TI Packing Instruction 366. The safety of the product is not affected by temperatures that exceed 10°C, but its marketability is negatively affected since its quality is compromised. The manufacturer in charge of product packaging enclosed the containers completely in clear and black plastic bags, respectively. Four of these glass containers were placed in one UN specification fiberboard box with 10 blue ice packs weighing 0.5 kg each and two digital temperature recorders, which, the ARAIB concludes, is suitable for air transportation.

The manufacturer handled the process from packaging to loading the product onto a transport vehicle. Yet its person in charge of DG packaging was not aware of the DG handling procedures and just understood that the product should be safely handled in a special custom-made durable box (UN specification) to be protected from damage in transit. The ARAIB recommends that, in accordance with Table 1-1 "Training Syllabus by Trainees" and Table 1-2 "Minimum Training Hours by Duty Categories" under MOLIT Regulation for Dangerous Goods by Air Transport, Article 14 (Training), the manufacturer's personnel who are delegated a packaging task by a dangerous goods handling agent receive the minimum DG-related training, i.e. Duty Category 2\(^\text{152)}\) DG training.

2.6.5.2 Photo-Resist/LCD

This product is a highly flammable liquid and is regulated as Class 3

\(^{152)}\) Duty Category 2: 16-hour training for employees in charge of DG packaging, consisting of 8 subjects in relation to DG handling (MOLIT Regulation for Dangerous Goods by Air Transport).
UN1866, Packing Group III, flammable liquid. Packaging was in accordance with ICAO TI Packing Instruction 355. The MSDS indicates that the flash point of the product is 41 - 47°C, and that the product may explode when heated. Photo-resist is used for LCD manufacturing, and it is either a bright blue or bright red liquid, designated by the "B" or the "R" in the product name. The integrity of the product is sensitive to temperature and light.

The product was contained in 53 brown plastic 10-liter containers, each of which was filled with 9 liters of a blue or red liquid. The containers were each enclosed in clear plastic bags and were packed 2 per 1 fiberboard box inside Styrofoam inserts with blue ice that keeps the product cold.

This product is stored at 5°C in the manufacturer's facility and transported in a refrigerated truck to a dangerous goods handling agent. The safety of this product is not affected by temperatures that exceed 5°C, but it is no longer marketable since the quality of the product is compromised. The dangerous goods handling agent repackaged the product by placing it inside Styrofoam inserts with 10 blue ice packs and 2 digital temperature recorders provided by the manufacturer. The ARAIB concludes that, apart from the basic DG packaging, the product was more safely repackaged to maintain its quality.

### 2.6.5.3 Paint

According to packaging for liquids specified in IATA DGR 55th edition, 5.0.2.7.1 and 5.0.2.7.2, the body and the closure of any packaging must be so constructed as to be able to adequately resist the effects of temperature and vibration occurring in normal conditions of transport. The closure device must be so designed that it can be completely closed and remains closed during transport. In addition, for the inner packaging containing liquids, closures must be held securely, tightly and effectively in place by secondary means. Examples of such
methods include: adhesive tape, friction sleeves, welding or soldering, positive locking wires, induction heat seals and child-resistant closures. When secondary means of closure cannot be applied, the inner packaging must be securely closed and placed in a leakproof liner and then placed in an outer packaging.

Flammable liquids (paint) loaded on the accident airplane were packaged by good-quality durable packaging materials that could endure impact during transport, and were sealed to prevent the contents from spilling due to a change of vibration, temperature, humidity, and pressure in normal conditions of transport, in compliance with the information provided by the manufacturer. Packaging materials were manufactured after tested by a specialized inspection agency, conformed to the tested design format, and were free from corrosion, contamination, and other damage prior to transportation.

The ARAIB found no evidence that paint was packaged in violation of Asiana Airlines' current regulations since the product was packaged in accordance with the current dangerous goods handling regulations, judging by the fact that paint containers were closed initially by a plastic lid and then by a metal screw cap, although not closed exactly by a secondary closure device mentioned above, and were placed in fiberboard boxes with Styrofoam inserts to prevent leakage.

2.6.5.4 Flammable Liquid Loading

Beginning January 2014, Asiana Airlines required that a copy of NOTOC listing the details of dangerous goods, specified in ICAO T.I Doc 9284, 7.4.1 and delivered to the captain, also be delivered to a flight dispatcher or a designated ground personnel responsible for flight operations, and then they examine the loaded status of the dangerous goods. Yet the ARAIB concludes that, in the case of AAR991, dangerous goods were loaded in accordance with more strict DG loading procedures than the requirement above since the
dangerous goods on board were photographed, and their photos were stored.

Also, the ARAIB concludes that DG checks before and after loading were appropriately conducted, judging by the fact that the loadmaster responsible for loading, together with the captain, personally inspected the locations and loaded status of the dangerous goods in the main deck cargo compartment when he provided NOTOC to the captain.

The ARAIB concludes that flammable dangerous goods loaded in a Class E cargo compartment were located near the aisle of the main deck cargo compartment accessible by the flight crew in accordance with MOLIT Regulation for Dangerous Goods by Air Transport, Article 180 (Loading and Fixing), paragraph 3 stating that "during operation or in case of emergency, crewmembers and relevant employees should easily check and access dangerous goods."

Yet the ARAIB recommends that, for safer transportation of dangerous goods, flammable dangerous goods (Class 3) bearing the "Cargo Aircraft Only" label 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.
3. Conclusions

3.1 Findings

1. The aircraft, HL7604, was manufactured by the Boeing Company on 15 February 2006. On 22 February 2006, it was delivered to Asiana Airlines and registered under the Korean Airworthiness Authority. The aircraft held a valid airworthiness certificate issued on 24 February 2006.

2. The flight crew of AAR991 held a valid airman certificate proper for operation and an airman medical certificate in accordance with the Aviation Act of the Republic of Korea.

3. Review of the maintenance history of the five months before the accident confirms that there were no faults and corrective actions in relation to this accident on the aircraft journey log.

4. The center of gravity (CG) in accordance with a flight plan was within the approved range of CG in accordance with a flight manual and the operating range of CG in accordance with company rules.

5. The weather conditions over Jeju Island and the accident site indicate that a southwest current of air and a westerly current of air flowed in at the middle and upper levels, respectively. Also, there were no convective cloud or other unusual weather phenomena.

6. On 28 July 2011, about 04:11, Asiana Airlines flight 991, a B747-400F airplane, crashed into the international waters about 130 km west of Jeju Airport after the flight crew reported a cargo fire to SHI ACC near a reporting point SADLI on airway A593 about 03:54 and attempted to divert
to Jeju Airport.

7. At 03:52:39, SHI ACC instructed AAR991, "AAR991 radar contact, off-set 5 miles right of track," and at 03:52:51, the flight crew acknowledged this instruction without mentioning a cargo fire.

8. At 03:54:23, the FO declared an emergency to SHI ACC due to a main deck cargo fire and requested a descent to 10,000 ft.

9. At 04:03:01, the FO called SHI ACC and stated that AAR991 was unable to contact FUK ACC. Consequently, SHI ACC instructed AAR991 to pass information to KAL886 and let KAL886 relay the information to FUK ACC and ICN ACC.

10. From 03:53 to 04:00, FDE messages were transmitted via ACARS. At 03:53, ACARS messages "CGO DET 11 MN DK" and "EQUIPMENT SMOKE" were first transmitted, followed by many other messages between 03:56 and 04:00, after which ACARS messages were not transmitted any more.

11. AAR991 had to exchange flight information via HUK ACC since there was no direct telephone line between SHI ACC and ICN ACC. As a result, a more rapid exchange of information on its emergency could not be made.

12. After the occurrence of an emergency, AAR991 attempted to communicate with ICN ACC on 124.525 MHz around 10,000 ft but to no avail, and thus, KAL886 flying at a higher altitude had to relay the information between AAR991 and ICN ACC.

13. AAR991 entered a communication dead zone while descending from 34,000 ft to 10,000 ft because of the location of the 124.525 MHz transceiver
antennas used for communication, thereby failing to communicate directly with ICN ACC.

14. Korea's AIP valid at the time of the accident did not contain frequency 128.375 MHz as an ATC frequency for airways A593 and B576, and the frequency was not used when AAR991 in an emergency situation was flying around 10,000 ft.

15. Immediately after being notified of AAR991’s accident, the ARAIB conducted search operations in four phases to locate the crash site and retrieve flight recorders. The Board recovered the chassis of the FDR but failed to locate its CSMU and the CVR.

16. The wreckage of AAR991 was distributed in the underwater area 3 km by 4 km, 130 km west of Jeju Airport, in southwest-northeast direction.

17. From 28 July 2011 to 10 June 2012, three times of wreckage recovery operations yielded about 40% of aircraft skin and about 15% of cargo.

18. According to wreckage examination results, blue photo-resist and electronic components loaded in the main deck cargo compartment were found on the top surface of the right wing.

19. The wreckage between FS1700 and APB, under which the pallets at positions ML and PR were located, sustained the most severe fire damage, and the evidence that smoke entered the flight deck was found.

20. Four out of the six riser ducts on AAR991 were recovered. All three left riser ducts sustained fire damage which was consistently more severe along the upper glass fiber portions and tapered off towards the bottom.
21. The ACARS message "ELT ON" was transmitted, but the distress signal was not received by any authorities concerned. The ELT installed on AAR991 is inoperable in the water.

22. The ARAIB awarded a contract to conduct "a study on wreckage reconstruction, and testing and analysis in relation to Asiana Airlines' crash accident," which dealt mainly with wreckage reconstruction, fire simulation, testing for determining the cause of a fire, etc.

23. As Asiana Airlines' simulator was a passenger configuration unable to support a full Fire Main Deck training for B747 freighters, pilots imagined that the simulator was a freighter and performed its non-normal procedures in the Fire Main Deck checklist.

24. AAR991 did not maintain 25,000 ft specified in the QRH's Fire Main Deck non-normal checklist. Judging from the size and condition of AAR991's fire, there is a possibility that, even if AAR991 had maintained 25,000 ft, the fire would not have been extinguished until the TOD point for Jeju Airport, and that, in this case, as an increase in oxygen during the descent had resulted in the spread of fire, the outcome of this accident would not have changed.

25. The flight crew failed to implement a procedure of operating the supernumerary oxygen switch, which was specified in the QRH's Fire Main Deck non-normal checklist.

26. It seems that the flight crew's implementation of the QRH's Fire Main Deck non-normal procedures was delayed.

27. The QRH available to the flight crew on AAR991 contained all procedures
applicable to Asiana Airlines' entire 747-400 fleet. This included two significantly different Fire Main Deck procedures, one unique to the 747-400 Combi and the other unique to the 747-400F.

28. There is a possibility that the flight crew implemented the Combi Fire Main Deck non-normal procedure instead of the Freighter one.

29. The QRH's non-normal procedures in relation to AAR991's fire situation were as follows: FIRE MAIN DECK; EQUIP COOLING; FIRE APU; Smoke Fire or Fumes; Smoke or Fumes Removal; and Ditching.

30. About 03:53, a fire was detected, and about 03:56, ACARS messages influencing flight control started to be generated.

31. Turbulence data from the ACMS was transmitted four times, about 03:57:23, 03:57:43, 03:58:47, and 03:59:29, while the aircraft was descending from 22,700 ft to 13,400 ft.

32. It is possible that the flight crew intentionally did not stay at 25,000 ft, fire suppression altitude, because they may have regarded their situation as serious, needing to make a ditching.

33. Boeing's B747 manuals for the flight crew failed to specify the basis for the 25,000 ft requirement, the effect and concept of fire suppression at 25,000 ft, and when to descend from 25,000 ft.

34. At 04:06:32, at 9,900 ft, the captain reported the loss of rudder control, and 04:09:47, at 12,800 ft, reported the loss of all flight controls, including rudder control, to ATCs. At 04:10:15, when the aircraft was flying at 423 kt at an altitude of 11,300 ft on a heading of 004°, the FO reported the loss
of altitude control and the impending ditching.

35. After notified of the recurrent simulation training syllabus and evaluation items in advance, the flight crew receive the training, and this kind of pre-notification compromises the flight crew's ability to judge and respond to unexpected situations and the effect of the CRM training. Therefore, it is necessary to improve Asiana Airlines' method of recurrent training and evaluation.

36. As the subject of Fire Main Deck that cannot be simulated as the same as on a B747 freighter is difficult to be selected as a recurrent training subject and thus less trained, the flight crew usually can possibly neglect the study of this subject.

37. As the captain in a B747 freighter's cockpit could not accurately check the size and the condition of a cargo fire, including whether it was suppressed, extinguished, or spread, it may have been difficult for him to determine whether a fire could be suppressed and how serious it was.

38. In the process of Asiana Airlines' acceptance, storage, and loading of dangerous goods in accordance with its current dangerous goods handling regulations and procedures, the ARAIB found no evidence that the company violated its current regulations and procedures.

39. The ARAIB visited the manufacturer of lithium-ion batteries and examined their safety, but failed to acquire the data that could prove the self-ignition possibility of the batteries.

40. Paint manufactured by a Japanese company provides moisture-proof insulating coating used for manufacturing mobile phones. It has a flash point of -1℃.
After a container of the product, tightly closed by internal and external closure devices and inserted in the enclosed plastic bag, was left for 2 hours at room temperature of 18°C, its volatile organic compound (VOC) emissions were measured, then detected, but when tested in the air transport environment (at a cabin altitude), were not detected. Also, it could not be proven whether internal and external closure devices of the product failed to function properly during AAR991’s flight.

41. Analysis of the ATC/pilot communications transcript and ACARS messages reveals that a fire occurred first in the aft fire zones rather than others. Thus, the ARAIB concludes that smoke was initially detected in fire zones 11 or 13.

42. When the FO communicated with SHI ACC at 03:52:51, he did not mention a fire, and the ARAIB thus concludes that a fire was initially detected between 03:52:51 and the time when "CGO DET 11 MN DK" was generated (03:53 - 03:54).

43. Review of the accident airplane's maintenance history revealed that no defect was caused by short-circuited wires.

44. The ARAIB assumes that a fire likely broke out first on or near the pallets containing dangerous goods, but physical evidence of the cause of the fire was not found.

45. After boarding the freighter with a similar flight pattern to that of the accident airplane, the ARAIB measured the amount of electrostatic energy accumulated in the plastic wrap used for cargo on the pallets, on one of which electrostatic energy measuring 0.23 mJ was found. Although this amount of energy was bigger than the MIE of a certain gas (methanol, one
of the molecules of paint, flammable material), it is difficult to conclude that electrostatic energy acted as an ignition source since flammable gas leakage tests revealed that VOCs were not detected at a cabin altitude (8,000 ft), same environment where the fire occurred on the accident airplane.

46. The ARAIB failed to acquire the data that could prove the self-ignition possibility of lithium-ion batteries in normal conditions of transport, but when they are heated externally, they can go into thermal runaway. The battery manufacturer argues that lithium-ion batteries are safe, but recalls have been issued because lithium-ion battery-operated computers caught on fire.

47. About 3 to 4 minutes after smoke detection, smoke spread rapidly throughout the main deck cargo compartment. Judging by the fact that a well defined soot trail was discovered on the exterior skin of the cockpit smoke evacuation shutter, smoke entered the flight deck. A fire did not spread beyond the APB.

48. The ARAIB concludes that powerful fire energy was produced to the extent that photo-resist/LCD and paint in position PR splattered on the top surface of the right wing, about 30 meters away from PR, that electronic components in position MR were imbedded in the composite wing upper surfaces, and that some portions of the fuselage separated from the airplane in midair.

49. Examination of two pieces of the reconstructed wreckage at FS2180 revealed that one piece of the wreckage could stand outward force because it was attached to the fuselage frame, whereas the skin of the other piece was bent outward due to energy on the inside. This indicates that the skin along the
wreckage sheared off in midair due to energy on the inside of the airplane.

50. The heat release from burning photo-resist in position ML is about 22.9 mega BTU. The total heat release from burning paint and photo-resist in position PR is about 19 mega BTU. A rapid increase in this thermal energy caused some portions of the fuselage to separate from the airplane in midair.

3.2 Causes

The Aviation and Railway Accident Investigation Board (ARAIB) determines the cause of this accident as follows:

A fire developed on or near the pallets containing dangerous goods but no physical evidence of the cause of the fire was found. The fire rapidly escalated into a large uncontained fire, and this caused some portions of the fuselage to separate from the aircraft in midair, thereby resulting in the crash.

3.3 Contributing Factors

1. Flammable materials like photo-resist (Class 3) were loaded in position ML, and flammable materials like paint, photo-resist, corrosive liquid, and lithium-ion batteries (Class 9) were loaded on one pallet in position PR.

2. It was difficult to contain a large scale of fire only by the fire suppression system of a Class E cargo compartment that was not equipped with an active fire suppression system.
4. Safety Recommendations

To Asiana Airlines

1. Ensure that flammable liquid dangerous goods (Class 3) and lithium batteries (Section 1, 1A)\textsuperscript{153} which are bearing the "Cargo Aircraft Only (CAO)" label are segregated and loaded on separate ULDs.

2. Load lithium batteries classified as dangerous goods (Section 1, 1A) in a Class C cargo compartment.

3. Produce and equip your aircraft with a QRH that contains only the procedures required for the operation of that specifically configured aircraft.

4. Operate your simulators in such a way that your flight crew can be realistically trained on non-normal procedures of a passenger, cargo or combi plane.

5. Add and run a recurrent simulation training program whose syllabus is not notified in advance to your flight crew to improve their ability to respond to unexpected non-normal situations, and give your flight crew more intensive training on non-normal situations.

To MOLIT (Office of Civil Aviation)

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

\textsuperscript{153} This refers to ICAO TI Packaging Instructions 965-967, Section 1, 1A.
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.

3. Develop loading standards for ensuring that flammable dangerous goods (Class 3) and lithium batteries classified as dangerous goods (Section 1, 1A) are loaded in a Class C cargo compartment or that they are loaded on ULDs equipped with a fire extinguishing system or made of fire-resistant materials.

4. Develop a Technical Standard Order (TSO) for ULDs to ensure that ULDs used for loading flammable dangerous goods or lithium batteries classified as dangerous goods (Section 1, 1A) are equipped with a fire extinguishing system or made of fire-resistant materials.

5. Prepare monitoring measures to ensure that manufacturers' personnel in charge of packaging dangerous goods perform their duty only after receiving dangerous goods-related training in accordance with Table 1-1 "Training Syllabus by Trainees" and Table 1-2 "Minimum Training Hours by Duty Categories" under MOLIT Regulation for Dangerous Goods by Air Transport, Article 14 (Training).

6. Revise related regulations to require Korean operators to produce a QRH that contains only the procedures required for the operation of each specifically configured aircraft (i.e. passenger, cargo or combi configuration).

7. Revise regulations related to simulation training to ensure that the flight
crew can be realistically trained on non-normal procedures of a passenger, cargo or combi plane.

8. Monitor whether Korean operators add and run their recurrent simulation training program whose syllabus is not notified in advance to the flight crew to improve their ability to respond to unexpected non-normal situations.

9. Study the correlation of fire with electrostatic energy that can be accumulated in the plastic wrap used for pallets on the ground and during flight, and develop standards for the use of the plastic wrap.

10. Establish a communications network between ICN ACC and SHI ACC so that they can exchange flight information directly.

11. Contain the use of frequency 128.375 MHz in the AIP so that airplanes on airways A593 and B576 can communicate with ATCs on that frequency.

To the Boeing Company

1. Seek feasible measures to improve a B747 freighter system, including development of a visual means for helping pilots in the cockpit check the condition of a cargo fire, including whether it is suppressed, extinguished, or spread, and determine whether a fire can be contained.

2. Conduct research that seeks measures to equip a freighter's Class E cargo compartment with an active fire extinguishing or suppression system controllable from the cockpit, like that of a Class C cargo compartment.
3. Ensure that its B747-400 Flight Crew Operations manuals (FCOM or equivalent) contain specific information on the basis for the 25,000 ft requirement, the effect of the fire suppression complying with the 25,000 ft requirement, and strategies to be considered for when to begin a descent to land from that altitude.

**To ICAO**

Recommend your Flight Data Recovery Working Group\(^{154}\) to deal with the following issues:

1. Address the ULB's weakness of being vulnerable to heat.

2. Resolve problems facing when the ULB is buried under the sea floor consisting of thick mud and sand.

3. Ensure that the chassis will not be separated from the CSMU.

4. Seek ways to install an ELT that can float to the water surface and operate, or be operable in the water.

5. Develop a deployable ELT broadcasting a GPS position.

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\(^{154}\) An international working group created to resolve technical problems about the recovery of recorders in the three following areas: flight data transmission; new flight recorder technology; and wreckage localization technology.
APPENDIXES

1. ACARS CMC Data Interpretation
2. Time-Based Aircraft Status and Events
3. Incheon Area Control Center's Radar Data
4. ATC Communication Transcript
5. Search Operations for Flight Recorders
6. Aircraft Cockpit Examination
7. AAR991's Flight Documents
9. QRH Procedures in Relation to AAR991's Fire
10. Results of Tests and Research
APPENDIX 1: ACRAS CMC Data Interpretation

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CARGO FIRE MAIN DECK ZONE-11 LOOP-

The Zone 11A detector was in alarm for at least 8 seconds without the Zone 11B detector being in alarm or the 11A detector failed to pass a “disagree” test from the zone 11 AFOLTS card or the wire from the zone 11A detector to the AFOLTS was open circuit when a “disagree” test was performed. Because this fault was correlated to “CGO DET 11 MN DK” and not to “MD CGO 11 LP A”, the Zone 11B detector was in alarm or faulted within 20 seconds of the Zone 11A detector. The above message would be consistent with Zone 11A and Zone 11B detectors being in alarm (detecting smoke) more than 8 seconds but less than 20 seconds apart.

<table>
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E/E COOLING SMOKE DETECTED

The Forward Equipment Cooling System includes a flow-through photoelectric type smoke detector in the exhaust (ventilation) portion of the system. Airflow from the main E/E bay ventilation hoods and the flight deck exhaust piccolo ducts is drawn-through the system by the exhaust fan, and a small portion of the fan outlet air is routed to the smoke detector for sampling. When smoke is detected by this smoke detector, a discrete electrical ground signal from the smoke detector will be output and sensed as an input to the EIU's. The EICAS Caution level message EQUIP COOLING and Status level message EQUIPMENT SMOKE will be displayed immediately by the EIU's. The EIU's will send the smoke detected signal to the CMC via the ARINC 429 digital bus. The CMC message 21422 E/E COOLING SMOKE DETECTED will be set by the CMC when it sees the E/E Cooling Smoke Detected ARINC 429 signal for 3 continuous seconds. The EICAS Caution level message EQUIP COOLING will go away if the smoke detector is no longer providing the discrete electrical ground signal (smoke is no longer being detected by the smoke detector). If the aircraft is in the air, the EICAS Status level message EQUIPMENT SMOKE will be latched in the Non-Volatile Memory (NVM) of the EIU's. All three messages (the two EICAS messages and the one CMC message) will be inhibited (by the use of relays to break the electrical ground signal from the smoke detector to the EIU's) for any of the following conditions: 1) Main Deck Cargo Compartment is ARMED, 2) Either the Forward or Aft Lower Lobe Cargo Compartment is ARMED, or 3) the Equipment Cooling System is in a Self-Test Mode (which normally occurs 30 secs after landing after 10 flight legs).

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Appendix 1.

18:53  21422  E/E COOLING SMOKE DETECTED

The Forward Equipment Cooling System includes a flow-through photoelectric type smoke detector in the exhaust (ventilation) portion of the system. Airflow from the main E/E bay ventilation hoods and the flight deck exhaust plenum ducts is drawn-through the system by the exhaust fan, and a small portion of the fan outlet air is routed to the smoke detector for sampling. When smoke is detected by this smoke detector, a discrete electrical ground signal from the smoke detector will be output and sensed as an input to the EIU's. The EICAS Caution level message EQUIP COOLING and Status level message EQUIPMENT SMOKE will be displayed immediately by the EIUs. The EIUs will send the smoke detected signal to the CMC via the ARINC 429 digital bus. The CMC message 21422 E/E COOLING SMOKE DETECTED will be set by the CMC when it sees the E/E Cooling Smoke Detected ARINC 429 signal for 3 continuous seconds. The EICAS Caution level message EQUIP COOLING will go away if the smoke detector is no longer providing the discrete electrical ground signal (smoke is no longer being detected by the smoke detector). If the aircraft is in the air, the EICAS Status level message EQUIPMENT SMOKE will be latched in the Non-Volatile Memory (NVM) of the EIUs. All three messages (the two EICAS messages and the one CMC message) will be inhibited (by the use of relays to break the electrical ground signal from the smoke detector to the EIUs) for any of the following conditions: 1) Main Deck Cargo Compartment is ARMED, 2) Either the Forward or Aft Lower Lobe Cargo Compartment is ARMED, or 3) the Equipment Cooling System is in a Self-Test Mode (which normally occurs 30 seconds after landing after 10 flight legs).

18:54  26328  CARGO FIRE MAIN DECK ZONE-10 LOOP-A

The Zone 10A detector was in alarm for at least 8 seconds without the Zone 10B detector in alarm or the 10A detector failed to pass a “disagree” test from the zone 10 AFOLTS card or the wire from the zone 10A detector to the AFOLTS was open circuit when a “disagree” test was performed. Because this fault was correlated to “CGO DET 10 MN DK” and not to “MD CGO 10 LP A”, the Zone 10B detector was in alarm or faulty within 20 seconds of the Zone 10A detector. The above message would be consistent with Zone 10A and Zone 10B detectors being in alarm (detecting smoke) more than 8 second but less than 20 seconds apart.

18:54  26329  CARGO FIRE MAIN DECK ZONE-6 LOOP-A

The Zone 6A detector was in alarm for at least 8 seconds without the Zone 6B detector in alarm or the 6A detector failed to pass a “disagree” test from the zone 6 AFOLTS card or the wire from the zone 6A detector to the AFOLTS was open circuit when a “disagree” test was performed. Because this fault was correlated to “CGO DET 6 MN DK” and not to “MD CGO 6 LP A”, the Zone 6B detector was in alarm or faulty within 20 seconds of the Zone 6A detector. The above message would be consistent with Zone 6A and Zone 6B detectors being in alarm (detecting smoke) more than 8 second but less than 20 seconds apart.

5/11/2015
### CARGO FIRE MAIN DECK ZONE-7 LOOP-A

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The Zone 7A detector was in alarm for at least 8 seconds without the Zone 7B detector being in alarm or the 7A detector failed to pass a “disagree” test from the zone 7 AFOLTS card or the wire from the zone 7A detector to the AFOLTS was open circuit when a “disagree” test was performed. Because this fault was correlated to “CGO DET 7 MN DK” and not to “MD CGO 7 LP A”, the Zone 7B detector was in alarm or faulted within 20 seconds of the Zone 7A detector. The above message would be consistent with Zone 7A and Zone 7B detectors being in alarm (detecting smoke) more than 8 second but less than 20 seconds apart.

### CARGO FIRE MAIN DECK ZONE-3 LOOP-A

<table>
<thead>
<tr>
<th>Time</th>
<th>Code</th>
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<th>Reason</th>
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</thead>
<tbody>
<tr>
<td>18:55</td>
<td>26314</td>
<td>FAIL</td>
<td>Intermittent</td>
<td>Inactive</td>
</tr>
</tbody>
</table>

The Zone 3A detector was in alarm for at least 8 seconds without the Zone 3B detector being in alarm or the 3A detector failed to pass a “disagree” test from the zone 3 AFOLTS card or the wire from the zone 3A detector to the AFOLTS was open circuit when a “disagree” test was performed. Because this fault was correlated to “CGO DET 3 MN DK” and not to “MD CGO 3 LP A”, the Zone 3B detector was in alarm or faulted within 20 seconds of the Zone 3A detector. The above message would be consistent with Zone 3A and Zone 3B detectors being in alarm (detecting smoke) more than 8 second but less than 20 seconds apart.

### CARGO FIRE MAIN DECK ZONE-8 LOOP-A

<table>
<thead>
<tr>
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<th>Code</th>
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<th>Condition</th>
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<tr>
<td>18:55</td>
<td>26324</td>
<td>FAIL</td>
<td>Intermittent</td>
<td>Inactive</td>
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</table>

The Zone 8A detector was in alarm for at least 8 seconds without the Zone 8B detector being in alarm or the 8A detector failed to pass a “disagree” test from the zone 8 AFOLTS card or the wire from the zone 8A detector to the AFOLTS was open circuit when a “disagree” test was performed. Because this fault was correlated to “CGO DET 8 MN DK” and not to “MD CGO 8 LP A”, the Zone 8B detector was in alarm or faulted within 20 seconds of the Zone 8A detector. The above message would be consistent with Zone 8A and Zone 8B detectors being in alarm (detecting smoke) more than 8 second but less than 20 seconds apart.

### CARGO FIRE MAIN DECK ZONE-4 LOOP-A

<table>
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<tr>
<td>18:55</td>
<td>26316</td>
<td>FAIL</td>
<td>Intermittent</td>
<td>Inactive</td>
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</table>

The Zone 4A detector was in alarm for at least 8 seconds without the Zone 4B detector being in alarm or the 4A detector failed to pass a “disagree” test from the zone 4 AFOLTS card or the wire from the zone 4A detector to the AFOLTS was open circuit when a “disagree” test was performed. Because this fault was correlated to “CGO DET 4 MN DK” and not to “MD CGO 4 LP A”, the Zone 4B detector was in alarm or faulted within 20 seconds of the Zone 4A detector. The above message would be consistent with Zone 4A and Zone 4B detectors being in alarm (detecting smoke) more than 8 second but less than 20 seconds apart.
Appendix 1.

ACARS CMC Data Interpretation

CARGO FIRE MAIN DECK ZONE-5 LOOP-B
18:55 26319 FAIL Intermittent Inactive DK
The Zone 5B detector was in alarm for at least 8 seconds without the Zone 5A detector being in alarm or the 5B detector failed to pass a “disagree” test from the zone 5 AFOLTS card or the wire from the zone 5B detector to the AFOLTS was open circuit when a “disagree” test was performed. Because this fault was correlated to “CGO DET 5 MN DK” and not to “MD CGO 5 LP B”, the Zone 5A detector was in alarm or faulted within 20 seconds of the Zone 5B detector. The above message would be consistent with Zone 5B and Zone 5A detectors being in alarm (detecting smoke) more than 8 second but less than 20 seconds apart.

CARGO FIRE MAIN DECK ZONE-16 LOOP-
18:55 26340 A FAIL Intermittent Inactive DK
The Zone 16A detector was in alarm for at least 8 seconds without the Zone 16B detector being in alarm or the 16A detector failed to pass a “disagree” test from the zone 16 AFOLTS card or the wire from the zone 16A detector to the AFOLTS was open circuit when a “disagree” test was performed. Because this fault was correlated to “CGO DET 16 MN DK” and not to “MD CGO 16 LP A”, the Zone 16B detector was in alarm or faulted within 20 seconds of the Zone 16A detector. The above message would be consistent with Zone 16A and Zone 16B detectors being in alarm (detecting smoke) more than 8 second but less than 20 seconds apart.

18:57 27201 SRM-R FAIL (SRM-R) Hard Active >STAB TRIM 2 274 005 00 STATUS
The SRM has experienced a non-recoverable failure. All discrete outputs are set to invalid, all ARINC 429 output labels have their SSM set to FAIL. All engaged relays are disengaged. Cyclic Redundancy Check failures of the Read Only Memory, the absence of subroutine activity, loss of the other channel (ARM or CONTROL) function for 3 seconds, changes in software iteration rate of the other channel (+150 % or -75%) and erroneous values published by the background monitor in the other channel all could cause the SRM FAIL message. Left or Right SRM is determined by the EIU based on SRM position.

HYD-2 STAB TRIM ACT BRAKE RELEASE
18:56 27292 SW FAIL (SRM-R) Hard Active >STAB TRIM 2 274 005 00 STATUS
The STCM secondary brake released for at least 2 seconds without either a valid SRM output trim command or an alternate electric trim command or the STCM secondary brake did not release within 2 seconds of a valid trim command when the stabilizer is within electric operating range, hydraulic pressure is high and STAB TRIM CONT 28 volts is present.

5/11/2015
18:56 27503 FLIGHT CONTROLS PSM RIGHT 1 FAIL  Hard  Active  F/D BAR BIAS  221 077 00  ADVISORY
The Flight Controls Electronics Power Supply Module Right 2 has detected a fault with one of the four power supplies (+15 Vdc, +5 Vdc, -15 Vdc or 26 Vac) or Power Supply Module Right 1 is missing (not connected).

18:57 22989 FCC-R FAIL (NO BUS OUTPUTS)  Hard  Active  F/D BAR BIAS  221 077 00  ADVISORY
Several systems reported failure of FCC-R. The Central Maintenance Computers, EFIS/EICAS Interface Units, Stabilizer Trim/Rudder Ratio Changer Modules, and/or cross-channel FCCs may have reported this problem. The cause could be an actual failure of FCC-R, or of the output bus interface from the FCC to one or more of the other systems.

18:58 34012 FMC-R TO FMC-L RESYNC (FMC-R)  Hard  Active  F/D BAR BIAS  221 077 00  ADVISORY
indicates that the Right FMC has detected that the left FMC is master, but the intersystem bus from the Left FMC to the right FMC is failed or inactive. The signal is held up for at least 60 seconds after the R FMC starts to report that the intersystem bus from the L FMC is failed or inactive.

18:57 27504 FLIGHT CONTROLS PSM RIGHT 2 FAIL  Hard  Active  F/D BAR BIAS  221 077 00  ADVISORY
The Flight Controls Electronics Power Supply Module Right 1 has detected a fault with one of the four power supplies (+15 Vdc, +5 Vdc, -15 Vdc or 26 Vac) or Power Supply Module Right 2 is missing (not connected).

18:58 34737 FMC-L FAIL (NO BUS OUTPUTS)  Intermittent  Inactive  F/D BAR BIAS  221 077 00  ADVISORY
EIUs are all valid and OK, the FMC power is OK, and all three EIUs and any MCDU report the L-FMC output buses failed for 5 seconds and the FMC is not in ground test.

18:57 27001 SRM-L FAIL (SRM-L)  Hard  Active  STAB TRIM  274 004 00  STATUS
The SRM has experienced a non-recoverable failure. All discrete outputs are set to invalid, all ARINC 429 output labels have their SSM set to FAIL. All engaged relays are disengaged. Cyclic Redundancy Check failures of the Read Only Memory, the absence of subroutine activity, loss of the other channel (ARM or CONTROL) function for 3 seconds, changes in software iteration rate of the other channel (+150 % or -75%) and erroneous values published by the background monitor in the other channel all could cause the SRM FAIL message. Left or Right SRM is determined by the EIU based on SRM position.

18:57 27201 SRM-R FAIL (SRM-R)  Hard  Active  STAB TRIM  274 004 00  STATUS
The SRM has experienced a non-recoverable failure. All discrete outputs are set to invalid, all ARINC 429 output labels have their SSM set to FAIL. All engaged relays are disengaged. Cyclic Redundancy Check failures of the Read Only Memory, the absence of subroutine activity, loss of
the other channel (ARM or CONTROL) function for 3 seconds, changes in software iteration rate of the other channel (+150 % or -75%) and erroneous values published by the background monitor in the other channel all could cause the SRM FAIL message. Left or Right SRM is determined by the EIU based on SRM position.

**HYD-2 STAB TRIM ACT BRAKE RELEASE**

18:56 27292  SW FAIL (SRM-R)  Hard Active STAB TRIM 274 004 00 STATUS
The STCM secondary brake released for at least 2 seconds without either a valid SRM output trim command or an alternate electric trim command or the STCM secondary brake did not release within 2 seconds of a valid trim command when the stabilizer is within electric operating range, hydraulic pressure is high and STAB TRIM CONT 28 volts is present.

18:57 27504  FLIGHT CONTROLS PSM RIGHT 2 FAIL  Hard Active STAB TRIM 274 004 00 STATUS
The Flight Controls Electronics Power Supply Module Right 1 has detected a fault with one of the four power supplies (+15 Vdc, +5 Vdc, -15 Vdc or 26 Vac) or Power Supply Module Right 2 is missing (not connected).

18:57 22651  YDM-LWR FAIL  Hard Active YAW DAMPER 222 102 00 STATUS
The lower yaw damper has detected a fault with the auto disengage relay, or a modal suppression accelerometer input is less than -0.425 g or greater than 0.425 g for 1 second, or the CONTROL or MONITOR channel has detected a rudder command difference of 0.35 Vrms for more than 0.5 seconds, or an internal yaw damper module fault has been detected.

18:56 22679  EXCITATION FAIL (YDM-LWR)  Hard Active LWR 222 102 00 STATUS
The lower YDM CONTROL processor has detected that the AC reference voltage output to the upper yaw damper servo LVDT has dropped below 18 Vrms for more than 1.5 seconds.

18:56 27503  FLIGHT CONTROLS PSM RIGHT 1 FAIL  Hard Active LWR 222 102 00 STATUS
The Flight Controls Electronics Power Supply Module Right 2 has detected a fault with one of the four power supplies (+15 Vdc, +5 Vdc, -15 Vdc or 26 Vac) or Power Supply Module Right 1 is missing (not connected).

**AFT SPD CARD FAIL OR AFT SPD CARD**

18:56 27970  OUTPUT BUS FAIL  Hard Active LWR 222 102 00 STATUS
The aft Surface Position Digitizer card has detected an internal fault, or the EIU has no input from the aft Surface Position Digitizer card.

5/11/2015
18:57 27504 FLIGHT CONTROLS PSM RIGHT 2 FAIL Hard Active A/P SINGLE SYS 221 084 00 STATUS
The Flight Controls Electronics Power Supply Module Right 1 has detected a fault with one of the four power supplies (+15 Vdc, +5 Vdc, -15 Vdc or 26 Vac) or Power Supply Module Right 2 is missing (not connected).

18:56 27503 FLIGHT CONTROLS PSM RIGHT 1 FAIL Hard Active A/P SINGLE SYS 221 084 00 STATUS
The Flight Controls Electronics Power Supply Module Right 2 has detected a fault with one of the four power supplies (+15 Vdc, +5 Vdc, -15 Vdc or 26 Vac) or Power Supply Module Right 1 is missing (not connected).

18:56 27503 FLIGHT CONTROLS PSM RIGHT 1 FAIL Hard Active FLAP SYS MONITOR 275 002 00 STATUS
The Flight Controls Electronics Power Supply Module Right 2 has detected a fault with one of the four power supplies (+15 Vdc, +5 Vdc, -15 Vdc or 26 Vac) or Power Supply Module Right 1 is missing (not connected).

18:57 27504 FLIGHT CONTROLS PSM RIGHT 2 FAIL Hard Active FLAP SYS MONITOR 275 002 00 STATUS
The Flight Controls Electronics Power Supply Module Right 1 has detected a fault with one of the four power supplies (+15 Vdc, +5 Vdc, -15 Vdc or 26 Vac) or Power Supply Module Right 2 is missing (not connected).

18:57 16006 FLAP 26 VAC 2 INTERFACE 1 FAIL Hard Active FLAP SYS MONITOR 275 002 00 STATUS
FCUs C & R report: 26 VAC 2 FAIL (26 VAC 2 comes from M7360 FCE POWER SUPPLY-1 RIGHT)

18:57 27746 FLAP 26 VAC-3 > FCU-R INTERFACE FAIL Hard Active FLAP SYS MONITOR 275 002 00 STATUS
FCU R reports: 26 VAC 3 FAIL (26 VAC 3 comes from M7361 FCE POWER SUPPLY-2 RIGHT)

18:57 22989 FCC-R FAIL (NO BUS OUTPUTS) Hard Active NO AUTOLAND 221 083 00 STATUS
Several systems reported failure of FCC-R. The Central Maintenance Computers, EFIS/EICAS Interface Units, Stabilizer Trim/Rudder Ratio Changer Modules, and/or cross-channel FCCs may have reported this problem. The cause could be an actual failure of FCC-R, or of the output bus interface from the FCC to one or more of the other systems.

18:57 27001 SRM-L FAIL (SRM-L) Hard Active NO AUTOLAND 221 083 00 STATUS
The SRM has experienced a non-recoverable failure. All discrete outputs are set to invalid, all ARINC 429 output labels have their SSM set to FAIL. All engaged relays are disengaged. Cyclic Redundancy Check failures of the Read Only Memory, the absence of subroutine activity, loss of the other channel (ARM or CONTROL) function for 3 seconds, changes in software iteration rate of the other channel (+150 % or -75%) and erroneous values
Appendix 1.

ACARS CMC Data Interpretation

published by the background monitor in the other channel all could cause the SRM FAIL message. Left or Right SRM is determined by the EIU based on SRM position.

18:57 27201 SRM-R FAIL (SRM-R) Hard Active NO AUTOLAND 221 083 00 STATUS
The SRM has experienced a non-recoverable failure. All discrete outputs are set to invalid, all ARINC 429 output labels have their SSM set to FAIL. All engaged relays are disengaged. Cyclic Redundancy Check failures of the Read Only Memory, the absence of subroutine activity, loss of the other channel (ARM or CONTROL) function for 3 seconds, changes in software iteration rate of the other channel (+150 % or -75%) and erroneous values published by the background monitor in the other channel all could cause the SRM FAIL message. Left or Right SRM is determined by the EIU based on SRM position.

18:56 27503 FLIGHT CONTROLS PSM RIGHT 1 FAIL Hard Active NO AUTOLAND 221 083 00 STATUS
The Flight Controls Electronics Power Supply Module Right 2 has detected a fault with one of the four power supplies (+15 Vdc, +5 Vdc, -15 Vdc or 26 Vac) or Power Supply Module Right 1 is missing (not connected).

18:57 27504 FLIGHT CONTROLS PSM RIGHT 2 FAIL Hard Active NO AUTOLAND 221 083 00 STATUS
The Flight Controls Electronics Power Supply Module Right 1 has detected a fault with one of the four power supplies (+15 Vdc, +5 Vdc, -15 Vdc or 26 Vac) or Power Supply Module Right 2 is missing (not connected).

18:58 34012 FMC-R TO FMC-L RESYNC (FMC-R) Intermittent Inactive NO AUTOLAND 221 083 00 STATUS
indicates that the Right FMC has detected that the left FMC is master, but the intersystem bus from the Left FMC to the right FMC is failed or inactive. The signal is held up for at least 60 seconds after the R FMC starts to report that the intersystem bus from the L FMC is failed or inactive.

18:58 34737 FMC-L FAIL (NO BUS OUTPUTS) Intermittent Inactive NO AUTOLAND 221 083 00 STATUS
EIUs are all valid and OK, the FMC power is OK, and all three EIUs and any MCDU report the L-FMC output buses failed for 5 seconds and the FMC is not in ground test.

18:59 22943 ELEVATOR SERVO-C/FCC-C FAIL Intermittent Inactive NO AUTOLAND 221 083 00 STATUS
A fault was detected in the actuator control loop between FCC-C and the center elevator autopilot servo. Elevator servo or force link common mode monitors may have detected shorted/broken wires or loss of LVDT excitation or the elevator servo command/response monitor may have detected a failure of the servo to move when commanded. The underlying failure may be in the FCC, the servo, the interface wiring, or the hydraulic supply to the servo.

5/11/2015
18:59 22501 RUDDER SERVO-C/FCC-C FAIL
Intermittent Inactive NO AUTOLAND 221 083 00 STATUS
A fault was detected in the actuator control loop between FCC-C and the center rudder autopilot servo. Rudder servo or force link common mode monitors may have detected shorted/broken wires or loss of LVDT excitation or the rudder servo command/response monitor may have detected a failure of the servo to move when commanded. The underlying failure may be in the FCC, the servo, the interface wiring, or the hydraulic supply to the servo.

19:00 22494 AILERON SERVO-C/FCC-C FAIL
Hard Active NO AUTOLAND 221 083 00 STATUS
A fault was detected in the actuator control loop between FCC-C and the center aileron autopilot servo. Aileron servo or force link common mode monitors may have detected shorted/broken wires or loss of LVDT excitation or the aileron servo command/response monitor may have detected a failure of the servo to move when commanded. The underlying failure may be in the FCC, the servo, the interface wiring, or the hydraulic supply to the servo.

19:01 22540 FCC-L~FCC-C INTERFACE FAIL
Hard Active NO AUTOLAND 221 083 00 STATUS
A failure in the cross-channel data bus transmitting from FCC-L to FCC-C was detected by the FCC cross-channel test word monitor. FCC-L may have lost power or shut down, or wiring may have failed between the FCC-L CROSS CHANNEL RIGHT output and the FCC-C CROSS CHANNEL LEFT input.

CARGO FIRE EXTINGUISHER ARMED ‘NO ACTION REQUIRED’
18:56 26177
Hard Active PACK 2 215 018 00 ADVISORY
The “CARGO FIRE EXTINGUISHER ARMED ‘NO ACTION REQUIRED’” message can be set by either pushing the Fwd, Aft or Main Deck Cargo Fire Arm switch. Arming the cargo fire extinguishing system will automatically shutdown Pack 2 and Pack 3 during normal operations (all Packs operational). The PACK 1, PACK 2 or PACK 3 advisory message will be set when the pack is commanded on but is detected off e.g. the Pack 2 selector switch is in the NORM position while PACK 2 is commanded off due to a cargo compartment being ARMed).

CARGO FIRE EXTINGUISHER ARMED ‘NO ACTION REQUIRED’
18:56 26177
Hard Active PACK 3 215 020 00 ADVISORY
The “CARGO FIRE EXTINGUISHER ARMED ‘NO ACTION REQUIRED’” message can be set by either pushing the Fwd, Aft or Main Deck Cargo Fire Arm switch. Arming the cargo fire extinguishing system will automatically shutdown Pack 2 and Pack 3 during normal operations (all Packs operational). The PACK 1, PACK 2 or PACK 3 advisory message will be set when the pack is commanded on but is detected off e.g. the Pack 2 selector switch is in the NORM position while PACK 2 is commanded off due to a cargo compartment being ARMed).
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19:00  21138  PACK 3 AIR FLOW SENSOR/WIRE FAIL  Hard  Active  PACK 3  215 020 00  ADVISORY
The Pack Air Flow Sensor failure message will be set if the Flow Control Valve (FCV) is detected NOT closed and measured flow is lower than 100 CFM for 75 seconds or the FCV is commanded closed and measured flow is greater than 3400 CFM for 75 seconds. The Pack Air Flow Sensor failure message is inhibited if the FCV failure message is already set.

19:02  21135  FLOW CONTROL VALVE-3/WIRING FAIL  Hard  Active  PACK 3  215 020 00  ADVISORY
The Pack Flow Control Valve (FCV) fault message will be set if the FCV is commanded close and the FCV is detected not closed for 60 seconds. The FCS is detected closed by a position switch which sends a ground analog discrete to the PTC.

18:56  23204  SATCOM SDU FAIL (NO BUS OUTPUTS)  Hard  Active  SATCOM SYSTEM  232 521 00  STATUS
CMC, MCDU and SCID-3 systems indicating they were not receiving the expected labels from SDU.
This is a Consolidated Message (CMC AND (CDU-L OR -C OR -R) AND ((SCID-3 AND OPTION SELECTED) OR OPTION NOT SELECTED) REPORT FAILURE.

18:56  23204  SATCOM SDU FAIL (NO BUS OUTPUTS)  Hard  Active  >SATCOM  232 501 00  STATUS
CMC, MCDU and SCID-3 systems indicating they were not receiving the expected labels from SDU.
This is a Consolidated Message (CMC AND (CDU-L OR -C OR -R) AND ((SCID-3 AND OPTION SELECTED) OR OPTION NOT SELECTED) REPORT FAILURE.

18:57  22989  FCC-R FAIL (NO BUS OUTPUTS)  Hard  Active  >NO LAND 3  221 006 00  ADVISORY
Several systems reported failure of FCC-R. The Central Maintenance Computers, EFIS/EICAS Interface Units, Stabilizer Trim/Rudder Ratio Changer Modules, and/or cross-channel FCCs may have reported this problem. The cause could be an actual failure of FCC-R, or of the output bus interface from the FCC to one or more of the other systems.

18:57  27001  SRM-L FAIL (SRM-L)  Hard  Active  >NO LAND 3  221 006 00  ADVISORY
The SRM has experienced a non-recoverable failure. All discrete outputs are set to invalid, all ARINC 429 output labels have their SSM set to FAIL. All engaged relays are disengaged. Cyclic Redundancy Check failures of the Read Only Memory, the absence of subroutine activity, loss of the other channel (ARM or CONTROL) function for 3 seconds, changes in software iteration rate of the other channel (+150 % or -75%) and erroneous values published by the background monitor in the other channel all could cause the SRM FAIL message. Left or Right SRM is determined by the EIU based on SRM position.

5/11/2015
<table>
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<tr>
<th>Time</th>
<th>Event Description</th>
<th>Status</th>
<th>Result</th>
<th>Code</th>
<th>Type</th>
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<td>SRM-R FAIL (SRM-R)</td>
<td>Hard</td>
<td>Active &gt;NO LAND 3</td>
<td>221 006 00</td>
<td>ADVISORY</td>
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<td>The SRM has experienced a non-recoverable failure.</td>
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<td>All discrete outputs are set to invalid, all ARINC 429</td>
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<td>output labels have their SSM set to FAIL. All engaged</td>
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<td>relays are disengaged. Cyclic Redundancy Check</td>
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<td>failures of the Read Only Memory, the absence of</td>
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<td>subroutine activity, loss of the other channel (ARM</td>
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<td>or CONTROL) function for 3 seconds, changes in</td>
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<td>software iteration rate of the other channel (+150 %</td>
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<td>or -75%) and erroneous values published by the</td>
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<td>background monitor in the other channel all could</td>
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<td>cause the SRM FAIL message. Left or Right SRM is</td>
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<td>determined by the EIU based on SRM position.</td>
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<tr>
<td>18:56</td>
<td>FLIGHT CONTROLS PSM RIGHT 1 FAIL</td>
<td>Hard</td>
<td>Active &gt;NO LAND 3</td>
<td>221 006 00</td>
<td>ADVISORY</td>
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<td></td>
<td>The Flight Controls Electronics Power Supply Module</td>
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<td>Right 2 has detected a fault with one of the four</td>
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<td>power supplies (+15 Vdc, +5 Vdc, -15 Vdc or 26 Vdc)</td>
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<td></td>
<td>or Power Supply Module Right 1 is missing (not</td>
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<td>connected).</td>
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<td>18:57</td>
<td>FLIGHT CONTROLS PSM RIGHT 2 FAIL</td>
<td>Hard</td>
<td>Active &gt;NO LAND 3</td>
<td>221 006 00</td>
<td>ADVISORY</td>
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<td></td>
<td>The Flight Controls Electronics Power Supply Module</td>
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<td>Right 1 has detected a fault with one of the four</td>
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<td>power supplies (+15 Vdc, +5 Vdc, -15 Vdc or 26 Vdc)</td>
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<td>or Power Supply Module Right 2 is missing (not</td>
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<td>connected).</td>
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<tr>
<td>18:58</td>
<td>FMC-R TO FMC-L RESYNC (FMC-R)</td>
<td>Intermittent</td>
<td>Inactive &gt;NO LAND 3</td>
<td>221 006 00</td>
<td>ADVISORY</td>
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<td></td>
<td>indicates that the Right FMC has detected the</td>
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<td>left FMC is master, but the intersystem bus from the</td>
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<td>Left FMC to the right FMC is failed or inactive. The</td>
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<td>signal is held up for at least 60 seconds after the R</td>
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<td></td>
<td>FMC starts to report that the intersystem bus from the</td>
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<td></td>
<td>L FMC is failed or inactive.</td>
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<tr>
<td>18:58</td>
<td>FMC-L FAIL (NO BUS OUTPUTS)</td>
<td>Intermittent</td>
<td>Inactive &gt;NO LAND 3</td>
<td>221 006 00</td>
<td>ADVISORY</td>
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<td>EIU's are all valid and OK, the FMC power is OK, and</td>
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<td>all three EIUs and any MCDU report the L-FMC output</td>
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<td>buses failed for 5 seconds and the FMC is not in</td>
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<td>ground test.</td>
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<td>18:57</td>
<td>FCC-R FAIL (NO BUS OUTPUTS)</td>
<td>Hard</td>
<td>Active &gt;NO AUTOLAND</td>
<td>221 004 00</td>
<td>ADVISORY</td>
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<td>Several systems reported failure of FCC-R. The</td>
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<td>Central Maintenance Computers, EFIS/EICAS Interface</td>
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<td>Units, Stabilizer Trim/Rudder Ratio Changer Modules,</td>
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<td>and/or cross-channel FCCs may have reported this</td>
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<td>problem. The cause could be an actual failure of FCC-</td>
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<td>R, or of the output bus interface from the FCC to one</td>
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<td>or more of the other systems.</td>
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</table>
18:57 27001 SRM-L FAIL (SRM-L) Hard Active >NO AUTOLAND 221 004 00 ADVISORY
The SRM has experienced a non-recoverable failure. All discrete outputs are set to invalid, all ARINC 429 output labels have their SSM set to FAIL. All engaged relays are disengaged. Cyclic Redundancy Check failures of the Read Only Memory, the absence of subroutine activity, loss of the other channel (ARM or CONTROL) function for 3 seconds, changes in software iteration rate of the other channel (+150% or -75%) and erroneous values published by the background monitor in the other channel all could cause the SRM FAIL message. Left or Right SRM is determined by the EIU based on SRM position.

18:57 27201 SRM-R FAIL (SRM-R) Hard Active >NO AUTOLAND 221 004 00 ADVISORY
The SRM has experienced a non-recoverable failure. All discrete outputs are set to invalid, all ARINC 429 output labels have their SSM set to FAIL. All engaged relays are disengaged. Cyclic Redundancy Check failures of the Read Only Memory, the absence of subroutine activity, loss of the other channel (ARM or CONTROL) function for 3 seconds, changes in software iteration rate of the other channel (+150% or -75%) and erroneous values published by the background monitor in the other channel all could cause the SRM FAIL message. Left or Right SRM is determined by the EIU based on SRM position.

18:56 27503 FLIGHT CONTROLS PSM RIGHT 1 FAIL Hard Active >NO AUTOLAND 221 004 00 ADVISORY
The Flight Controls Electronics Power Supply Module Right 2 has detected a fault with one of the four power supplies (+15 Vdc, +5 Vdc, -15 Vdc or 26 Vac) or Power Supply Module Right 1 is missing (not connected).

18:57 27504 FLIGHT CONTROLS PSM RIGHT 2 FAIL Hard Active >NO AUTOLAND 221 004 00 ADVISORY
The Flight Controls Electronics Power Supply Module Right 1 has detected a fault with one of the four power supplies (+15 Vdc, +5 Vdc, -15 Vdc or 26 Vac) or Power Supply Module Right 2 is missing (not connected).

18:58 34012 FMC-R TO FMC-L RESYNC (FMC-R) Intermittent Inactive >NO AUTOLAND 221 004 00 ADVISORY
indicates that the Right FMC has detected that the left FMC is master, but the intersystem bus from the Left FMC to the right FMC is failed or inactive. The signal is held up for at least 60 seconds after the R FMC starts to report that the intersystem bus from the L FMC is failed or inactive.

18:58 34737 FMC-L FAIL (NO BUS OUTPUTS) Intermittent Inactive >NO AUTOLAND 221 004 00 ADVISORY
EIUs are all valid and OK, the FMC power is OK, and all three EIUs and any MCDU report the L-FMC output buses failed for 5 seconds and the FMC is not in ground test.

18:59 22943 ELEVATOR SERVO-C/FCC-C FAIL Intermittent Inactive >NO AUTOLAND 221 004 00 ADVISORY
A fault was detected in the actuator control loop between FCC-C and the center elevator autopilot servo. Elevator servo or force link common mode monitors may have detected shorted/broken wires or loss of LVDT excitation or the elevator servo command/response monitor may have detected a failure of the servo to move when commanded. The underlying failure may be in the FCC, the servo, the interface wiring, or hydraulic supply to the...
servo.

18:59  22501  RUDDER SERVO-C/FCC-C FAIL  Intermittent Inactive  >NO AUTOLAND  221 004 00 ADVISORY
A fault was detected in the actuator control loop between FCC-C and the center rudder autopilot servo. Rudder servo or force link common mode monitors may have detected shorted/broken wires or loss of LVDT excitation or the rudder servo command/response monitor may have detected a failure of the servo to move when commanded. The underlying failure may be in the FCC, the servo, the interface wiring, or the hydraulic supply to the servo.

19:00  22494  AILERON SERVO-C/FCC-C FAIL  Hard Active  >NO AUTOLAND  221 004 00 ADVISORY
A fault was detected in the actuator control loop between FCC-C and the center aileron autopilot servo. Aileron servo or force link common mode monitors may have detected shorted/broken wires or loss of LVDT excitation or the aileron servo command/response monitor may have detected a failure of the servo to move when commanded. The underlying failure may be in the FCC, the servo, the interface wiring, or the hydraulic supply to the servo.

19:01  22540  FCC-L--FCC-C INTERFACE FAIL  Hard Active  >NO AUTOLAND  221 004 00 ADVISORY
A failure in the cross-channel data bus transmitting from FCC-L to FCC-C was detected by the FCC cross-channel test word monitor. FCC-L may have lost power or shut down, or wiring may have failed between the FCC-L CROSS CHANNEL RIGHT output and the FCC-C CROSS CHANNEL LEFT input.

18:57  22651  YDM-LWR FAIL  Hard Active  LWR  222 101 00 ADVISORY
The lower yaw damper has detected a fault with the auto disengage relay, or a modal suppression accelerometer input is less than -0.425 g or greater than 0.425 g for 1 second, or the CONTROL or MONITOR channel has detected a rudder command difference of 0.35 Vrms for more than 0.5 seconds, or an internal yaw damper module fault has been detected.

18:56  22679  EXCITATION FAIL (YDM-LWR)  Hard Active  LWR  222 101 00 ADVISORY
The Lower YDM CONTROL processor has detected that the AC reference voltage output to the upper yaw damper servo LVDT has dropped below 18 v rms for more than 1.5 seconds.

AFT SPD CARD FAIL OR AFT SPD CARD
18:56  27970  OUTPUT BUS FAIL  Hard Active  LWR  222 101 00 ADVISORY
The aft Surface Position Digitizer card has detected an internal fault, or the EIU has no input from the aft Surface Position Digitizer card.

18:57  22989  FCC-R FAIL (NO BUS OUTPUTS)  Hard Active  DISC  221 002 00 WARNING
Several systems reported failure of FCC-R. The Central Maintenance Computers, EFIS/EICAS Interface Units, Stabilizer Trim/Rudder Ratio Changer
Appendix 1.

Modules, and/or cross-channel FCCs may have reported this problem. The cause could be an actual failure of FCC-R, or of the output bus interface from the FCC to one or more of the other systems.

18:57 27001 SRM-L FAIL (SRM-L) Hard Active DISC 221 002 00 WARNING >AUTOPILOT
The SRM has experienced a non-recoverable failure. All discrete outputs are set to invalid, all ARINC 429 output labels have their SSM set to FAIL. All engaged relays are disengaged. Cyclic Redundancy Check failures of the Read Only Memory, the absence of subroutine activity, loss of the other channel (ARM or CONTROL) function for 3 seconds, changes in software iteration rate of the other channel (+150% or -75%) and erroneous values published by the background monitor in the other channel all could cause the SRM FAIL message. Left or Right SRM is determined by the EIU based on SRM position.

18:57 27201 SRM-R FAIL (SRM-R) Hard Active DISC 221 002 00 WARNING >AUTOPILOT
The SRM has experienced a non-recoverable failure. All discrete outputs are set to invalid, all ARINC 429 output labels have their SSM set to FAIL. All engaged relays are disengaged. Cyclic Redundancy Check failures of the Read Only Memory, the absence of subroutine activity, loss of the other channel (ARM or CONTROL) function for 3 seconds, changes in software iteration rate of the other channel (+150% or -75%) and erroneous values published by the background monitor in the other channel all could cause the SRM FAIL message. Left or Right SRM is determined by the EIU based on SRM position.

18:56 27503 FLIGHT CONTROLS PSM RIGHT 1 FAIL Hard Active DISC 221 002 00 WARNING >AUTOPILOT
The Flight Controls Electronics Power Supply Module Right 2 has detected a fault with one of the four power supplies (+15 Vdc, +5 Vdc, -15 Vdc or 26 Vac) or Power Supply Module Right 1 is missing (not connected).

18:57 27504 FLIGHT CONTROLS PSM RIGHT 2 FAIL Hard Active DISC 221 002 00 WARNING >AUTOPILOT
The Flight Controls Electronics Power Supply Module Right 1 has detected a fault with one of the four power supplies (+15 Vdc, +5 Vdc, -15 Vdc or 26 Vac) or Power Supply Module Right 2 is missing (not connected).

18:58 34012 FMC-R TO FMC-L RESYNC (FMC-R) Intermittent Inactive DISC 221 002 00 WARNING >AUTOPILOT
indicates that the Right FMC has detected that the left FMC is master, but the intersystem bus from the Left FMC to the right FMC is failed or inactive. The signal is held up for at least 60 seconds after the R FMC starts to report that the intersystem bus from the L FMC is failed or inactive.

18:58 34737 FMC-L FAIL (NO BUS OUTPUTS) Intermittent Inactive DISC 221 002 00 WARNING >AUTOPILOT
EIUs are all valid and OK, the FMC power is OK, and all three EIUs and any MCDU report the L-FMC output buses failed for 5 seconds and the FMC is not in ground test.

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**Appendix 1. ACARS CMC Data Interpretation**

18:58 34737 FMC-L FAIL (NO BUS OUTPUTS)  
Intermittent Inactive FMC LEFT 346 107 00 ADVISORY  
EIUs are all valid and OK, the FMC power is OK, and all three EIUs and any MCDU report the L-FMC output buses failed for 5 seconds and the FMC is not in ground test.

18:57 34338 FMC-L->E IU-R BUS FAIL  
Intermittent Active FMC LEFT 346 107 00 ADVISORY  
indicates the EIUs are OK, and the EIU-R has detected the FMC-L output buses failed for 40 seconds.

18:58 34012 FMC-R TO FMC-L RESYNC (FMC-R)  
Intermittent Inactive FMC LEFT 346 107 00 ADVISORY  
indicates that the Right FMC has detected that the left FMC is master, but the intersystem bus from the Left FMC to the right FMC is failed or inactive. The signal is held up for at least 60 seconds after the R FMC starts to report that the intersystem bus from the L FMC is failed or inactive.

18:57 26043 APU BOTTLE LOW PRESSURE  
Hard Active >BOTTLE LOW 262 201 00 ADVISORY  
APU fire extinguishing bottle pressure is low (@ 200-250 psig). Bottle has either been discharged, or may have discharged through pressure relief valve, or leaked through a crack somewhere in the bottle, or the pressure switch on the bottle may not be connected properly, or a ground or open circuit between the pressure switch and EIU has occurred.

18:57 26037 APU FIRE LOOP-B  
Hard Active >DET FIRE APU 261 504 00 ADVISORY  
If the CMCS message 26036 also is shown, then both loops are faulted. Fault correlated to “DET FIRE APU” indicates both loops faulted.

18:57 26036 APU FIRE LOOP-A  
Hard Active >DET FIRE APU 261 504 00 ADVISORY  
If the CMCS message 26037 also is shown, then both loops are faulted. Fault correlated to “DET FIRE APU” indicates both loops faulted.  
**BOTTLE LOW**

18:57 26043 APU BOTTLE LOW PRESSURE  
Hard Active APU 262 202 00 STATUS  
APU fire extinguishing bottle pressure is low (@ 200-250 psig). Bottle has either been discharged, or may have discharged through pressure relief valve, or leaked through a crack somewhere in the bottle, or the pressure switch on the bottle may not be connected properly, or a ground or open circuit between the pressure switch and EIU has occurred.

18:57 26037 APU FIRE LOOP-B  
Hard Active B 261 502 00 STATUS  
If the CMCS message 26036 also is shown, then both loops are faulted. Fault correlated to “DET FIRE APU” indicates both loops faulted.
Appendix 1.

APU FIRE LOOP-A

18:57  26036    APU FIRE LOOP-A    Hard    Active    A    261 501 00    STATUS

If the CMCS message 26037 also is shown, then both loops are faulted. Fault correlated to “DET FIRE APU” indicates both loops faulted.

18:57  27001    SRM-L FAIL (SRM-L)    Hard    Active    NO LAND 3    221 082 00    STATUS

The SRM has experienced a non-recoverable failure. All discrete outputs are set to invalid, all ARINC 429 output labels have their SSM set to FAIL. All engaged relays are disengaged. Cyclic Redundancy Check failures of the Read Only Memory, the absence of subroutine activity, loss of the other channel (ARM or CONTROL) function for 3 seconds, changes in software iteration rate of the other channel (+150 % or -75%) and erroneous values published by the background monitor in the other channel all could cause the SRM FAIL message. Left or Right SRM is determined by the EIU based on SRM position.

18:58  34012    FMC-R TO FMC-L RESYNC (FMC-R)    Intermittent    Inactive    NO LAND 3    221 082 00    STATUS

indicates that the Right FMC has detected that the left FMC is master, but the intersystem bus from the Left FMC to the right FMC is failed or inactive. The signal is held up for at least 60 seconds after the R FMC starts to report that the intersystem bus from the L FMC is failed or inactive.

18:58  34737    FMC-L FAIL (NO BUS OUTPUTS)    Intermittent    Inactive    NO LAND 3    221 082 00    STATUS

EIUs are all valid and OK, the FMC power is OK, and all three EIUs and any MCDU report the L-FMC output buses failed for 5 seconds and the FMC is not in ground test.

18:57  22989    FCC-R FAIL (NO BUS OUTPUTS)    Hard    Active    NO LAND 3    221 082 00    STATUS

Several systems reported failure of FCC-R. The Central Maintenance Computers, EFIS/EICAS Interface Units, Stabilizer Trim/Rudder Ratio Changer Modules, and/or cross-channel FCCs may have reported this problem. The cause could be an actual failure of FCC-R, or of the output bus interface from the FCC to one or more of the other systems.

18:57  27201    SRM-R FAIL (SRM-R)    Hard    Active    NO LAND 3    221 082 00    STATUS

The SRM has experienced a non-recoverable failure. All discrete outputs are set to invalid, all ARINC 429 output labels have their SSM set to FAIL. All engaged relays are disengaged. Cyclic Redundancy Check failures of the Read Only Memory, the absence of subroutine activity, loss of the other channel (ARM or CONTROL) function for 3 seconds, changes in software iteration rate of the other channel (+150 % or -75%) and erroneous values published by the background monitor in the other channel all could cause the SRM FAIL message. Left or Right SRM is determined by the EIU based on SRM position.

18:56  27503    FLIGHT CONTROLS PSM RIGHT 1 FAIL    Hard    Active    NO LAND 3    221 082 00    STATUS

The Flight Controls Electronics Power Supply Module Right 2 has detected a fault with one of the four power supplies (+15 Vdc, +5 Vdc, -15 Vdc or 26
Appendix 1. ACARS CMC Data Interpretation

Vac) or Power Supply Module Right 1 is missing (not connected).

18:57 27504 FLIGHT CONTROLS PSM RIGHT 2 FAIL Hard Active NO LAND 3 221 082 00 STATUS
The Flight Controls Electronics Power Supply Module Right 1 has detected a fault with one of the four power supplies (+15 Vdc, +5 Vdc, -15 Vdc or 26 Vac) or Power Supply Module Right 2 is missing (not connected).

18:57 31308 FLIGHT RECORDER FAIL Hard Active SYS 313 101 00 STATUS
Boeing records indicate DFDAC P/N 285U0071-207 and SSFDR 980-4700-042 were installed on RM863 at delivery.
CMC Fault message #31308 (FLIGHT RECORDER FAIL) is reported by the DFDAC (Digital Flight Data Acquisition Card) on the status of the SSFDR (Solid State Flight Data Recorder). The DFDAC monitors the FDR “Status” analog discrete signal and FDR “Maintenance” analog discrete signal from the SSFDR. The FDR “Status” discrete is set to OK (28 VDC) when the FDR acquires the correct sync words from the acquisition unit at the correct rate. If the sync words are not available or the transmission rate is incorrect, the FDR “Status” is set to FAIL (Ground, 0 VDC). The FDR “Maintenance” discrete is set to OK (Ground, 0 VDC) when the FDR internal BITE is OK. If the FDR has an internal fault, the FDR “Maintenance” discrete is set to FAIL (OPEN).

For CMC message #31308, the following items must be TRUE:
AC BUS #3 is OK
DC BUS #3 is OK
MAWEC/DFDAC Relay for FDR Power is ON

If the FDR “Status” or FDR “Maintenance” discrete signals indicate FAIL for 55 seconds and items above are true, CMC message #31308 is set.

If the FDR “Status” wire was broken/gone and FDR “Maintenance” was still OK, the message would NOT be set. OPEN state for FDR “Status” would not indicate FAIL to the DFDAC.

If the FDR “Maintenance” wire was broken/gone, this CMC message would be set.

The CMC does report DFDAC faults and failures. However, the PLF report provided to Boeing did not list any DFDAC faults.

The EICAS FDE “FLIGHT RECORDER SYS” is a status message (message # L31603) to indicate to the crew the FDRS (Flight Data Recorder System) has fail or is off while engines are running. The EIU monitors an analog discrete signal from the DFDAC. The EICAS message is annunciates when the DFDAC reports a FDRS failure for 60 continuous seconds and at least one engine is running. The DFDAC will indicate a FDRS failure when:

a. FDR “Status” discrete input indicates FAIL (Ground, 0 VDC); or

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b. FDR “Maintenance” discrete input indicates FAIL (open); or
c. A DFDAC internal fault is detected.

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<thead>
<tr>
<th>Time</th>
<th>Code</th>
<th>Description</th>
<th>Status</th>
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<tbody>
<tr>
<td>18:57</td>
<td>27001</td>
<td>SRM-L FAIL (SRM-L)</td>
<td>CUTOUT</td>
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<td>the other channel (ARM or CONTROL) function for 3 seconds, changes in</td>
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<td>18:56</td>
<td>27292</td>
<td>HYD-2 STAB TRIM ACT BRAKE RELEASE</td>
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<td>STAB AUTO</td>
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<td>18:57</td>
<td>27504</td>
<td>FLIGHT CONTROLS PSM RIGHT 2 FAIL</td>
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<td>Changer Modules, and/or cross-channel FCCs may have reported this problem.</td>
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<td>The cause could be an actual failure of FCC-R, or of the output bus</td>
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<td>interface from the FCC to one or more of the other systems.</td>
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18:57 27001 SRM-L FAIL (SRM-L)
The SRM has experienced a non-recoverable failure. All discrete outputs are set to invalid, all ARINC 429 output labels have their SSM set to FAIL. All engaged relays are disengaged. Cyclic Redundancy Check failures of the Read Only Memory, the absence of subroutine activity, loss of the other channel (ARM or CONTROL) function for 3 seconds, changes in software iteration rate of the other channel (+150 % or -75%) and erroneous values published by the background monitor in the other channel all could cause the SRM FAIL message. Left or Right SRM is determined by the EIU based on SRM position.

18:57 27201 SRM-R FAIL (SRM-R)  
Hard Active TRIM 274 022 00 STATUS

The SRM has experienced a non-recoverable failure. All discrete outputs are set to invalid, all ARINC 429 output labels have their SSM set to FAIL. All engaged relays are disengaged. Cyclic Redundancy Check failures of the Read Only Memory, the absence of subroutine activity, loss of the other channel (ARM or CONTROL) function for 3 seconds, changes in software iteration rate of the other channel (+150 % or -75%) and erroneous values published by the background monitor in the other channel all could cause the SRM FAIL message. Left or Right SRM is determined by the EIU based on SRM position.

18:57 27504 FLIGHT CONTROLS PSM RIGHT 2 FAIL  
Hard Active TRIM 274 022 00 STATUS

The Flight Controls Electronics Power Supply Module Right 1 has detected a fault with one of the four power supplies (+15 Vdc, +5 Vdc, -15 Vdc or 26 Vdc) or Power Supply Module Right 2 is missing (not connected).

18:57 27153 CLOSED FAIL [SRM'S]  
Hard Active TRIM 274 022 00 STATUS

The Motor Operated Valve position feedback signal has not become positive more than 5 seconds after the command signal became positive.

18:57 31454 L&C  
Intermittent Active EIU DISAGREE 316 108 00 STATUS

This would be related to the FMC-L to EIU R bus fail. The EIU cross compares all of the input signals between EIUs. This message is simply telling you the R EIU is missing ARINC bus activity that the other 2 EIUs have. In this case of the FMC bus missing from the R EIU (34338 FMC-L->EIU-R BUS FAIL), the CMC message text actually tells you which EIU (FMC L to R EIU) so this message is just redundant and does not provide any additional information.

18:58 34338 FMC-L->EIU-R BUS FAIL  
Intermittent Active EIU DISAGREE 316 108 00 STATUS

indicates the EIUs are OK, and the EIU-R has detected the FMC-L output buses failed for 40 seconds.

18:57 52104 DOOR L 5 SWITCH FAIL  
Hard Active 5 527 109 00 ADVISORY

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The EICAS FDE "DOOR ENTRY L 5" is an advisory message (message # L52306) to indicate to the crew that the L5 Door is not latched. The EIU monitors an analog discrete signal from Door sensor. Not Latched = Ground; Latched = Open CMC message # 52104 (DOOR ENTRY L 5 SWITCH FAIL) is the Flight Deck Effect (FDE). CMC will indicate fault if FDE has been set for 5 seconds.

18:58 34012 FMC-R TO FMC-L RESYNC (FMC-R)  Intermittent Inactive DISC  346 101 00 CAUTION
indicates that the Right FMC has detected that the left FMC is master, but the intersystem bus from the Left FMC to the right FMC is failed or inactive. The signal is held up for at least 60 seconds after the R FMC starts to report that the intersystem bus from the L FMC is failed or inactive.

18:58 34737 FMC-L FAIL (NO BUS OUTPUTS)  Intermittent Inactive DISC  346 101 00 CAUTION
EIUs are all valid and OK, the FMC power is OK, and all three EIUs and any MCDU report the L-FMC output buses failed for 5 seconds and the FMC is not in ground test.

18:58 26169 CARGO BOTTLE A LOW PRESSURE  Hard Active DISCH  262 409 00 ADVISORY
The bottle A Temperature Compensated Pressure Sensor (TCPS) has detected a low bottle pressure. When the bottle pressure drops below 300 +/- 30 psig (@70F), the TCPS closes, and provides a 28 VDC analog signal. The TCPS has a normally closed failure mode, so a failed TCPS will also produce this message.

18:58 26170 CARGO BOTTLE B LOW PRESSURE  Hard Active DISCH  262 409 00 ADVISORY
The bottle A and B Temperature Compensated Pressure Sensors (TCPSs) (each bottle has its own independent TCPS) have detected a low bottle pressure. When the bottle pressure drops below 300 +/- 30 psig (@70F), the TCPS closes, and provides a 28 VDC analog signal. The TCPS has a normally closed failure mode, so a failed TCPS will also produce this maintenance message. In flight, the >CGO BTL DISCH advisory message is triggered when both the CARGO BOTTLE A & B LOWER PRESSURE maintenance messages are true.

18:58 27401 ELEVATOR FEEL COMPUTER FAIL  Hard Active FEEL  273 001 00 STATUS
Excessive pressure difference between metered pressure inputs or airspeed inputs. Inhibited by hydraulic system 2 or 3 pressure less than 1200 PSI.

18:58 26169 CARGO BOTTLE A LOW PRESSURE  Hard Active CARGO A  262 302 00 STATUS
The bottle A Temperature Compensated Pressure Sensor (TCPS) has detected a low bottle pressure. When the bottle pressure drops below 300 +/- 30 psig (@70F), the TCPS closes, and provides a 28 VDC analog signal. The TCPS has a normally closed failure mode, so a failed TCPS will also produce this message.
Appendix 1.

ACARS CMC Data Interpretation

18:58 26165 CARGO AFT-4 LOOP-A FAIL

Intermittent Inactive CGO DET AFT 4 261 627 00 STATUS
The Aft lower lobe Zone 4A detector was in alarm for at least 8 seconds without the Zone 4B detector being in alarm or the 4A detector failed to pass a "disagree" test from the zone 4 AFOLTS card or the wire from the zone 4A detector to the AFOLTS was open circuit when a "disagree" test was performed. Because this fault was correlated to "CGO DET AFT 4" and not to "AFT CGO 16 LP A", the Zone 4B detector was in alarm or faulted within 20 seconds of the Zone 4A detector. The above message would be consistent with Zone 4A and Zone 4B detectors being in alarm (detecting smoke) more than 8 second but less than 20 seconds apart.

18:58 34012 FMC-R TO FMC-L RESYNC (FMC-R)

Intermittent Inactive >FMC MESSAGE 346 109 00 ADVISORY
indicates that the Right FMC has detected that the left FMC is master, but the intersystem bus from the Left FMC to the right FMC is failed or inactive. The signal is held up for at least 60 seconds after the R FMC starts to report that the intersystem bus from the L FMC is failed or inactive.

18:58 34737 FMC-L FAIL (NO BUS OUTPUTS)

Intermittent Inactive >FMC MESSAGE 346 109 00 ADVISORY
EIUs are all valid and OK, the FMC power is OK, and all three EIUs and any MCDU report the L-FMC output buses failed for 5 seconds and the FMC is not in ground test.

EMERGENCY LOCATOR TRANSMITTER

18:59 23600 ON

Hard Active >ELT ON 232 401 00 ADVISORY
The "ELT ON" ACARS message indicates that the automatic-fixed ELT has been activated (turned on) either by the flight crew via the ELT control panel in the flight deck, or it has been automatically activated by g-forces.
Note: The source of the ACARS message is the "ELT ON" EICAS message via the CMC. The source of the "ELT ON" EICAS message is an analog discrete from the ELT to the EIUs via a MAWEA SCID card.

18:59 35006 SUPERNUMERARY OXYGEN ON

Hard Active ON 352 109 00 ADVISORY
SUPRNMRY OXY
The EICAS Flight Deck Effect (FDE) "SUPRNMRY OXY ON" is an advisory message (message # L35306) to indicate to the crew that the supernumerary oxygen flow control unit is actuated. The EIU monitors an analog discrete signal from Supernumerary Oxygen system.
CMC message #35006 (SUPERNUMERARY OXYGEN ON) echoes the Flight Deck Effect (FDE) message #L35360. CMC will indicate fault if FDE has been set for 55 seconds.
This message can be triggered manually through a switch in the flight deck overhead P5 panel (labeled SUPRNMRY OXY) or pneumatically when the cabin altitude exceeds 8.7 ± .2 psia. It is a open/ground discrete. The discrete set to ground indicates SUPRNMRY OXY ON.
Source of the signal is the Oxygen Flow-Surge Control Unit (equipment number M101) located at STA 770 WL160 RBL105.

5/11/2015
Appendix 1.

ACARS CMC Data Interpretation

747-400F airplanes were delivered with an Electro-Pneumatic Flow Control Unit (FCU). In case of decompression, the system is actuated automatically at cabin altitude of approx 8.7 ± .2 psia which is equivalent to a value in the range of 13,250 to 14,400 feet or may be activated by means of a switch on the overhead panel in the flight deck. The nominal activation altitude value is approximately 13,800 feet.

It is possible that the message is related to the fire suppression procedure. The third step of the main deck cargo fire checklist directs crew to turn the SUPERNMRY OXY switch to the ON position. Immediately after this step the crew is directed to ARM the Main Deck Cargo Fire Arm switch. However, the timing on the ACARS data is inconsistent with the checklist sequence. The PACK 2 and PACK 3 advisory messages occur at 18:56:xx whereas the SUPRNMRY OXY ON message occurs at 18:59:xx whereas. Once we have DFDR data we may be able to see if the SUPRNMRY OXY message was triggered due to the cabin altitude exceeding the trigger altitude due to the aircraft being depressurized per procedure.

18:59 24098 DC CURRENT SENSOR-6 FAIL (BCU-2) Intermittent Inactive >BAT DISCH APU 243 005 00 ADVISORY

The CMC message "DC CURRENT SENSOR-6 FAIL" indicated that the APU Battery Current Sensor has failed and this failure caused the EICAS Advisory message >BAT DISCH APU displayed. The EICAS Advisory message >BAT DISCH APU will display whenever the APU Battery current is sensed less than 0 amps for 3 minutes or less than 6 amps.

18:59 36301 APU DUCT FAIL Hard Active APU 491 101 00 ADVISORY

The APU DUCT FAIL message is set by an overheat being sensed in the vicinity of the APU duct when the battery bus is energized (which is normally the case). Both the overheat condition and energized battery bus criteria must persist for 10 or more seconds for the CMC message to be set. The APU duct runs from the APU in the tail cone, through the bottom of the rear pressure dome and then along the left cheek adjacent to the aft lower cargo compartment until it reaches the wheel well. There are 20 thermal switches, 15 are located along the duct adjacent to the aft lower cargo compartment, and 5 are located along the duct in the area aft of the bulk cargo compartment. 7 more switches are located between the APU isolation valve and APU check valve near the wheel well. When the local air temperature exceeds 250 F, the thermal switches close triggering a ground analog discrete into the EIU on pin C15. The EIU then passes a discrete to the CMC indicating the overheat. Note: the system has no self-test capability.

19:00 27664 FLAP LEVER RVDT FAIL (FCU' S) Hard Active CONTROL 275 003 00 CAUTION

All 3 FCUs report: 2 out of the 3 Flap Lever RVDTs have failed or 2 out of the 3 26VAC excitation inputs have failed.

19:00 22607 UPPER YAW DAMPER ACTUATOR LVDT Intermittent Inactive YAW DAMPER 222 104 00 STATUS

As seen by the Upper YDM CONTROL processor, the sum of the voltages of the two upper rudder yaw damper servo LVDT windings has dropped below 7 vms for more than 2 seconds, or the voltage of one individual winding has dropped below 2 vms for more than 2 seconds, in the presence of a nominal 26 vms excitation reference.

5/11/2015
19:00 22629 EXCITATION FAIL (YDM-UPR) Hard Active UPR 222 104 00 STAT
The Upper YDM CONTROL processor has detected that the AC reference voltage output to the upper yaw damper servo LVDT has dropped below 18
vrms for more than 1.5 seconds.

UPPER YAW DAMPER ACTUATOR LVDT
19:00 22607 FAIL (YDM-UPR) Intermittent Inactive UPR 222 103 00 ADVISORY
As seen by the Upper YDM CONTROL processor, the sum of the voltages of the two upper rudder yaw damper servo LVDT windings has dropped
below 7 vrms for more than 2 seconds, or the voltage of one individual winding has dropped below 2 vrms for more than 2 seconds, in the presence of a
nominal 26 vrms excitation reference.

19:00 22629 EXCITATION FAIL (YDM-UPR) Hard Active UPR 222 103 00 ADVISORY
The Upper YDM CONTROL processor has detected that the AC reference voltage output to the upper yaw damper servo LVDT has dropped below 18
vrms for more than 1.5 seconds.

UPR RUDDER RATIO ACTUATOR
19:00 27108 FEEDBACK FAIL (SRM-L) Intermittent Active DUAL 272 021 00 ADVISORY
The upper rudder ratio changer actuator feedback signal to the SRM has been less than .35 Vdc for 0.75 seconds.

UPR RUDDER RATIO CHANGER 115 VAC
19:00 27158 FAIL (SRM* S) Hard Active DUAL 272 021 00 ADVISORY
The SRM has determined that the upper rudder ratio changer has lost 115 Vac power for at least 2 seconds.

UPR RUDDER RATIO CHANGER 28 VDC
19:00 27160 FAIL (SRM* S) Hard Active DUAL 272 021 00 ADVISORY
The SRM has determined that the upper rudder ratio changer has lost 28 Vdc power for at least 2 seconds.

UPR RUDDER RATIO ACTUATOR
19:00 27308 FEEDBACK FAIL (SRM-R) Intermittent Active DUAL 272 021 00 ADVISORY
The upper rudder ratio changer actuator feedback signal to the SRM has been less than .35 Vdc for 0.75 seconds.

5/11/2015
## APPENDIX 2: Time-based Aircraft Status and Events

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<thead>
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<th>ATC (OIMT)</th>
<th>Aircraft Altitude (ft)</th>
<th>Airspeed (Kts)</th>
<th>Lat</th>
<th>Long</th>
<th>Event</th>
<th>Message Type</th>
<th>TOE Code</th>
<th>Msg Message Code</th>
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**Shanghai control, good morning, AAR591 direct SADU, maintain level 340L (FO)**

**ATC & Racer**

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**ATC & Racer**
## Time-based Aircraft Status and Events

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Appendix 2.

Time-based Aircraft Status and Events

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## Appendix 2.

### Time-based Aircraft Status and Events

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## Appendix 2

### Time-based Aircraft Status and Events

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<td>(In Korean) &quot;If you have a contact with us now&quot; (PC)</td>
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Appendix 3.

Incheon Area Control Center's Radar Data

APPENDIX 3: Incheon Area Control Center's Radar Data
Incheon Area Control Center's Radar Data (28 July 2011)
Detection Radar-based Position
Time(UTC)
X
Y

Altitude
Feet
Type

Speed
Knots

Heading
Degrees

A/C position
LAT
LONG

0354:23.435

-137.37

-248.72

34000

LEVEL

461.43

252.75

N315228

E245346

0354:35.480

-138.94

-248.72

34000

LEVEL

466.26

261.55

N315226

E245156

0354:47.550

-140.41

-248.84

34000

LEVEL

464.94

265.77

N315216

E245013

0354:59.577

-142.06

-248.91

33900

DSCND

473.29

268.02

N315209

E244817

0355:11.540

-143.62

-249.06

33300

DSCND

474.83

267.93

N315158

E244627

0355:23.573

-145.22

-249.22

32400

DSCND

476.37

266.85

N315146

E244435

0355:35.633

-146.75

-249.56

31400

DSCND

473.95

264.14

N315123

E244248

0355:47.607

-148.31

-249.87

30300

DSCND

472.63

261.64

N315101

E244059

0355:59.648

-149.91

-250.19

29300

DSCND

476.37

259.76

N315040

E243907

0356:12.405

-151.34

-250.59

28200

DSCND

470.00

257.70

N315013

E243727

0356:24.367

-153.06

-250.50

27000

DSCND

475.93

261.28

N315015

E243526

0356:36.002

-154.62

-250.44

25800

DSCND

475.27

265.37

N315016

E243336

0356:48.391

-156.19

-250.12

24700

DSCND

472.63

271.39

N315033

E243145

0357:00.087

-157.75

-249.53

23900

DSCND

478.12

278.89

N315105

E242954

0357:12.067

-159.22

-248.84

23300

DSCND

482.52

286.12

N315144

E242809

0357:24.119

-160.44

-248.12

22800

DSCND

468.24

292.36

N315225

E242642

0357:36.138

-161.75

-247.00

21900

DSCND

473.07

300.13

N315330

E242508

0357:48.175

-162.81

-245.91

20800

DSCND

471.09

306.99

N315433

E242351

0358:05.769

-163.66

-244.56

19100

DSCND

480.98

328.05

N315553

E242248

0358:12.211

-164.19

-242.91

18800

DSCND

484.06

330.53

N315731

E242207

0358:29.850

-164.69

-241.37

18000

DSCND

494.17

341.34

N315902

E242128

0358:36.310

-165.19

-239.94

17100

DSCND

486.69

341.26

N320027

E242050

0358:48.283

-165.28

-238.59

15900

DSCND

451.76

345.00

N320148

E242041

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-165.12

-236.91

14900

DSCND

450.88

352.28

N320329

E242048

0359:12.258

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-235.50

14200

DSCND

445.17

1.59

N320455

E242115

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-234.06

13600

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E242147

0359:36.305

-163.75

-232.47

13100

DSCND

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14.63

N320758

E242215

0359:48.676

-163.12

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DSCND

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11900

DSCND

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N321016

E242358

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N321144

E242439

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0400:42.353

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N321426

E242606

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DSCND

428.25

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E242734

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N321741

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32.61

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<td>410.89</td>
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<td>CLIMB</td>
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<td>CLIMB</td>
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<td>18.85</td>
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<td>DSCND</td>
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<td>E245816</td>
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<td>13400</td>
<td>DSCND</td>
<td>395.51</td>
<td>8.46</td>
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<td>E245820</td>
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<td>0409:53.592</td>
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<td>12200</td>
<td>DSCND</td>
<td>404.74</td>
<td>4.89</td>
<td>N331012</td>
<td>E245822</td>
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<td>0410:05.405</td>
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<td>-169.87</td>
<td>11600</td>
<td>DSCND</td>
<td>411.33</td>
<td>3.80</td>
<td>N331133</td>
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<td>11200</td>
<td>DSCND</td>
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<td>4.97</td>
<td>N331301</td>
<td>E245844</td>
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<td>9600</td>
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<td>-130.72</td>
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<td>9600</td>
<td>DSCND</td>
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<td>N331425</td>
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<td>0410:34.000</td>
<td>MCRC</td>
<td>SR</td>
<td>6500</td>
<td>19</td>
<td>N331459</td>
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<td>MCRC</td>
<td>SR</td>
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<td>42</td>
<td>N331512</td>
<td>E245934</td>
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</tbody>
</table>

| NTSB SUGGESTED IMPACT PT | N331532 | E245942 |
- AAR991's Flight Track Based on ICN ACC's Radar Data

[Diagram of flight track with labeled points and coordinates]
### Major Events Based on Radar Flight Track Data

<table>
<thead>
<tr>
<th>Track No</th>
<th>Time</th>
<th>Position</th>
<th>Alt</th>
<th>Speed</th>
<th>Heading</th>
<th>Major Events</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>18:54:23</td>
<td>N315228</td>
<td>340</td>
<td>461</td>
<td>252</td>
<td>AAR991 declared an emergency due to a main deck fire and requested SHI ACC to allow emergency descent to 10,000 ft.</td>
</tr>
<tr>
<td>2</td>
<td>18:55:08</td>
<td>N315158</td>
<td>339</td>
<td>473</td>
<td>268</td>
<td>AAR991 requested SHI ACC to allow a diversion to Jeju Airport.</td>
</tr>
<tr>
<td>3</td>
<td>18:56:32</td>
<td>N315016</td>
<td>258</td>
<td>475</td>
<td>265</td>
<td>SHI ACC instructed AAR991 to turn right.</td>
</tr>
<tr>
<td>4</td>
<td>18:59:13</td>
<td>N320455</td>
<td>142</td>
<td>445</td>
<td>001</td>
<td>AAR991 requested a radar vector to Jeju.</td>
</tr>
<tr>
<td>5</td>
<td>18:59:26</td>
<td>N320622</td>
<td>136</td>
<td>446</td>
<td>010</td>
<td>AAR991 reported a rear cargo fire to SHI ACC.</td>
</tr>
<tr>
<td>6</td>
<td>18:59:50</td>
<td>N320915</td>
<td>124</td>
<td>454</td>
<td>019</td>
<td>SHI ACC instructed AAR991 to fly heading 045.</td>
</tr>
<tr>
<td>7</td>
<td>19:00:23</td>
<td>N321307</td>
<td>111</td>
<td>441</td>
<td>028</td>
<td>AAR991 attempted to contact ICN ACC on 124.52 but to no avail.</td>
</tr>
<tr>
<td>8</td>
<td>19:02:00</td>
<td>N322233</td>
<td>092</td>
<td>412</td>
<td>032</td>
<td>AAR991 attempted to contact SHI ACC on 133.6 but to no avail.</td>
</tr>
<tr>
<td>9</td>
<td>19:03:07</td>
<td>N322936</td>
<td>088</td>
<td>407</td>
<td>027</td>
<td>KAL886 started to relay information between AAR991 and ICN ACC.</td>
</tr>
<tr>
<td>10</td>
<td>19:04:48</td>
<td>N323845</td>
<td>095</td>
<td>426</td>
<td>042</td>
<td>ICN ACC instructed KA886 to relay the message to AAR991 that AAR991 should maintain heading 060 and descend to 8,000 or 7,000 ft.</td>
</tr>
<tr>
<td>11</td>
<td>19:05:32</td>
<td>N324330</td>
<td>104</td>
<td>417</td>
<td>031</td>
<td>KAL886 relayed ICN ACCs instruction to AAR991.</td>
</tr>
<tr>
<td>12</td>
<td>19:06:32</td>
<td>N325004</td>
<td>098</td>
<td>406</td>
<td>010</td>
<td>The captain stated, &quot;Ah... we are now that rudder control is not working and seems to be fired... (jamming).&quot;</td>
</tr>
<tr>
<td>13</td>
<td>19:07:34</td>
<td>N325559</td>
<td>105</td>
<td>416</td>
<td>036</td>
<td>The captain stated, &quot;We have to open the hatch, hatch.&quot;</td>
</tr>
<tr>
<td>14</td>
<td>19:08:52</td>
<td>N330333</td>
<td>131</td>
<td>411</td>
<td>031</td>
<td>ICN ACC instructed KAL886 to relay the message to AAR991 that JEJ APP established radar contact with AAR991 and that AAR991 should contact JEJ APP on 121.2.</td>
</tr>
<tr>
<td>15</td>
<td>19:09:08</td>
<td>N330458</td>
<td>139</td>
<td>414</td>
<td>025</td>
<td>KAL886 relayed ICN ACCs instruction to AAR991.</td>
</tr>
<tr>
<td>16</td>
<td>19:09:47</td>
<td>N331010</td>
<td>134</td>
<td>396</td>
<td>008</td>
<td>When AAR991 made first contact with JEJ ACC, the captain stated, &quot;Rudder control... flight control, all are not working.&quot;</td>
</tr>
<tr>
<td>17</td>
<td>19:10:15</td>
<td>N331301</td>
<td>112</td>
<td>424</td>
<td>005</td>
<td>The FO stated, &quot;Altitude control is not available due to heavy vibration, going to ditch... ah.&quot;</td>
</tr>
<tr>
<td>18</td>
<td>19:10:29</td>
<td>N331425</td>
<td>096</td>
<td>433</td>
<td>011</td>
<td>The last location detected by ICN ACC's secondary air route surveillance radar (ARSR).</td>
</tr>
</tbody>
</table>
APPENDIX 4: ATC Communication Transcript

ATC communication transcript
Between aircraft and ATC facilities

Legend
AAR991: Asiana flight 991
AAR724: Asiana flight 724
CES2015: China Eastern flight 2015
FO: Co-pilot
CDITW: Clearance Delivery in Incheon ATC Tower
RCICA: Ramp Control in Incheon airport
ICTOW: Incheon ATC Tower
SLDEC: Seoul Departure Control
ICNACC: Incheon Area Control Center
JEJAPP: Jeju Approach Control
KAL886: Korean Air flight 886
SHIACC: Shanghai Area Control Center

Note: All the times in the table are Korean standard time

<table>
<thead>
<tr>
<th>Transmission time</th>
<th>Transmitter</th>
<th>Contents of transmission</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Communication under the Clearance Delivery in Incheon ATC Tower</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>02:42:27</td>
<td>AAR991</td>
<td>Incheon delivery, good morning, AAR991. (FO)</td>
</tr>
<tr>
<td>02:42:31</td>
<td>CDITW</td>
<td>Good morning, AAR991. Delivery, go ahead.</td>
</tr>
<tr>
<td>02:42:34</td>
<td>AAR991</td>
<td>Request ATC clearance to Pudong, proposing FL340, stand 624, information Lima. (FO)</td>
</tr>
<tr>
<td>02:42:41</td>
<td>CDITW</td>
<td>AAR991, Cleared to Shanghai Pudong runway 15L MALPA 1R departure via Y51 RINBO B576, maintain FL340, departure frequency 125.15, squawk 7163.</td>
</tr>
<tr>
<td>02:42:56</td>
<td>AAR991</td>
<td>Cleared to Pudong runway 15L MALPA 1R departure. Y51 RINBO B576 maintain FL340, 125.15, squawking 7163, AAR991. (FO)</td>
</tr>
<tr>
<td>02:43:10</td>
<td>CDITW</td>
<td>AAR991, read back is correct, contact ramp 121.87.</td>
</tr>
<tr>
<td>02:43:14</td>
<td>AAR991</td>
<td>121.87 AAR991, 수고하십시오(good bye). (FO)</td>
</tr>
<tr>
<td>02:43:18</td>
<td>CDITW</td>
<td>수고하십시오(good bye).</td>
</tr>
<tr>
<td><strong>Communication under the Ramp Control in Incheon airport</strong></td>
<td></td>
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</tr>
<tr>
<td>02:47:49</td>
<td>AAR991</td>
<td>Ramp control AAR991, request push back and start, stand 624. (FO)</td>
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</table>
## Communication under the Incheon ATC Tower

<table>
<thead>
<tr>
<th>Time</th>
<th>Identifier</th>
<th>Message</th>
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</thead>
<tbody>
<tr>
<td>02:47:55</td>
<td>RCICA</td>
<td>AAR991 push back and start approved, good morning.</td>
</tr>
<tr>
<td>02:47:59</td>
<td>AAR991</td>
<td>Push back and start AAR991, good morning.</td>
</tr>
<tr>
<td>02:53:52</td>
<td>AAR991</td>
<td>Ramp control AAR991 request taxi.</td>
</tr>
<tr>
<td>02:53:57</td>
<td>RCICA</td>
<td>AAR991 taxi to delta, contact tower 118.2, good day.</td>
</tr>
<tr>
<td>02:54:03</td>
<td>AAR991</td>
<td>Taxi to delta, tower 118.2, AAR991, good day, 수고하십시오(good bye).</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Time</th>
<th>Identifier</th>
<th>Message</th>
</tr>
</thead>
<tbody>
<tr>
<td>02:54:25</td>
<td>AAR991</td>
<td>Incheon tower, good morning AAR991 approaching 4Y. (FO)</td>
</tr>
<tr>
<td>02:54:30</td>
<td>ICTOW</td>
<td>AAR991, good morning, taxi to runway 15L via Delta then Lima.</td>
</tr>
<tr>
<td>02:54:36</td>
<td>AAR991</td>
<td>15L, Delta then Lima, AAR991.</td>
</tr>
<tr>
<td>03:01:14</td>
<td>ICTOW</td>
<td>AAR991 confirm ready for departure.</td>
</tr>
<tr>
<td>03:01:19</td>
<td>AAR991</td>
<td>Ready for departure, AAR991.</td>
</tr>
<tr>
<td>03:01:22</td>
<td>ICTOW</td>
<td>AAR991, wind 190 at 20 knots, cleared for takeoff runway 15L.</td>
</tr>
<tr>
<td>03:01:28</td>
<td>AAR991</td>
<td>Cleared for takeoff runway 15L, AAR991.</td>
</tr>
<tr>
<td>03:04:28</td>
<td>AAR991</td>
<td>AAR991 rolling. (Captain)</td>
</tr>
<tr>
<td>03:04:30</td>
<td>ICTOW</td>
<td>Roger.</td>
</tr>
<tr>
<td>03:05:35</td>
<td>ICTOW</td>
<td>AAR991 contact departure 125.15, 수고하십시오(good bye).</td>
</tr>
<tr>
<td>03:05:39</td>
<td>AAR991</td>
<td>125.15 AAR991, 수고하십시오(good bye). (Captain)</td>
</tr>
</tbody>
</table>

## Communication under the Seoul Departure Control

<table>
<thead>
<tr>
<th>Time</th>
<th>Identifier</th>
<th>Message</th>
</tr>
</thead>
<tbody>
<tr>
<td>03:05:48</td>
<td>AAR991</td>
<td>Departure, good morning, AAR991 now passing 1,800. (Captain)</td>
</tr>
<tr>
<td>03:05:54</td>
<td>SLDEC</td>
<td>AAR991 Seoul departure radar contact, climb to FL340, no altitude restriction.</td>
</tr>
<tr>
<td>03:06:02</td>
<td>AAR991</td>
<td>Climb 340, no altitude restriction, AAR991, thank you. (Captain)</td>
</tr>
<tr>
<td>03:07:45</td>
<td>SLDEC</td>
<td>AAR991 direct MALPA then Y51.</td>
</tr>
</tbody>
</table>
### Communication under the Incheon Area Control Center

<table>
<thead>
<tr>
<th>Time</th>
<th>Code</th>
<th>Text</th>
</tr>
</thead>
<tbody>
<tr>
<td>03:07:49</td>
<td>AAR991</td>
<td>MALPA then Y51, AAR991, thank you. (Captain)</td>
</tr>
<tr>
<td>03:12:19</td>
<td>SLDEC</td>
<td>AAR991 contact Incheon control 128.3, good day.</td>
</tr>
<tr>
<td>03:12:24</td>
<td>AAR991</td>
<td>128.3, 수고하세요(good bye). (Captain)</td>
</tr>
<tr>
<td>03:12:35</td>
<td>AAR991</td>
<td>Incheon, Good morning AAR991, Now passing 180 for 340. (captain)</td>
</tr>
<tr>
<td>03:12:43</td>
<td>ICNACC</td>
<td>AAR991, Incheon ... AAR991, Incheon control, Climb to FL340.</td>
</tr>
<tr>
<td>03:12:52</td>
<td>AAR991</td>
<td>Climb 340, AAR991. (captain)</td>
</tr>
<tr>
<td>03:13:05</td>
<td>ICNACC</td>
<td>AAR991, clear direct NIRAT.</td>
</tr>
<tr>
<td>03:13:08</td>
<td>AAR991</td>
<td>Direct NIRAT, AAR991, thank you. (captain)</td>
</tr>
<tr>
<td>03:13:20</td>
<td>ICNACC</td>
<td>AAR991, change to my frequency 124.52.</td>
</tr>
<tr>
<td>03:26:11</td>
<td>AAR991</td>
<td>124.52, AAR991. (FO)</td>
</tr>
<tr>
<td>03:26:18</td>
<td>AAR991</td>
<td>Incheon control, AAR991 with you. (FO)</td>
</tr>
<tr>
<td>03:26:21</td>
<td>ICNACC</td>
<td>AAR991, Incheon control, clear direct SADLI.</td>
</tr>
<tr>
<td>03:26:26</td>
<td>AAR991</td>
<td>Direct SADLI. 감사합니다(thank you). (FO)</td>
</tr>
<tr>
<td>03:50:46</td>
<td>ICNACC</td>
<td>AAR991, radar service terminated, contact Shanghai control 134.0.</td>
</tr>
<tr>
<td>03:50:55</td>
<td>AAR991</td>
<td>134.7, AAR991. (FO)</td>
</tr>
<tr>
<td>03:50:58</td>
<td>ICNACC</td>
<td>AAR991, negative, frequency 134.0.</td>
</tr>
<tr>
<td>03:51:04</td>
<td>AAR991</td>
<td>134.0, AAR991. 수고하십시오(see you later). (FO)</td>
</tr>
<tr>
<td>03:51:08</td>
<td>ICNACC</td>
<td>수고하십시오(see you later).</td>
</tr>
<tr>
<td>04:04:18</td>
<td>KAL886</td>
<td>Incheon control, KAL886.</td>
</tr>
<tr>
<td>04:04:22</td>
<td>ICNACC</td>
<td>KAL886, Incheon control, radio check, how do you read me?</td>
</tr>
<tr>
<td>04:04:25</td>
<td>KAL886</td>
<td>KAL886, Relay for AAR991, AAR991, diverting to Jeju due to cargo fire, emergency, they descent emergency, ah, and they request radar vector to Jeju. Request radar contact with AAR991.</td>
</tr>
<tr>
<td>04:04:48</td>
<td>ICNACC</td>
<td>Okay KAL886, please delivery my message to AAR991. Fly heading, fly heading 060 vector for final approach and maintain, pilot discretion maintain 8,000 or 7,000 approved.</td>
</tr>
<tr>
<td>Time</td>
<td>Airline/Call Sign</td>
<td>Message</td>
</tr>
<tr>
<td>------</td>
<td>------------------</td>
<td>---------</td>
</tr>
<tr>
<td>04:05:10</td>
<td>KAL886</td>
<td>Roger, Stand by.</td>
</tr>
<tr>
<td>04:05:52</td>
<td>ICNACC</td>
<td>KAL886, Incheon.</td>
</tr>
<tr>
<td>04:07:55</td>
<td>ICNACC</td>
<td>AAR991, AAR991, this is Incheon on guard, if you hear me contact Jeju Approach 121.2, 121.2, acknowledge by IDENT.</td>
</tr>
<tr>
<td>04:08:23</td>
<td>KAL886</td>
<td>AAR991, KAL886, radio check.</td>
</tr>
<tr>
<td>04:08:28</td>
<td>ICNACC</td>
<td>AAR991, this is Incheon control, loud and clear. How do you read?</td>
</tr>
<tr>
<td>04:08:34</td>
<td>KAL886</td>
<td>Incheon control, stand by, stand by, KAL886. AAR991, Do you read KAL886?</td>
</tr>
<tr>
<td>04:08:45</td>
<td>ICNACC</td>
<td>Roger, stand by.</td>
</tr>
<tr>
<td>04:08:47</td>
<td>KAL886</td>
<td>Incheon control, this is KAL886. Has any message for Asiana?</td>
</tr>
<tr>
<td>04:08:52</td>
<td>ICNACC</td>
<td>Okay, Please delivery my message. Jeju Approach radar contact AAR991. At this time contact Jeju Approach 1212, 1212.</td>
</tr>
<tr>
<td>04:09:06</td>
<td>KAL886</td>
<td>Roger, Stand by.</td>
</tr>
<tr>
<td>04:09:08</td>
<td>KAL886</td>
<td>AAR991, this is KAL886. Relay message from Incheon. Jeju Approach has radar contact to you. Jeju Approach has radar contact to you. Please try to contact Jeju on 121.2, 121.2.</td>
</tr>
<tr>
<td>04:09:34</td>
<td>KAL886</td>
<td>Affirmative, affirmative. Try to contact Jeju 121.2, They request radar contact with you.</td>
</tr>
<tr>
<td>04:09:46</td>
<td>KAL886</td>
<td>Ah, unable to control?</td>
</tr>
<tr>
<td>04:09:49</td>
<td>KAL886</td>
<td>아, control이 안 되신다고? (ah, did you say that control is not working?)</td>
</tr>
<tr>
<td>04:09:55</td>
<td>KAL886</td>
<td>아... (ah)</td>
</tr>
<tr>
<td>04:09:58</td>
<td>KAL886</td>
<td>Asiana, KAL886.</td>
</tr>
<tr>
<td>04:10:08</td>
<td>AAR724</td>
<td>Incheon control, AAR724.</td>
</tr>
<tr>
<td>04:10:13</td>
<td>ICNACC</td>
<td>AAR724, go ahead.</td>
</tr>
<tr>
<td>04:10:15</td>
<td>AAR724</td>
<td>에. 지금 현재 그 AAR991 바로 들리는 거로는 control이 안 됩니다. control이 안 된다고 잡안 조종사가 알이 나왔습니다 (yes, I heard at a moment, AAR991 says that control is not working).</td>
</tr>
</tbody>
</table>
## Communication under the Shanghai Area Control Center

<table>
<thead>
<tr>
<th>Time</th>
<th>Call Sign</th>
<th>Message</th>
</tr>
</thead>
<tbody>
<tr>
<td>03:51:15</td>
<td>AAR991</td>
<td>Shanghai control, good morning, AAR991 direct SADLI maintain level 340. (FO)</td>
</tr>
<tr>
<td>03:51:21</td>
<td>SHIACC</td>
<td>AAR991 Shanghai, squawk 6353.</td>
</tr>
<tr>
<td>03:51:25</td>
<td>AAR991</td>
<td>Squawking 6353, AA991. (FO)</td>
</tr>
<tr>
<td>03:52:39</td>
<td>SHIACC</td>
<td>AAR991 radar contact, off-set 5 miles right of track.</td>
</tr>
<tr>
<td>03:52:43</td>
<td>AAR991</td>
<td>Offset 5 miles romeo side, AAR991, confirm? (FO)</td>
</tr>
<tr>
<td>03:52:48</td>
<td>SHIACC</td>
<td>Affirm, 5 miles right side.</td>
</tr>
<tr>
<td>03:52:51</td>
<td>AAR991</td>
<td>Ok, 5 miles romeo side AAR991, thank you. (FO)</td>
</tr>
<tr>
<td>03:54:23</td>
<td>AAR991</td>
<td>Shanghai control, shanghai control, AAR991 request emergency descent. Emergency, declare emergency due to fire main deck. Request descent, and descent to one-zero thousand. (FO)</td>
</tr>
<tr>
<td>03:54:37</td>
<td>SHIACC</td>
<td>AAR991 cleared to descend and turn at own discretion.</td>
</tr>
<tr>
<td>03:54:42</td>
<td>AAR991</td>
<td>Maintain...descend one-zero thousand on own discretion, AAR991. (FO)</td>
</tr>
<tr>
<td>03:54:47</td>
<td>SHIACC</td>
<td>东方2015雷达引导右转30度由于间隔,避让 (Eastern 2015 radar vector right turn heading 030 due to separation, avoidance)</td>
</tr>
<tr>
<td>03:54:51</td>
<td>CES2015</td>
<td>雷达引导右转30度, 东方2015 (Radar vector right turn 030, eastern 2015)</td>
</tr>
<tr>
<td>03:55:05</td>
<td>SHIACC</td>
<td>AAR991 say again emergency.</td>
</tr>
<tr>
<td>03:55:08</td>
<td>AAR991</td>
<td>We have fire main deck, AAR991. Return to Jeju, AAR991. (FO)</td>
</tr>
<tr>
<td>Time</td>
<td>Source</td>
<td>Message</td>
</tr>
<tr>
<td>-------</td>
<td>----------</td>
<td>-------------------------------------------------------------------------</td>
</tr>
<tr>
<td>03:55:29</td>
<td>SHIACC</td>
<td>AAR991 confirm fire in the cabin?</td>
</tr>
<tr>
<td>03:55:47</td>
<td>AAR991</td>
<td>Shanghai AAR991. (captain)</td>
</tr>
<tr>
<td>03:55:57</td>
<td>SHIACC</td>
<td>Go ahead.</td>
</tr>
<tr>
<td>03:55:58</td>
<td>AAR991</td>
<td>Request divert to Jeju. (captain)</td>
</tr>
<tr>
<td>03:56:02</td>
<td>SHIACC</td>
<td>AAR991 do you need to turn right back to..eoh...do you need to turn right immediately?</td>
</tr>
<tr>
<td>03:56:13</td>
<td>AAR991</td>
<td>Right turn immediately AAR991. (captain)</td>
</tr>
<tr>
<td>03:56:15</td>
<td>SHIACC</td>
<td>approved.</td>
</tr>
<tr>
<td>03:56:25</td>
<td>SHIACC</td>
<td>AAR991 confirm request divert to romeo-kilo-papa-charlie?</td>
</tr>
<tr>
<td>03:56:30</td>
<td>AAR991</td>
<td>Affirmative. (captain)</td>
</tr>
<tr>
<td>03:56:32</td>
<td>SHIACC</td>
<td>Roger, you may turn right, turn right now.</td>
</tr>
<tr>
<td>03:57:19</td>
<td>SHIACC</td>
<td>AAR991 confirm you need to descend and maintain flight level 030?</td>
</tr>
<tr>
<td>03:57:36</td>
<td>SHIACC</td>
<td>AAR991 shanghai confirm you need to descend and maintain three thousand feet, meter?</td>
</tr>
<tr>
<td>03:57:43</td>
<td>AAR991</td>
<td>One zero thousand, return to Jeju. (FO)</td>
</tr>
<tr>
<td>03:57:48</td>
<td>SHIACC</td>
<td>Oh, roger, stand by.</td>
</tr>
<tr>
<td>03:58:03</td>
<td>SHIACC</td>
<td>AAR991, roger, maintain one-zero thousand feet.</td>
</tr>
<tr>
<td>03:58:25</td>
<td>SHIACC</td>
<td>KAL886 shanghai.</td>
</tr>
<tr>
<td>03:58:27</td>
<td>KAL886</td>
<td>Shanghai KAL886, go ahead sir.</td>
</tr>
<tr>
<td>03:58:32</td>
<td>SHIACC</td>
<td>If you receive any information from the AAR991 and I didn't respond to him, please relay information to me, thank you.</td>
</tr>
<tr>
<td>03:58:41</td>
<td>KAL886</td>
<td>Roger, 886. they are descending one-zero thousand feet and now direct to Jeju.</td>
</tr>
<tr>
<td>03:58:48</td>
<td>SHIACC</td>
<td>Roger, thank you.</td>
</tr>
<tr>
<td>03:59:03</td>
<td>SHIACC</td>
<td>AAR991, do you have any other special request?</td>
</tr>
<tr>
<td>Time</td>
<td>AAR991</td>
<td>Text</td>
</tr>
<tr>
<td>-------</td>
<td>---------------</td>
<td>----------------------------------------------------------------------</td>
</tr>
<tr>
<td>03:59:13</td>
<td>Yeh, AAR991 request radar vector to Jeju please.</td>
<td></td>
</tr>
<tr>
<td>03:59:22</td>
<td>SHIACC</td>
<td>AAR991, do you have your own heading to Jeju?</td>
</tr>
<tr>
<td>03:59:26</td>
<td>AAR991</td>
<td>Roger, AAR991 we have rear, after cargo, fire after cargo, Descend to one-zero thousand and request radar vector to Jeju please.</td>
</tr>
<tr>
<td>03:59:40</td>
<td>KAL886</td>
<td>Shanghai 886, they request radar vector to Jeju.</td>
</tr>
<tr>
<td>03:59:50</td>
<td>SHIACC</td>
<td>AAR991 fly heading 045.</td>
</tr>
<tr>
<td>03:59:55</td>
<td>AAR991</td>
<td>Heading 045 AAR991.</td>
</tr>
<tr>
<td>04:00:23</td>
<td>SHIACC</td>
<td>AAR991 contact Incheon on 124.52 for vector to Jeju.</td>
</tr>
<tr>
<td>04:00:32</td>
<td>AAR991</td>
<td>Say again AAR991.</td>
</tr>
<tr>
<td>04:00:34</td>
<td>SHIACC</td>
<td>Contact frequency 124.52 for Jeju, correction, for Incheon.</td>
</tr>
<tr>
<td>04:00:39</td>
<td>AAR991</td>
<td>AAR991.</td>
</tr>
<tr>
<td>04:00:56</td>
<td>SHIACC</td>
<td>东方2015上海(Eastern 2015 shanghai)</td>
</tr>
<tr>
<td>04:00:58</td>
<td>CES2015</td>
<td>请讲2015(go ahead 2015)</td>
</tr>
<tr>
<td>04:01:02</td>
<td>SHIACC</td>
<td>你拿另外一部开一下124.52听一下韩亚991有没有过去叫(Please tune another radio 124.52 and listen to Asiana 991 if calling you)</td>
</tr>
<tr>
<td>04:01:08</td>
<td>CES2015</td>
<td>好的 (roger)</td>
</tr>
<tr>
<td>04:01:15</td>
<td>AAR991</td>
<td>Shanghai AAR991.</td>
</tr>
<tr>
<td>04:01:17</td>
<td>SHIACC</td>
<td>Go ahead.</td>
</tr>
<tr>
<td>04:01:18</td>
<td>AAR991</td>
<td>Unable contact Jeju 124.52.</td>
</tr>
<tr>
<td>04:01:22</td>
<td>SHIACC</td>
<td>AAR991, initial monitor this frequency, monitor 134.0.</td>
</tr>
<tr>
<td>04:01:27</td>
<td>AAR991</td>
<td>Monitor one two, three four decimal zero(1234.0).</td>
</tr>
<tr>
<td>04:01:50</td>
<td>SHIACC</td>
<td>东方2015 你现在联系下。。。稍等(Eastern 2015 you contact … wait a moment)</td>
</tr>
<tr>
<td>Time</td>
<td>Callsign</td>
<td>Text</td>
</tr>
<tr>
<td>-------</td>
<td>------------</td>
<td>-------------------------------------------------------------------------------------------------------------------------------------</td>
</tr>
<tr>
<td>04:02:00</td>
<td>SHIACC</td>
<td>AAR991 contact Fukuoka on 133.6, if unable make establish contact, return to my frequency 133.6</td>
</tr>
<tr>
<td>04:02:10</td>
<td>AAR991</td>
<td>AAR991. (FO)</td>
</tr>
<tr>
<td>04:02:22</td>
<td>AAR991</td>
<td>Fukuoka AAR991 mayday mayday mayday, we have cargo fire, request direct to Jeju please. (FO)</td>
</tr>
<tr>
<td>04:02:35</td>
<td>SHIACC</td>
<td>东方2015你现在开一下1336看一下那边有没有韩亚991叫 (Eastern 2015 you tune 1336, check if any Asiana 991 calling)</td>
</tr>
<tr>
<td>04:02:40</td>
<td>CES2015</td>
<td>好的2015(roger 2015)</td>
</tr>
<tr>
<td>04:02:42</td>
<td>SHIACC</td>
<td>你在那边不要发话,你就听一下韩亚991有没有过去 (You do not need to transmit, just monitor radio if any Asiana 991 around there)</td>
</tr>
<tr>
<td>04:02:46</td>
<td>CES2015</td>
<td>好的(Roger)</td>
</tr>
<tr>
<td>04:03:01</td>
<td>AAR991</td>
<td>Shanghai control AAR991. (FO)</td>
</tr>
<tr>
<td>04:03:03</td>
<td>SHIACC</td>
<td>Go ahead.</td>
</tr>
<tr>
<td>04:03:05</td>
<td>AAR991</td>
<td>Unable contact at Fukuoka. (FO)</td>
</tr>
<tr>
<td>04:03:07</td>
<td>SHIACC</td>
<td>AAR991 now you relay inform., pass information to the Korean Air 886 and let him relay information to Fukuoka and Incheon.</td>
</tr>
<tr>
<td>04:03:19</td>
<td>AAR991</td>
<td>Korean air, AAR991. (FO)</td>
</tr>
<tr>
<td>04:03:24</td>
<td>KAL886</td>
<td>Stand by 991, this is KAL886, I will relay to Incheon your message, stand by.</td>
</tr>
<tr>
<td>04:03:29</td>
<td>AAR991</td>
<td>예, 지금(Yes, now) direct Jeju heading 030. (FO)</td>
</tr>
<tr>
<td>04:03:34</td>
<td>KAL886</td>
<td>Shanghai gave you heading 045, 045, stand by, I will relay to Incheon.</td>
</tr>
<tr>
<td>04:03:44</td>
<td>AAR991</td>
<td>Heading 045. (FO)</td>
</tr>
<tr>
<td>04:04:14</td>
<td>SHIACC</td>
<td>KAL886 shanghai.</td>
</tr>
<tr>
<td>04:04:17</td>
<td>KAL886</td>
<td>Shanghai KAL886, go ahead sir.</td>
</tr>
<tr>
<td>04:04:20</td>
<td>SHIACC</td>
<td>You use another frequ., another transmitter to contact Incheon on 124.52 and request heading to Jeju from your present position and tell me please.</td>
</tr>
<tr>
<td>Time</td>
<td>Flight</td>
<td>Transcript</td>
</tr>
<tr>
<td>-------</td>
<td>--------</td>
<td>---------------------------------------------------------------------------</td>
</tr>
<tr>
<td>04:04:34</td>
<td>KAL886</td>
<td>Roger we are contacting Incheon control.</td>
</tr>
<tr>
<td>04:05:30</td>
<td>AAR991</td>
<td>886, AAR991. (captain)</td>
</tr>
<tr>
<td>04:05:32</td>
<td>KAL886</td>
<td>AAR991, KAL886, relay from Incheon control, from Incheon control, maintain heading 060, radar vector for final, and you may descend to 7000 feet.</td>
</tr>
<tr>
<td>04:05:49</td>
<td>AAR991</td>
<td>Seven thousand. (captain)</td>
</tr>
<tr>
<td>04:05:52</td>
<td>KAL886</td>
<td>KAL886 relay for AAR991, maintain heading 060 radar vector for final, and descend to 7000 feet.</td>
</tr>
<tr>
<td>04:06:05</td>
<td>AAR991</td>
<td>Descend seven thousand feet. (captain)</td>
</tr>
<tr>
<td>04:06:07</td>
<td>KAL886</td>
<td>Affirmative, affirmative</td>
</tr>
<tr>
<td>04:06:25</td>
<td>AAR991</td>
<td>Korean Air, AAR991. (captain)</td>
</tr>
<tr>
<td>04:06:28</td>
<td>AAR991</td>
<td>Korean Air, AAR991. (captain)</td>
</tr>
<tr>
<td>04:06:30</td>
<td>KAL886</td>
<td>Stand by, stand by.</td>
</tr>
<tr>
<td>04:06:32</td>
<td>AAR991</td>
<td>아.. 우리 rudder control도 안 되고 fire가 지급...(jamming)...것 같아요 (Ah.. we are now that rudder control is not working and seems to be fired....). (captain)</td>
</tr>
<tr>
<td>04:06:41</td>
<td>SHIACC</td>
<td>KAL886 contact Incheon control 124.52.</td>
</tr>
<tr>
<td>04:07:06</td>
<td>AAR991</td>
<td>Korean Air, AAR991. (captain)</td>
</tr>
<tr>
<td>04:07:16</td>
<td>SHIACC</td>
<td>AAR991 call KAL886 on 124.52, please try.</td>
</tr>
<tr>
<td>04:07:25</td>
<td>AAR991</td>
<td>124.52. (captain)</td>
</tr>
<tr>
<td>04:07:28</td>
<td>SHI ACC</td>
<td>Confirm Korea air on 12452.</td>
</tr>
<tr>
<td>04:07:30</td>
<td>AAR991</td>
<td>12452. (captain)</td>
</tr>
<tr>
<td>04:07:34</td>
<td>AAR991</td>
<td>해치를 열어야 할 것 같아. 해치 (we have to open the hatch, hatch). (captain)</td>
</tr>
<tr>
<td>04:07:40</td>
<td>KAL886</td>
<td>AAR991, this is KAL886.</td>
</tr>
<tr>
<td>04:07:44</td>
<td>AAR991</td>
<td>AAR991 go ahead. (captain)</td>
</tr>
<tr>
<td>04:07:47</td>
<td>KAL886</td>
<td>AAR991 please change frequency to 124.52, 12452. Incheon control I have relayed for you.</td>
</tr>
<tr>
<td>04:08:00</td>
<td>AAR991</td>
<td>12452. (captain)</td>
</tr>
<tr>
<td>Time</td>
<td>Flight Number</td>
<td>Communication</td>
</tr>
<tr>
<td>-------</td>
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<td>---------------</td>
</tr>
<tr>
<td>04:08:01</td>
<td>KAL886</td>
<td>Affirmative, 124.52</td>
</tr>
<tr>
<td>04:09:47</td>
<td>AAR991</td>
<td>Rudder control... flight control이 다 안 되요 (rudder control... flight control, all are not working). (captain)</td>
</tr>
<tr>
<td>04:09:50</td>
<td>AAR991</td>
<td>Jeju AAR991. (FO)</td>
</tr>
<tr>
<td>04:09:53</td>
<td>JEJAPP</td>
<td>AAR991 Jeju approach, go ahead.</td>
</tr>
<tr>
<td>04:09:56</td>
<td>AAR991</td>
<td>Did you contact? 어... 저희들 contact 하고 있어요? (Do you contact with us?) (FO)</td>
</tr>
<tr>
<td>04:10:02</td>
<td>JEJAPP</td>
<td>AAR991.. 그.. 예 들립니다...(gue... yes I can hear you).</td>
</tr>
<tr>
<td>04:10:06</td>
<td>AAR991</td>
<td>저희들 항공기 진동이 너무 심해서 emergency landing, emergency ditching 해야 될 것 같아요... (We have heavy vibration on the airplane, may need to make emergency landing, emergency ditching) (FO)</td>
</tr>
<tr>
<td>04:10:13</td>
<td>JEJAPP</td>
<td>에... 다시 한 번 말씀해주십시요... (Yes.. say again please)</td>
</tr>
<tr>
<td>04:10:15</td>
<td>AAR991</td>
<td>항공기 진동이 너무 심해서 고도 control 이 안 됨.... 곧 ditching 할 것 같애... 아..... (attitude control is not available due to heavy vibration, going to ditch... ah...) (FO)</td>
</tr>
<tr>
<td>04:10:26</td>
<td>JEJAPP</td>
<td>AAR991 제주 approach로 접근 가능하십니까? (can you make approach to Jeju?)</td>
</tr>
<tr>
<td>04:10:37</td>
<td>JEJAPP</td>
<td>AAR991 this is Jeju approch, guard out. Jeju approach로 접근 가능하십니까? (Is it possible to approach to Jeju)</td>
</tr>
<tr>
<td>04:10:50</td>
<td>JEJAPP</td>
<td>AAR991 AAR991, this is Jeju approach, guard out if you hear me, squawk ident.</td>
</tr>
<tr>
<td>04:11:18</td>
<td>JEJAPP</td>
<td>AAR991 AAR991 Jeju approach, this is Jeju approach, you are able to land at Jeju airport if you hear me direct da... direct MAMMY expect ILS/DME RWY 6 approach.</td>
</tr>
</tbody>
</table>
APPENDIX 5: Search Operations for Flight Recorders

The first-phase search operation was conducted from 28 July until 4 August 2011, and the summary of the operation is as follows:

- Participants
  - ARAIB: 1 person (investigator specializing in flight recorders)
  - Coast Guard: 2 persons (search support)
  - Navy: 5 persons (search support)
  - Asiana Airlines: 1 person (search support)

- Search Equipment
  - Portable Pinger Receiver: 1 set (ARAIB)
  - Pinger Location Sonar: 1 set (fitted to the Navy vessel)

- Search Area and Operation
  The vessels of the Navy and the Coast Guard searched for wreckage by dividing the area into seven zones as shown in [Figure 1]. For the flight recorders, the naval vessels searched Zones 3 and 4 at intervals of 2 km (radius: 1 km), and for the wreckage, the naval boats searched Zones 1, 2, 5, 6, and 7 at random intervals.

The second-phase search operation was conducted from 10 August until 14 August 2011, and the summary of the operation is as follows:

- Participants
  - ARAIB: 2 persons (investigators specializing in ATC & flight recorders)
  - Coast Guard: Crew aboard the Coast Guard ship (search support)
  - Singapore AAIB: 2 persons (participation in search)
  - Asiana Airlines: 6 persons (participation in search)
Appendix 5. Search Operations for Flight Recorders

- Portable Pinger Receiver: 5 sets (ARAIB: 1/Benthos 275, AAIB: 2/RJE 275, ASC: 1/RJE 275, Boeing Company: 1/Dukane N30A5B)
- Coast Guard Boat: 4 boats

- Search Area and Operation
  The second-phase search area is shown in [Figure 2], and it was decided to be 14.4 km in width by 66 km in length so that the area could incorporate points between where the aircraft passed one minute before the pilot said that the rudder control was lost and where the northeastern end of the wreckage distribution area was.

  On the site, pinger receivers were tested to measure their effective distance. As a result, in consideration of the shortest effective distance (1,000 m), the receivers were dropped at 256 points in the area at intervals of 1,800 m (radius: 900 m) to carry out search operations.
The third-phase search operation was conducted from 16 August until 20 August 2011, and the summary of the operation is as follows:

○ Participants
  - ARAIB: 1 person (investigator specializing in ATC)
  - Coast Guard: all crew aboard the Coast Guard ship (search support)
  - Taiwan ASC: 1 person (participation in search)
  - Asiana Airlines: 3 persons (participation in search)

○ Search Equipment
  - Portable Pinger Receiver: 3 sets (ARAIB: 1/Benthos 275, ASC: 1/RJE 275, Boeing Company: 1/Dukane N30A5B)
  - Coast Guard Boat: 3 boats
○ Search Area and Operation
The third-phase search area is shown in [Figure 3], and it was decided to cover the area from the whole wreckage distribution area located by a side scan sonar to the point where AAR991 had the last communication. The area was more closely searched at 127 points at intervals of 500 m (radius: 250 m) than in the second-phase operation.

[Figure 3] Third-Phase Search Area for Flight Recorders

☐ The fourth-phase search operation was conducted from 21 August until 27 August 2011, and the summary of the operation is as follows:

○ Participants
- ARAIB: 1 person (investigator specializing in flight recorders)
- Coast Guard: all crew aboard the Coast Guard ship (search support except for 1 person participating in search)
- Asiana Airlines: 4 persons (participation in search)

○ Search Equipment
- Portable Pinger Receiver: 2 sets (ARAIB: 1/Benthos 275, Boeing Company: 1/Dukane N30A5B)
- Coast Guard Boat: 2 boats

○ Search Area and Operation
The fourth-phase search area is shown in [Figure 4], and it was decided to cover the area from the point where AAR991 was flying at 14,600 ft to the southern part of the third-phase search area. In consideration of the strong southwest wind at the time of the accident, the area along a 5km band east of the flight track was also searched.

[Figure 4] Fourth-Phase Search Area for Flight Recorders
APPENDIX 6: Aircraft Cockpit Examination

January 18, 2012

A. ACCIDENT ID (NTSB #): DCA11RA087
LOCATION: Near Jeju Island, Korea
DATE/TIME: July 28, 2011
AIRCRAFT: Boeing 747-400, Asiana Airlines flight 911, registered as HL7604

B. GROUP:
Technical Advisor: Robert L. Swaim
National Transportation Safety Board (NTSB)
Washington, DC

C. SUMMARY:
Only July 28, 2011, about 04:12 am local Korean time (July 27, 2011 at 1912 UTC), Asiana Airlines flight 991, a Boeing 747-400F cargo airplane (HL7604), disappeared from air traffic control radar and crashed into the East China Sea, approximately 70 miles west of Jeju Island, Republic of Korea, shortly after the flight crew reported a main cargo deck fire. The two flight crew members were fatally injured. The airplane was being operated as a scheduled cargo flight from Incheon International Airport, Seoul, Korea, to Pudong, China.

D. DETAILS OF THE INVESTIGATION:

STRUCTURE:
The overall cockpit section extended from about fuselage station 200 to almost station 400 and the roof of the cab had been cut away prior to arrival of the group. The roof structure had generally been removed near the windows on the side of the first officer and the windshield frame structures have been cut between the windshield panes on the side of the captain.
A crush line extended from about STA 200, two frames forward of the top of the nose door, to the top of the fuselage at about fuselage station 400. The captain's side of the roof was crushed into the flight deck more than the side of the first officer. The exterior of the cockpit roof skins were extensively pressure formed to the contours of the interior frames and stringers. The aft of the cockpit roof was found twisted to the right. The heavy structures that had been the frames of the windshield were found deformed downward. The lower windshield frame collapsed downward with a sharp bend directly in front of the captains seat.
The upper deck skins and underlying structure had different types of damage on the left and right sides of the cockpit. The skins on the captain’s side were flat. Little existed of the skins from the side of the first officer and the underlying structure was buckled vertically.

Forward of the cockpit, the upper portion of the nose cargo door remained with the cockpit. The left side separated below the upper deck floor (separated about 7 stringers beneath the hinge) and the right side separated roughly at the level of the cockpit floor. The nose door remained closed with the cockpit portion of the fuselage and with a separate fragment of the left fuselage. The right pivot of the nose door had been displaced upward, the right side of the door had torn so that it was missing at three to four stringers beneath the hinge.

The center pedestal had been displaced left to the midpoint of the captains Multi Function display. The seat of the first officer had also displaced left to contact the displaced center pedestal.

The main deck hand fire extinguisher was found protruding upward through the cockpit floor between the FSTA frames 330 and 340, at the airplane centerline. The bottom of the fire extinguisher was to the right and the hose was caught on structure further to the right. The pin was in place and the indicator showed a full charge.

The overhead hatch remained in the closed position, with the handle at the mid-point of the range of travel. The range of travel is normally 180 degrees and the handle was found immovable at about 90 degrees from the stowed position. The exterior surface of the hatch had been pressure formed.

All of the cockpit emergency descent devices were found with the cockpit roof and all were partially extended, not in normal storage positions.

All of the cockpit windshields were accounted for, mostly in the frames and displaced inward.

**SEATS**

The captain seat was found detached from the cockpit. The floor in the vicinity of the captain seat tracks was gouged consistent with spacing of the seat attachments, such that the marks were less than three inches from full forward. The gouges were to the right and forward.

The complete seat of the captain was found with the back broken aft. The seat retained three of the four mounts and the forward right floor track remained with the seat. All four mounting points were oriented so that the rear of the seat was displaced to the
right, which corresponded with the structural intrusion into the seat space. The captain seat pan had no hydroform type of downward damage. The cushions had no thermal damage and were not blackened in color. Both lap belts had been cleanly cut and the buckle was not with the seat, when observed. The lower strap and shoulder straps remained with the seat.

The captains seatbelt buckle was found and matched to the lap straps. Both of the captain lap belt straps had been cleanly cut. The lower (crotch) and shoulder belts were found intact.

The first officer seat was found immovable on the seat rails at 8 to 9 inches from the forward stop. The seat pan is not displaced or hydroformed downward. The seat back is broken aftward to the level of the glareshield.

The first officer shoulder harness straps are both in the stowed positions. The left and crotch straps are both complete with metal tangs that would engage with the buckle mechanism. The remaining right strap has a ragged tension separation in the middle of the strap that matches the portion remaining attached to the buckle.

The two cockpit observer seats were found complete, with the back assembly of each broken aft. The lap belts had damage similar to that seen at the first officer seat.

OXYGEN SYSTEM

The supplies for the oxygen system were not seen and this section only describes the cockpit portions found.

The captains stowage box for the normal oxygen mask had been partially crushed, with the top of the control yoke found in the box. The supply hose was complete to the fitting where the mask assembly had connected. The captains oxygen mask was not seen.

Found with the seat of the captain was an empty oxygen mask box from the cockpit, marked EROS by Intertechnique, P/N MXP147-3, S/N SE09373. The mask box was deformed in a way that captured two laminated NORMAL PROCEDURES checklists. In another Asiana 747, the checklists were found in a pocket on top of the glareshield.

Two oxygen masks of the observer type were found. The mask found near the first officer seat was complete with the head bands and a selector on the bridge of the nose (goggle vent) was initially found at a mid position, closer to the marking “KEEP CLOSED WITHOUT GOGGLES."

The smoke mask of the first officer was found on floor next to the F/O seat, attached to a supply hose.
The stowage area for the mask had been disrupted and the mask had extensively more damage than the observer masks, including a broken lens, headbands separated from one end, and extensive damage was found to the microphone/valve area. None of the masks were darkened internally or externally with soot-like deposits.

**FORWARD INSTRUMENT PANELS AND PEDESTAL**

Notes:
1. Nearly all of the annunciator lights were seized and could not be opened normally to check the bulbs. The mechanisms had to be soaked and then pried open.
2. Lightbulbs were examined with a 10X glass on-site and then separately under magnification of 50-200X with a digital microscope.
3. Two types of annunciator lights were found. Typical of the larger was model OL387 and AS150. Typical of the smaller bulb was stamped model OL-685-15.
4. The following references were used for the light bulb examination:
5. As noted in the studies pertaining to incandescent light bulbs, tungsten achieves white luminosity at about 3000-5000 degrees F and becomes ductile at about 480 F. Variables involved in the stretch of filaments include temperature, impact load, and filament age.

At the left edge of the forward instrument panel, the captains SOURCE SELECT switches were found with the FLT DIR selected to Left, NAV to FMC Left, EIU to Auto, IRS to Left, and Air Data selected to Left.

The captain shoulder heater was at low, the foot heat at high, and windshield heater at high.

The captains clock was missing the glass and sweep needle. The captains RMI had intact facial glass that was not completely clear. Two orange INOP flags could be seen
through the glass. Both external knobs were oriented upward.
The faces were shattered on the captains Primary Flight Display (PFD) and the Multi Function Display (MFD) units.
The top of the captains control column had been broken downward by the downward displacement of the glareshield. Most of the control yoke was in the oxygen mask box, without the right handle.
Beneath the PFD, the HYD BRAKE PRESS gauge was obscured by the captains right grab handle / foot rest. The AUTOBRAKES selector was folded into a damaged area ahead of the displaced throttle pedestal.
Above the captain PFD, the panel was bent and the display selector knobs were missing. The shaft flats for the knobs were configured for the INBD CRT to display the PFD and the LWR CRT to display EICAS PRI.
The standby attitude indicator was partially crushed and the face had been contacted by the left Multifunction Control Display Unit (MCDU, shown in some documents as CDU). In areas of disruption were the EIU SEL assembly, the FMC selector, as well as the selectors for the first officer LWR CRT and INBD CRT.
The captains stabilizer trim indicator shows OFF. The speed brake control handle is 1.1 inches aft of the flight detent, with the autopilot Mode Control Panel (MCP) resting against it. The parking brake lever was found extended.
The MCP was also resting against the remnants of all four thrust levers, which were found at the aft edges of travel. Each of the four thrust levers were missing the top knob and all four were bent to the right. All four thrust reverser levers were found in the stowed positions.
Both EICAS display units had crushed facial glass and the lower unit had been twisted by the displaced pedestal.
The landing gear handle was found past the up position, bending the top of the handle box, with the frame of the right MCDU resting against the bottom of the handle.
The panel for alternate flap and alternate landing gear selection and annunciator assemblies was crushed into a disrupted area. The only remaining light bulb was of the small type from the NOSE/BODY switch light and under magnification, the filament had a fracture at one end. The filament had not stretched in general form or in individual coils.
On the right side of the pedestal, the stabilizer trim indicator displayed the word OFF.
A crease line extended from the right edge of the throttles diagonally aft, folding the
set of stabilizer trim switches to the right.
The faces were shattered on the first officer Primary Flight Display (PFD) and the Multi Function Display (MFD) units. The first officer clock facial glass was missing and the sweep needle was at the parked position (up). The top of the first officer control column had been crushed downward, separating the control yoke, which had the right handle broken off.
The first officer master caution warning annunciator was not seen. At the right edge of the forward instrument panel, the first officer SOURCE SELECT switches were found with the FLT DIR knob missing and the flat of the shaft selected to Right, NAV to FMC Right, EIU to Auto, IRS to Right, and Air Data selected to Right.
The first officer shoulder heater was at high, the foot hear at low, and windshield heater at high.
The components mounted on the glareshield had been crushed and twisted. The captains electronic flight instrument control (EFIS) control was selected to MAP with a range of 320 miles. The captain flight director was to OFF. The FMC control panel was broken across the vertical speed selector. The selected speed was 239 knots, the heading selection was in an indented area and closest to the display of 143 degrees. The autopilot disengage switch was in a bent area of the panel. The first officer flight director was at OFF, the EFIS control panel was selected to MAP with a range of 160 miles.
Aft of the pedestal were the four fuel cutoff (FCO) switches that were documented in place, removed, rinsed in tap water to remove salt deposits, and under magnification.
**FUEL CUTOFF SWITCH #1**
When removed from the pedestal, the plastic body of the switch was found cracked.
Found with the toggle in the ON position and with corresponding microscopic marks on the gate and finger of the latching mechanism. Under magnification, the lock/latch mechanism was found unremarkable and no metal smears or deformation was noted.
The red plastic cap was removed to access a lightbulb. The glass of the bulb was found in fragments and the filament was not found.
**FUEL CUTOFF SWITCH #2** When removed from the pedestal, the plastic body of the switch was found cracked.
Found with the toggle in the ON position and with corresponding microscopic marks on the gate and finger of the latching mechanism. Under magnification, the lock/latch mechanism was found past the spring loaded locking feature and twisted, so that the
left finger was on top of the locking gate and the right finger was a full finger-width past the gate. The ON side of the left finger had a strike and rust mark corresponding with the ON side of the gate. The ON side of the left gate had a smear toward the OFF side. The top of the right gate (ON position) had a strike mark and a corresponding mark was on the finger.

The red plastic cap containing a bulb was not present when the switch was first found. FUEL CUTOFF SWITCH #3 When removed from the pedestal, the body of the switch was found intact.

Found with the toggle in the OFF position, with microscopic markings at the ON position on the gate and finger of the latching mechanism. Under magnification, the ON side of the left finger had a single strike mark at the edge, consistent with the toggle displaced to the right and fully seated on the gate. The bottom/ON side of the right finger had a set of diagonal contact marks that were out of plane with normal operation. The direction for the top of the diagonal was consistent with displacement to the right. The OFF sides of the left and right fingers had significant rust deposits and wear spots. What was visible of the surfaces did not have strike marks or metal displaced.

The red plastic cap was removed to access a light bulb. The glass of the bulb was found intact and the filament had broken into multiple small fragments with no stretching of the coils.

FUEL CUTOFF SWITCH #4 When removed from the pedestal, the plastic body of the switch was found intact.

Found with the toggle in the OFF position, with microscopic markings at the ON position on the gate and finger of the latching mechanism. Under magnification, the top sides of both gates had marks in the metal and the right gate had smeared metal at the top corner. The ON side of the left finger had minor marks, the right finger had no visible marks. The OFF sides of the gates were partially obscured by rust, the visible metal was not damaged.

The red plastic cap of FCO #4 was removed to access a light bulb. The glass of the bulb was found intact and the filament had broken into multiple small fragments with no stretching of the coils.

The captains audio panel selections were for Left VOR and Center MKR.
The NO SMOKING selector was at AUTO, the SEATBELTS selector was at OFF. The rudder trim indicator was found with the OFF flag showing at 8 units left of center.
The AUTOBRAKES rotary selector was found at DISARM.

**OVERHEAD PANELS**

All overhead panels have extensive evidence of contact, impact damage, and deformation. Many had to be extensively cut into smaller pieces to extricate annunciator and switch assemblies. The luminescent panels had broken and exposed the underlying tracks were black and missing the normal copper color.

Forward of the overhead luminescent panels was a black residue on the plastic panels that had been above the forward windshields.

The **lighting control panel** from the captain side has 2 of 4 knobs broken away at the panel. The circuit breaker and glareshield lighting control knobs were found deformed. The **AISLE STAND PANEL FLOOD** knob was at full on.

Other than the OUTBD LEFT (on), the landing lights were found at OFF. The RWY TURNOFF left switch had been broken and the right had been bent. The taxi light switch was found at OFF.

Of the lighting switches on the side of the first officer, none had an intact toggle and shaft.

The **hydraulic control panel** had grossly deformed facial features.

The #1 system knob was missing and the knob flat was at AUTO.

The two large style **PRESS** annunciator bulbs were found broken into smaller sections and neither had stretching in general form or of the individual coils. One smaller ON bulb had a single filament break and the other had a fragment break free; no stretching in form or of individual coils was seen in either filament.

The two large style **SYS FAULT 1** annunciator bulbs both had the filaments fracture into multiple small parts with no stretch observed.
The #2 system knob was between AUTO and ON. 
The filaments of the two large style PRESS annunciator bulbs were found broken into smaller 
fragments and none had stretching in general form or of the individual coils. Both 
smaller ON 
bulbs had a section of the filament separate and neither had stretching in form or of 
individual 
coils. 
The two large style SYS FAULT 2 annunciator bulbs each had the filament break and 
stretching was found in some of the fragments. The right bulb had fragments appear to adhere 
to the inside of the glass. 
The #3 system knob was at AUTO. 
The filaments of the two large style PRESS annunciator bulbs were found broken into smaller 
fragments and none had stretching in general form or of the individual coils. Both 
smaller ON 
bulbs had the filament break into small fragments and none had stretching in form or of 
individual coils. 
The two large style SYS FAULT 3 annunciator bulbs had a difference in appearance of the 
filaments, although both had broken into smaller portions. In one the portions were small and 
brITTLE looking. Some of the fragments of the second filament had extensive amounts of stretch 
and some had no stretch. 
The #4 system knob was between AUTO and ON. 
The filaments of the two large style PRESS annunciator bulbs were found broken into smaller 
fragments and none had stretching in general form or of the individual coils. Both 
smaller ON 
bulbs had the filament break into small fragments and none had stretching in form or of 

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individual coils. 

The **electrical control panel** was extensively disrupted and deformed. The following items were observed:

The switch mechanism for the Standby Power rotary knob had separated from the back of the panel and no clear alignment characteristics were found.

**UTILITY LEFT,**

The left filament from the OFF annunciation had broken into fragments with extensive stretching to the general form and individual coils of two fragments. The glass enclosure of the second OFF bulb was found fragmented and no filament was seen. The left ON filament had broken into small fragments and individual coils, with no stretching characteristics. The right ON filament had broken, with fragments adhered to the glass and a two exhibiting gross stretching.

**UTILITY RIGHT,**

Both ON filaments had broken into numerous small fragments and no stretching was seen. Both OFF bulb glass enclosures had broken and the filaments were not seen. The APU selector on the electrical control panel was found at OFF and the STDBY selector was missing.

**BATTERY ANNUNCIATOR BULBS,**

The ON left bulb filament had broken into smaller fragments, with at least two individual coils. 

No distortion of the major features or of more than a single localized coil was seen. The ON right bulb filament had broken into small fragments with no distortion of the major features or of the single localized coils.

The battery annunciator OFF left bulb filament had two loose fragments. One filament fragment
had a sharp bend and minor coil stretches. The second fragment had distortion of the major features and of single localized coils. The OFF right bulb filament had a single break with stretched coils near the break and in at least two other locations, as well as a sharp bend in the coil.

BUS TIE #2
The filament from one of the smaller bulbs that had been behind the AUTO legend had broken in one location and an indefinite amount of mild stretched across the mid portion, with tight coils near the posts. The second filament had not broken and was unremarkable. Two large style bulbs were behind the legend ISLN. One ISLN filament had a slightly opaque glass and the visible filament had a section fractured from the middle, with no visible stretching. The second ISLN filament had a sagging filament that had broken between the posts.

BUS TIE #3
The filaments of the smaller bulbs that had been behind the AUTO legend had both broken without stretching. The two large style bulbs were behind the legend ISLN and both had broken into small fragments. The two small style bulbs had broken filaments that exhibited no stretching in form or of the individual coils.
The IRS panel was found with all three selectors at NAV. The Digital Electronic Engine Control (DEEC) annunciators had two smaller bulbs behind the NORM legend and two larger bulbs behind the ALTN legend. The DEEC #1 ALTN filaments had both broken and no stretching was noted. One had a long single portion separate and the second filament broke into
numerous small fragments. The two small style NORM filaments had broken into filaments that exhibited no stretching in form or of the individual coils. The DEEC #2 ALTN filaments had both broken into smaller fragments and no stretching was noted. One of the two NORM bulb filaments was intact and the other had a break; neither had stretching in form or of the individual coils. One of the DEEC #3 ALTN filaments had broken in a single location and the second into smaller fragments; no stretching was noted in either. Both of the NORM bulb filaments broke into small fragments and neither had stretching in form or of the individual coils. The DEEC #4 ALTN filaments had both broken into smaller fragments and no stretching was noted. Both of the two NORM bulb filaments had broken and neither had stretching in form or of the individual coils. At the forward center of the overhead panel, the window heat panel left wiper switch was at low and the right was at high. The fuel control panel was grossly distorted. The start panel had the left STDBY igniter knob missing, the AUTO knob to SINGLE, and the fuel jettison knob at OFF. The fire control panel contained a pull handle for each of the four engines and one for the APU. None of the engine or APU handles had been turned to the discharge positions. An apparent difference in extensions of the handles observed was subsequently found to be displacement of the handle bodies that were located behind the panels. Once the displacement was accounted for, all of the extension measurements equated to the stowed positions.
ENGINE #1 Fire Handle
Of the four bulbs, one bulb had broken and was missing the filament and a second bulb was filled with fluid. The filaments in each glass had broken and no stretch in general form or individual coils was observed.

ENGINE #2 Fire Handle
Of the four bulbs, one bulb glass was missing and two had holes in the glass. The filament in the complete bulb had broken into small fragments and no stretch in general form or individual coils was observed. One of the bulbs with a hole had about a third of the filament remain and no stretch in general form or individual coils was observed.

ENGINE #3 Fire Handle
Of the four bulbs, one bulb had broken and was missing the filament. The filaments in each glass had broken and no stretch in general form or individual coils was observed.

ENGINE #4 Fire Handle
Of the four bulbs, two bulbs were missing the glass, with filament fragments remaining in the base. The filaments in each and the intact bulbs (each contained filament fragments) had no stretch in general form or individual coils.

APU Fire Handle
Bulbs #1-#4: Two of the four bulbs had broken glass and retained filament fragments within the base areas. All four bulb filaments had broken and no stretch in general form or individual coils was observed.

APU BTL DISCH
One of the two bulbs contained a broken filament and neither of the filaments had stretch in general form or stretching of the individual coils.
BTL A DISCH, Engines 3 and 4,
The left and right bulb filaments had each broken into multiple fragments with no distortion of
the major features or of the single localized coils.

BTL B DISCH, Engines 3 and 4,
The left and right bulb filaments had each broken into multiple fragments with no distortion of
the major features or of the single localized coils.
The EMER LIGHTS toggle was found at the ARMED position with the guard broken away.
The OBSERVER AUDIO SYSTEM lift/latch switch was found at NORM. The CAPT
AUDIO SYSTEM
toggle was found bent upward past NORM. The INTERPHONE SERVICE TOGGLE
was found at ON
and the CARGO/CABIN switch was found at OFF.
The Smoke Evac handle was found in the stowed position with a coiled microphone
type of cord
wrapped around the T, which could not be freed without extending the handle. The Teleflex cable
attached to the back of the handle was found to retain a broken arm from the valve
assembly at the
opposite end of the cable and the arm had been caught by the edge of the overhead hatch. The teleflex
cable was found extended to the full length, past the sliding extension at the end, so
that about 4 inches
of the flexible cable was exposed. The shutter for the valve was found closed.
The pneumatic control panel contained the following items:
The left isolation valve annunciator had two types of bulb. The larger bulbs were
behind the
legend VALVE and the smaller were behind a horizontal line that could be illuminated to
complete a flow path. None of the filaments exhibited stretch in general form or of
individual
coils.
The right isolation valve annunciator had two types of bulb and the glass enclosures had separated from the two larger bulbs with more than half of the filaments remaining. None of the filaments exhibited stretch in general form or of individual coils. The APU pneumatic supply annunciator had two types of bulb. The larger bulbs were behind the legend VALVE. The smaller bulbs were behind the word ON. Both ON bulb filaments had broken at the ends of indefinite stretched areas between the posts. Both VALVE bulb filaments had broken into many small fragments with no stretching in general or of individual coils. The #1 pack selector was at NORM on January 9, 2012, as it was observed in Korean notes of August 11, 2011. The body of the switch assembly had not rotated in the mount. The #2 pack selector was missing the knob and the shaft flat was at NORM on January 9, 2012, as it was observed in Korean notes of August 11, 2011. The body of the switch assembly had not rotated in the mount. The #3 selector was at OFF on January 9, 2012, as it was observed in Korean notes of August 11, 2011. The body of the switch assembly had not rotated in the mount. The two #1 SYS FAULT light bulbs were intact and the filaments exhibited no stretching of the general form or of the individual coils. The two #2 SYS FAULT light bulbs were intact and the filaments exhibited no stretching of the general form or of the individual coils. The two #3 SYS FAULT bulbs had extensive amounts of filament stretch between the tops of the posts. The two #4 SYS FAULT bulbs had some sag and minor amounts of filament stretch in
localized areas.
The Environmental Control System (ECS) control panels contained the following items:

Both outflow valves indicators were found at the full open positions.

MANUAL OUTFLOW VALVE ANNUNCIATOR, LEFT (MAN L)
The assembly contained two bulbs and two blanking plugs. Neither bulb had a filament stretched in general form or with stretching of the individual coils.

MANUAL OUTFLOW VALVE ANNUNCIATOR, RIGHT (MAN R)
The assembly contained two bulbs and two blanking plugs. Neither bulb had a filament stretched in general form or with stretching of the individual coils.

FAN
Neither bulb had a filament stretched in general form or with stretching of the individual coils.

ZONE RST
The left SYS FAULT bulb was found broken into small fragments with no distortion of the major features or of the localized coils. The right bulb had a single break and indefinite minor stretching of the general features. The upper two bulb positions were filled with plastic plugs.

TRIM AIR
The filaments of the two bulbs each had one major portion loose within the glass enclosure. No distortion of the major features or of the localized coils was seen. The lower two positions had plastic plugs installed.

HI FLOW
The assembly contained moist dirt, both bulbs had broken, and the filaments could not be examined.

PACK RST
The left SYS FAULT filament had a separated section and a short area of one had minor stretched beyond normal, with none of the coils clearly stretched. The right SYS FAULT bulb had two
filament fragments that had clearly been stretched. The upper two holes were filled with plastic blanking plugs.

**AFT CARGO HT, ON and TEMP**
The four filaments within the AFT CARGO HT annunciator had each broken into small fragments with no distortion of the major features or of the localized coils.

The temperature control panel had the following control positions:
- flight deck knob at AUTO,
- the MAIN DECK FWD at about 2 o’clock,
- the MAIN DECK AFT shaft flat (no knob) near AUTO,
- the LOWER LOBE FWD TEMP knob missing and the shaft flat at about 9 o’clock,
- the LOWER LOBE AFT TEMP knob missing and the shaft flat at about 3 o’clock.

**CARGO FIRE PANEL**

**MAIN DECK**
The lower two bulbs in the annunciator were behind a red caption that was labeled MAIN DECK.

The left filament had major distortion and distortion of the localized coils. The right filament had a single large central section separate and major distortion or distortion of the localized coils was not visible. Both ARMED bulb filaments were intact and unstretched.

**FWD CARGO**
The lower two bulbs in the annunciator were behind a red caption that was labeled FWD. The left FWD filament had broken into separate pieces, one of which adhered to the glass at least two exhibited both stretching in general form and of individual coils. The right FWD bulb filament had two fragments separate, one of which was grossly stretched toward one end.

Additional stretching was seen in a fragment remaining attached to the base. The left ARMED filament was found with a single break and no distortions of the general form or individual coils. The right
ARMED filament was found intact.

AFT CARGO
The lower two bulbs in the annunciator were behind a red caption that was labeled AFT. The left filament had sag and a single break, with no distortion of the major features or of the single localized coils. The right bulb for the red AFT annunciation had at least four loose fragments within the glass and no distortion of the major features or of the single localized coils was seen.
Both ARMED bulb filaments were intact and unstretched.

CARGO FIRE DEPRESS/DISCH
The upper two bulbs were behind a caption DEPRESS and the lower two bulbs were behind the caption DISCH. The left DEPRESS filament had broken into a large section and at least two smaller fragments. The general filament did not exhibit generalized stretching; some individual coils had stretched near a post. The right DEPRESS filament was intact with some sag and minor individualized coil stretches near one post. The filament of the left DISCH bulb exhibited stretching of the general form and individual coils near both posts and down one side.
The filament of the right DISCH bulb exhibited gross stretching of the general form and individual coils, with one break of the filament.
The supernumerary passenger oxygen switch guard was safety wired (frangible wire) in the closed and OFF position.
The yaw damp annunciators had two types of bulb. The larger bulbs were behind the legend INOP and the smaller were behind the word ON.
The left yaw damp annunciator INOP bulbs had broken filaments, combined with areas
of
stretching the general form. Both of the smaller filaments had no stretching and brittle
types of
breakage.
The right yaw damp annunciator and the smaller were behind the word. The larger
INOP bulbs
had broken filaments and areas of stretching the general form. Both of the smaller ON
filaments
had no stretching and brittle types of breakage.

**AFT OVERHEAD PANELS**

An unlabeled switch (seen as the ELT switch in another airplane) that had been located
aft of the
Digital Electronic Engine Control (DEEC) panel was in an impacted area and labeled
ON ARMED
RESET. The heavily damaged switch was missing the guard and the damaged toggle
was found at
RESET.
The GND TESTS switch at the aft left corner of the overhead panels was found
extensively impact
damaged.
The FLT CONTROL HYD switches were all found in the closed (guarded) positions,
with damage to
the guards.
An extensively damaged area contained remnants of guarded toggle switches labeled
GEN FIELD
MAN RESET and SPLIT SYSTEM BREAKER.
The LOWER LOBE CARGO CONDITIONED AIR FLOW RATE rotary selector was
found to the left
of OFF.

List of removed parts
Asiana 911 — HL7604
Note that most of the following parts were removed to access other components. The
NVM items were
removed for preservation.
1. No Smoking / Seatbelt Panel with two switches:
1A. No Smoking Rotary Switch
Janco
P/N: AC45-0008-2
S/N: 8592
Date: 05 09
1B. Seatbelt Rotary Switch
Janco
P/N: AC45-0008-2
S/N: 8588
Date: 05 09
2. Rudder/Aileron Trim Module
233T6201-21
233T6201-324
S/N: D02592
3. Call Light Panel
BAE Systems
P/N: 285U1004-1
S/N: D00137
4. Autobrake Panel-Autobrake Selector Switch
Janco
Boeing P/N: S283T022-3
Janco P/N: AC30-0003-3
S/N: 2903
Date Code: 9649
5. CON-4B Control Unit (Radar)
Honeywell
SER CON 4B-05338
DMF: 082005
MFR: 97896
S/N: 0543
6. TCAS Panel
P/N: G6992-03
S/N: 4310
7. Chronometer — Labeled “‘F/O Side’”
Smiths
PNR: 2510-08-1
SER: CL5080
Boeing P/N: 60800303-107
Software P/N: S00076-SW-04
8. Audio Control Panel — Labeled “‘Pedestal Observer Seat’”
Hughes/Avicom
Hughes P/N: 1167015-141
Boeing P/N: S220U000-203
S/N: D-9103000783
NVM Note: No NVM
9. Audio Control Panel — Labeled “‘Captain’”
Hughes/Avicom
Hughes P/N: 1167015-141
Boeing P/N: S220U000-203
S/N: 9502040340
NVM Note: No NVM
10. Audio Control Panel — Labeled “‘F/O’”
Hughes/Avicom
Hughes P/N: 1167015-141
Boeing P/N: S220U000-203
S/N: D-9102000737
NVM Note: No NVM
11. Multi Input Printer
Matsushita
MFR P/N: RD-AC1203-5B3
S/N: 200341
Date: 02 97
12. MCDU
Honeywell
Honeywell P/N: 4058650
Boeing P/N: S242T102-152
S/N: 91091428
NVM Note: No Aircraft Status recorded, only hardware faults and software exceptions with no time tags.

13. Radio Communication Panel — Labeled ““Captain””
   BAE Systems
   P/N: 285U0037-613
   S/N: D03188
   NVM Note: Records frequencies, modes, BITE status.

   BAE Systems
   P/N: 285U0037-613
   S/N: D01980
   NVM Note: Records frequencies, modes, BITE status.

15. Radio Communication Panel — Labeled ““Captain””
   BAE Systems
   P/N: 285U0037-613
   S/N: D03214
   NVM Note: Records frequencies, modes, BITE status.

16. Mode Control Panel
   NVM Note: Records last selections, such as crew section of airspeed, selected altitude, and selected heading. Does not record system failures.

17. MCDU — Labeled ““Captain CDU””
   Honeywell
   P/N: 4077880-998
   S/N: 31804106
   NVM Note: No Aircraft Status recorded, only hardware faults and software exceptions with no time tags.

18. Brake Pressure Indicator
   P/N: 162LCP639
   S/N: 05105424

19. Integrated Standby Flight Display (ISFD)
   Thales Avionics
P/N: C16221LA03
S/N: C16221005129
NVM Note: No Aircraft Status recorded, only hardware faults and software exceptions.

20. RMI
Collins
P/N: 203
S/N: 1R951

21. Chronometer
Smiths
P/N: 2610-08-1
S/N: CL6225

22. MCDU Keyboard
Honeywell
P/N: MS90451-7132
S/N: 2595
NVM Note: Records internal fault status only.

23. Display Unit -- Labeled ""Upper EICAS"
Rockwell/Collins
P/N: 4V792
S/N: 160TG0

NVM Note: Records internal fault status only.

24. Display Unit -- Labeled ""Capt (Left) PFD"
Rockwell/Collins
P/N: 4V792
S/N: 1RLHV

NVM Note: Records internal fault status only.

25. Display Unit -- Labeled ""Copilot Left"
Rockwell/Collins
P/N: 4V792
S/N: 160TG1

NVM Note: Records internal fault status only.

26. Display Unit -- Labeled ""Copilot RT"
Rockwell/Collins
P/N: 4V792
S/N: 160TG5
NVM Note: Records internal fault status only.
27. Display Unit — Labeled ““Capt MFD””
Rockwell/Collins
P/N: 4V792
S/N: 1RL2B
NVM Note: Records internal fault status only.
28. Display Unit — Labeled ““EICAS Lower””
Rockwell/Collins
P/N: 4V792
S/N: 1RMLY
NVM Note: Records internal fault status only.
29. MCDU — Labeled ““Copilot CDU””
Honeywell
P/N: 4058650-90
S/N: 94062367
NVM Note: No Aircraft Status recorded, only hardware faults and software exceptions with no time tags.
## APPENDIX 7: AAR991's Flight Documents

### Flight Plan (5/5)

![Flight Plan Image]

**Flight Plan 1/5**

### TYPICAL FLIGHT PLAN

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**TTL RSV 0739 03.26**

* TANKERING SECTR *
* GAIN(F) 1001 (042500 LBS) *
* DISPAYN DEFINED *

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**CTF FUD ASR3 NIKAT DCT**

**CTF FUD ASR9 JTNS 0204 AND**

**AM27A**
Flight Plan 2/5
### Flight Plan 3/5

**OZ 991/27 JUL/ICN-PVG**

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**Flight Plan 4/5**
### OZ 991/27 JUL/ICN-PVG

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Flight Plan 5/5
## Load Sheet

**LOAD SHEET**  B747-400F  
**ALL WEIGHTS IN LBS**

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### STAB TAKE-OFF 4.2

| TAXI FUEL 1500  | TAXI WT 604401  | MRW 870000 |

### UNDERLOAD BEFORE LMC 17599

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### SI

| PANTRY CODE A |

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Appendix 7.  AAR991's Flight Documents

● Flight and Maintenance Log

![Flight and Maintenance Log](image)

● Fuel Information

icnod

보낸 사람: gmcpow@asianemsg.com
보낸 날짜: 2011년 7월 28일 금요일 오후 1:19
받는 사람: Icnod
제목: [QD] MVT
 중요도: 높음

QD ICNODOZE .GMCPWZ 041828JUL 023DC4
MVT
OZ0991/27.HL7604 .ICN
AD1747/1865 HA2933 PVG
DL8G/0902
FX000/000/000
SI RMFP/D108600 APLD/0145368

- 271 -
### Appendix 7.

**NOTOC**

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http://www.abrackcargo.com
● CJU Chart

- Airport Chart
- Runway 06 ILS Procedure
- Runway 24 ILS Procedure
- Radar Minimum Altitude
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APPENDIX 8: 2011 Recurrent Training and Evaluation for B747-400 Flight Crew

● **B747-400 Type Transition Training, Recurrent Training and Evaluation for AAR991 Flight Crew**

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● **Fire-related Ground and Simulator Training for AAR991 Flight Crew**

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Recurrent Training for B747-400 Flight Crew in the 1st Half of 2011
- CAP

ASIANA AIRLINES
B747-400

RECURRENT TRAINING (CAPT with CAT II/III )
THE 1ST HALF OF 2011
## Appendix 8.

### 2011 Recurrent Training and Evaluation for B747-400 Flight Crew

- F/O

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### ASIANA AIRLINES

#### B747-400

#### Recurrent Training (Co-pilot (F/O))

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### Remark

1. **RECURRENT TRAINING ITEMS.**
2. **AFTER MSD APP INSTRUCTOR CAN BE RELOCATED ON BASE LEO OR FINAL LEO FOR SAVING TIME.**
3. **FM should not take over PF's flight control.**

---

2011.04.11 REV O3

**FLIGHT CREW TRAINING TEAM**
## Proficiency Check for B747-400 Flight Crew in the 1st Half of 2011

- CAP

### ASIANA AIRLINES

**B747-400 FLIGHT CREW CHECK GUIDE**

### PERIODIC PROFICIENCY CHECK PROFILE (for Captain)

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### REMARK

1. **NON-NORMAL EVENTS**
2. **CAP** All Weather Operation Requirements (CAT-II & CAT-III)
3. Checker can give variable wind conditions, but MAX steady crosswind component is 10KTS. (CAT-I/II : MAX 10KTS)

---

**REVISON NO: 0 (JAN 01 2011)**

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- F/O

ASIANA AIRLINES
B747-400 FLIGHT CREW CHECK GUIDE

PERIODIC PROFICIENCY CHECK PROFILE (for Co-pilot (F/O))

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<th>RVR</th>
<th>VIS</th>
<th>CROSS WIND</th>
<th>WT (LBS)</th>
<th>RWY COND</th>
<th>ATC CLR</th>
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<td>800</td>
<td>00</td>
<td>5000</td>
<td>25%</td>
<td>600</td>
<td>13%</td>
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</tr>
<tr>
<td>2000</td>
<td>00</td>
<td>5000</td>
<td>23%</td>
<td>600</td>
<td>22%</td>
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</tr>
<tr>
<td>RVR 18</td>
<td>10KTS</td>
<td>50</td>
<td>600</td>
<td>23%</td>
<td>600</td>
<td>22%</td>
</tr>
<tr>
<td>CAT-1</td>
<td>10KTS</td>
<td>50</td>
<td>600</td>
<td>23%</td>
<td>600</td>
<td>22%</td>
</tr>
<tr>
<td>CAT-1</td>
<td>10KTS</td>
<td>50</td>
<td>600</td>
<td>23%</td>
<td>600</td>
<td>22%</td>
</tr>
</tbody>
</table>

Remark

(1) **~** Non-Normal Events
(2) Checkers can give variable wind conditions, but MAX steady crosswind component is 15KTS. (CAT-1/2/3/MAX 10KTS)
(3) If the CAPT check is not completed within 2HRS, it could be extended 2HRS by taking Co-pilot (F/O) check time. But total check time for 2 Pilots shouldn't exceed 4HRS
(4) In the event non-normal conditions occur while Co-pilot (F/O) takes off after V1 speed, Co-pilot (F/O) shall play a role as a PF.
Recurrent Training for B747-400 Flight Crew in the 2nd Half of 2011
- CAP

- F/O

### Recurrent Training (Co-pilot (F/O))

**ASIANA AIRLINES**

**B747-400**

**The 2nd Half of 2011**

<table>
<thead>
<tr>
<th>FOG: VIS</th>
<th>X-WIND</th>
<th>OW Cond</th>
<th>RWY Cond</th>
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<td>300.0</td>
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<tr>
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<td>10K</td>
<td>600.0</td>
<td>24%</td>
</tr>
<tr>
<td>CVOK</td>
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<td>600.0</td>
<td>24%</td>
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</tr>
<tr>
<td>CVOK</td>
<td>10K</td>
<td>600.0</td>
<td>24%</td>
</tr>
</tbody>
</table>

**Remarks**

1. **“”** Recurrent training items (fire cargo FWD replaces smoke or fume)
2. All RWY brake actions are wet in summer and snow in winter.

**2011.7.1 REV 00**

---

**FLIGHT CREW TRAINING TEAM**

---

- 285 -
### Post-LOFT Training for B747-400 Flight Crew in the 2nd Half of 2011

- CAP & F/O

---

<table>
<thead>
<tr>
<th>POST LOFT TRAINING</th>
<th>CAPT/ Co-pilot(FO)</th>
<th>THE 2nd HALF OF 2011</th>
</tr>
</thead>
<tbody>
<tr>
<td>CAVOK X-WIND 10 K</td>
<td>RKSI 15L WET</td>
<td>RKSI 7/0 POST</td>
</tr>
<tr>
<td>CAVOK X-WIND 25 K</td>
<td>RKSI 33R DRY</td>
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</tr>
<tr>
<td>CAVOK X-WIND 10 K</td>
<td>RKSI 33R WET</td>
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</tr>
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</table>

---

**REMARK**

1. INSTRUCTOR PILOTS DO NOT HAVE TO DO R/H SIDE RECURRENT TRAINING
2. PRE-BRIEFING FOR CDO IS REQUIRED BEFORE SIM TRAINING (JEPP 20-1P CDO Procedure)
3. ONE ENGINE SHUT DOWN TAXI IN PROCEDURE GATE 17; #3 ENGINE CUT OFF 3MIN AFT T/O

---

2011.07.01. REV 00

FLIGHT CREW TRAINING TEAM
- Post-LOFT Training for B747-400 Flight Crew in the 2nd Half of 2011 (after 2011.08.05.)
  - CAP & F/O

---

**Appendix 8.**  
2011 Recurrent Training and Evaluation for B747-400 Flight Crew

---

### POST LOFT TRAINING CAPT/Co-pilot(FO) THE 2ND HALF OF 2011

<table>
<thead>
<tr>
<th>O/I</th>
<th>WIND</th>
<th>G/W</th>
<th>SHVE</th>
<th>ALT</th>
<th>82 108 CLOSED TO NET AIRPORT 86L18 SEP O/S 130 MAINTAIN 8000' DEP PRED 125.15 92 2600 LAT</th>
<th>RKPC</th>
<th>T/O FLAP 10</th>
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<td>X-</td>
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<td>15L</td>
<td>WET</td>
<td>IT 15L</td>
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<tr>
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<td>WIND</td>
<td>10 K</td>
<td>600.0</td>
<td>24%</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>CAVOK</td>
<td>WIND</td>
<td>25 K</td>
<td>600.0</td>
<td>24%</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>CAVOK</td>
<td>WIND</td>
<td>10 K</td>
<td>600.0</td>
<td>24%</td>
<td></td>
<td></td>
<td></td>
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</tbody>
</table>

1. **ENGINE FAILURE after V1 T/O FLAP 10**
   - ILS DME RWY 15L with ONE ENG INOP
   - MISSED APPROACH by IP
   - 6NM ON FINAL
   - ILS DME RWY 15L
   - ONE ENG' SHUT DOWN TAXI INTO GATE 17

2. **<< MAIN DECK CARGO FIRE TRAINING >>**
   - FLT ROUTE: ICN > PVG (HL7436)
   - PF: CAPT
   - FIRE CARGO FWD at SADLY (FL340)
   (Fire Cargo FWD replaces FIRE MAIN DECK)

---

**REMARK**

1. INSTRUCTOR PILOTS DO NOT HAVE TO DO R/H SIDE RECURRENT TRAINING
2. ONE ENGINE SHUT DOWN TAXI IN PROCEDURE (GATE 17): #3 ENGINE CUT OFF: 3MIN AFT T/O

---

2011.08.05. REV 01  FLIGHT CREW TRAINING TEAM
## Appendix 8.

### 2011 Recurrent Training and Evaluation for B747-400 Flight Crew

**● AAR991 Flight Crew's Monthly Schedule for July 2011**

| EMPNO : 702402 | NAME : 최상기 | EFFECTIVE : 110701 - 110731 |
| POSITION : B747–CAP | CHOI SANG KI | Mail Box : |

<table>
<thead>
<tr>
<th>DATE</th>
<th>SHOWUP 근무구분 (DUTY)</th>
<th>근무구간(SECTOR)</th>
<th>ETD</th>
<th>ETA</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 FR</td>
<td>DAY OFF</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2 SA</td>
<td>298/298 ORD ICN/ ANC/ ORD</td>
<td>07/02–23:05 07/02–23:25</td>
<td></td>
<td></td>
</tr>
<tr>
<td>3 SU</td>
<td>ORD</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>4 MO</td>
<td>ORD</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>5 TU</td>
<td>298 ORD/ JFK</td>
<td>07/05–23:50 07/06–02:55</td>
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<td></td>
</tr>
<tr>
<td>6 WE</td>
<td>297 JFK/ ANC</td>
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<td></td>
</tr>
<tr>
<td>7 TH</td>
<td>2831 ANC/ ICN</td>
<td>07/07–06:30 07/08–07:50</td>
<td></td>
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</tr>
<tr>
<td>8 FR</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>9 SA</td>
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</tr>
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<td>11 MO</td>
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<td>VIE</td>
<td></td>
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<td></td>
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<tr>
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<td>775 VIE/ MXP</td>
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</tr>
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<td>PEK</td>
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<tr>
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</table>
## Appendix 8.

### 2011 Recurrent Training and Evaluation for B747-400 Flight Crew

#### ASIANA AIRLINES

**Cockpit Crew Monthly Schedule**

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<td>11/07/01 - 11/07/31</td>
<td>B744-F/O</td>
<td>Lee Jeongwoong</td>
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<table>
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<tr>
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<th>근무구간 (SECTOR)</th>
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<td>SA</td>
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</tr>
<tr>
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<td>SU</td>
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<td>MO</td>
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<td>standby</td>
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<tr>
<td>31</td>
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<td>standby</td>
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</tr>
</tbody>
</table>

- 289 -
APPENDIX 9: QRH Procedures in Relation to AAR991’s Fire

● COMBI - FIRE MAIN DECK (April 1, 2011)

Condition: Smoke is detected in the main deck cargo area.

1. Instruct the designated crewmember to verify presence of smoke or fire.

2. Choose one:
   - Presence of smoke or fire is verified:
     - Go to step 3
   - Presence of smoke or fire is not verified:
     A crewmember must monitor the cargo compartment for the rest of the flight.

3. MAIN Deck CARGO FIRE
   ARM switch ................. Confirm .......... ARMED
   Pack 3 will shut down.

4. PACK 3 control selector ................. OFF

5. PACK 1 and 2 control selectors .... One pack on, one pack OFF

6. CARGO FIRE DISCH switch .... Push and hold for 1 second
   90 minutes of fire suppression are available.

7. TRIM AIR switch ................. Off

Continued on next page

FIRE MAIN DECK (April 1, 2011-COMBI) 1/3
8.30


▼ FIRE MAIN DECK continued ▼

8 Choose one:
- Airplane is at or below 8,000 feet:
   - Go to step 11
- Airplane is above 8,000 feet:
   - Go to step 9

9 LDG ALT switch ......................... MAN

10 LDG ALT selector ................. Set between 8000 8500

11 Plan to land at the nearest suitable airport

12 Do not accomplish the following checklists:
   - LANDING ALT
   - TEMP ZONE
   - TRIM AIR OFF

13 Checklist Complete Except Deferred Items

Before descent
   - LDG ALT switch ......................... AUTO

Descent Checklist
   - Recall ................................. Checked
   - Autobrake ..............................
   - Landing data ...................... VREF___, Minimums___

▼ Continued on next page ▼
<table>
<thead>
<tr>
<th>Approach briefing</th>
<th>Completed</th>
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</thead>
</table>

**Approach Checklist**

- Altimeters

**Warning! Inform ground personnel not to open the cargo door until all passengers and crew have exited the airplane and fire fighting equipment is nearby.**

**Landing Checklist**

- Speedbrake
- Landing gear
- Flaps

- ■ ■ ■ ■
● FREIGHTER - FIRE MAIN DECK (April 1, 2011)

8.32

ASIANA AIRLINES

FIRE MAIN DECK
FIRE MN DK AFT, FWD, MID

HL7413 - HL7415, HL7419, HL7420, HL7436 - HL7616

Condition: Smoke is detected in the main deck cargo area(s).

1. Don the oxygen masks.
2. Establish crew communications.
3. SUPRMRY OXY switch ................. ON
4. MAIN Deck CARGO FIRE
   ARM switch .............. Confirm .... ARMED

   HL7436 - HL7616
   SATCOM will shut down to prevent overheating.

   Two packs are automatically shut down and the
   associated PACK messages are shown.

   Select the pack control selectors that have the
   PACK messages shown.

5. PACK control selectors ........ One pack on,
   two packs OFF

Warning! Either pack 1 or 3 must be operating to
prevent excessive smoke accumulation on the flight deck.

6. CARGO FIRE
   DEPRES/DISCH switch .......... Push and hold
   for 1 second

8.32  D6-30151-423(AAR)  April 1, 2011

FIRE MAIN DECK (April 1, 2011-FREIGHTER) 1/3
8.33

7 Climb or descend to 25,000 feet when conditions and terrain allow.
8 Plan to land at the nearest suitable airport.
9 Do not accomplish the following checklists:
   - CABIN ALTITUDE or Rapid Depressurization
   - TEMP ZONE
   - TRIM AIR OFF

10 Checklist Complete Except Deferred Items

\[Continued\ on\ next\ page\]\(\)
### Descent Checklist
- Recall: Checked
- Autobrake: ___
- Landing data: VREF___, Minimums___
- Approach briefing: Completed

### Approach Checklist
- Altimeters: ___

### Warning!
Inform ground personnel not to open the cargo door until all supernumeraries and crew have exited the airplane and fire fighting equipment is nearby.

### Landing Checklist
- Speedbrake: Armed
- Landing gear: DOWN
- Flaps: ___

---

FIRE MAIN DECK (April 1, 2011-FREIGHTER) 3/3
FREIGHTER - FIRE MAIN DECK (May 10, 2011)

Condition: Smoke is detected in the main deck cargo area(s).

1. Don the oxygen masks.
2. Establish crew communications.
3. SUPRNMRY OXY switch . . . . . . . . . . . . . . . ON
4. MAIN Deck CARGO FIRE ARM switch . . . . . . . . . Confirm . . . ARMED

HL7413 - HL7415, HL7419, HL7420, HL7436 - HL7616

SATCOM will shut down to prevent overheating.
Two packs are automatically shut down and the associated PACK messages are shown.

5. PACK 2 control selector . . . . . . . . . . . . . . . OFF

Warning! Either pack 1 or 3 must be operating to prevent excessive smoke accumulation on the flight deck.

6. CARGO FIRE DEPRES/DISCH switch . . . . . . . Push and hold for 1 second

7. Expedite a climb or descent to 25,000 feet when conditions and terrain allow. Plan to stay at 25,000 feet as long as possible. After the descent has been started, do not delay the approach and landing.

Continued on next page

FIRE MAIN DECK (May 10, 2011-FREIGHTER) 1/3
8. Plan to land at the nearest suitable airport.
9. Do not accomplish the following checklists:
    CABIN ALTITUDE or Rapid Depressurization
    PACK
    TEMP ZONE
    TRIM AIR OFF

10. Checklist Complete Except Deferred Items

Deferred Items

Descent Checklist
Recall .................................. Checked
Autobrake ................................
Landing data ................. VREF__, Minimums__
Approach briefing ................. Completed

Approach Checklist
Altimeters ...............

Warning! Inform ground personnel not to open
the cargo door until all
supernumeraries and crew have exited
the airplane and fire fighting
equipment is nearby.

Continued on next page
Landing Checklist

- Speedbrake: Armed
- Landing gear: DOWN
- Flaps: __________

FIRE MAIN DECK (May 10, 2011-FREIGHTER) 3/3
Appendix 9.  QRH Procedures in Relation to AAR991’s Fire

● FREIGHTER- EQUIP COOLING (April 1, 2011)

2.18

ASIANA AIRLINES

EQUIP COOLING

Condition: One of these occurs:
- On the ground, the ground exhaust valve is not in the commanded position
- With Equipment Cooling selector in NORM or STBY, one or more of these occur:
  - Airflow is insufficient
  - An overheat is sensed
  - Smoke is sensed
- With Equipment Cooling selector in OVRD, differential pressure for reverse flow cooling is not sufficient.

1. Avionics/electronic equipment and displays may become unreliable or fail.

2. Choose one:
   - On the ground:
     EQUIP COOLING selector . . . . . . STBY

   - In flight:
     ►►Go to step 3

3. EQUIP COOLING selector. . . . . . . . . . . OVRD

Continued on next page

EQUIP COOLING (April 1, 2011) 1/2
4 Choose one:

- EQUIP COOLING message *stays blank*:
  ✔ ✔ ✔ ✔

- EQUIP COOLING message *stays shown or shows again*:
  Plan to land at the nearest suitable airport.
  ✔ ✔ ✔ ✔
● FREIGHTER - FIRE APU (April 1, 2011)

FIRE APU (April 1, 2011)
FREIGHTER - FIRE CARGO AFT (April 1, 2011)

8.20

FIRE CARGO AFT

Condition: Smoke is detected in the aft lower cargo compartment.

1. AFT CARGO FIRE
   ARM switch ............ Confirm ............ ARMED
   HL7436 - HL7616
   SATCOM will shut down to prevent overheating.
   Two packs are automatically shut down and the associated PACK messages are shown.

2. Select the pack control selectors that have the PACK messages shown.

3. PACK control selectors ........ One pack on, two packs OFF
   CARGO FIRE DEPRESS/
   DISCH switch ............ Push and hold for 1 second
   HL7413 - HL7415
   195 minutes of fire suppression are available.
   HL7419, HL7420, HL7436 - HL7616
   210 minutes of fire suppression are available.

↓ Continued on next page ↓
4. Choose one:
   - Airplane is at or below 8,000 feet:
     - Go to step 8
   - Airplane is above 8,000 feet:
     - Go to step 5

5. LDG ALT switch ................. MAN
6. LDG ALT selector ............... Set between 8000 and 8500

7. If airplane is above 25,000 ft descend to 25,000 ft.
8. Plan to land at the nearest suitable airport
9. Do not accomplish the following checklist:
   - LANDING ALT

10. Checklist Complete Except Deferred Items

   ▼ Continued on next page ▼
8.22

**Deferred Items**

**Before descent**

LDG ALT switch ...................... AUTO

**Descent Checklist**

Recall ................................. Checked
Autobrake ............................. ___
Landing data .............. VREF___, Minimums___
Approach briefing ........................ Completed

**Approach Checklist**

Altimeters ............................ ___

---

**Warning!** Inform ground personnel not to open the cargo door until all supernumeraries and crew have exited the airplane and fire fighting equipment is nearby.

---

**Landing Checklist**

Speedbrake ............................ Armed
Landing gear ........................... DOWN
Flaps ................................. ___

---

FIRE CARGO AFT (April 1, 2011) 3/3
● FREIGHTER - CABIN ALTITUDE or Rapid Depressurization (April 1, 2011)

CABIN ALTITUDE or Rapid Depressurization

Condition: A cabin altitude exceedance occurs.

1. Don the oxygen masks.
2. Establish crew communications.
3. Check the cabin altitude and rate. Verify packs are on and outflow valves are closed.
   **HL7413 - HL7415**
4. In case of decompression, an aural warning will be given automatically for 30 seconds.
   SEATBELTS selector ................. ON
5. If the cabin altitude is uncontrollable:
   **SUPRNMRY OXY** switch ................. ON
   Without delay, descend to the lowest safe altitude or 14,000 feet, whichever is higher.
   To descend:
   - Move the thrust levers to idle.
   - Extend the speedbrakes.
   - If structural integrity is in doubt, limit airspeed and avoid high maneuvering loads.
   - Descend at VMO/MMO.

Continued on next page
6 If OUTFLOW VLV L, OUTFLOW VLV R, and CABIN ALT AUTO messages are shown:

Do not accomplish the following checklists:

- CABIN ALT AUTO
- OUTFLOW VLV L, R

CABIN ALTITUDE or Rapid Depressurization 2/2
● FREIGHTER - Smoke Fire or Fumes (April 1, 2011)

Smoke, Fire or Fumes
HL7413 - HL7415, HL7419, HL7420, HL7436 - HL7616

Condition: Smoke, fire or fumes occur.
1. Diversion may be needed.
2. Don the oxygen masks, if needed.
3. Establish crew communications.
4. Instruct the supernumeraries to turn on the upper deck reading lights.
5. UTILITY power switches (both) ............... Off
6. FLT DECK FAN switch ......................... Off
7. APU selector .................................... OFF
8. Passenger signs ................................. ON

9. MAIN DECK SIGNALING switch ............ Push

10. **Anytime** the smoke or fumes become the greatest threat:
   
   ►► Go to the Smoke or Fumes Removal checklist on page 8.44
   
   ▼ Continued on next page ▼

---

Smoke Fire or Fumes (April 1, 2011) 1/5
8.12

Smoke, Fire or Fumes continued

11 Choose one:

- Source of the smoke, fire or fumes is obvious and can be extinguished quickly:
  
  Isolate and extinguish the source of the smoke, fire or fumes.
  
  If possible, remove power from the affected equipment by switch or circuit breaker in the flight deck or upper deck.

  ▶▶ Go to step 12

- Source of the smoke, fire or fumes is not obvious or cannot be extinguished quickly:

  ▶▶ Go to step 13

12 Choose one:

- Source is visually confirmed to be extinguished and smoke or fumes are decreasing:
  
  Continue the flight at the captain’s discretion.
  
  Restore unpowered items at the captain’s discretion.

  ▶▶ Go to step 24

- Source is not visually confirmed extinguished or smoke or fumes continue:

  ▶▶ Go to step 13

Continued on next page
13 Divert to the nearest suitable airport while continuing the checklist.

14 Consider an immediate landing if the smoke, fire or fumes situation becomes uncontrollable.

15 Do not delay landing in an attempt to complete the following steps.

16 ISLN valve switches (both) ................. Off
   This isolates the left and right sides of the bleed air system.

17 PACK 2 control selector ......................... OFF

18 **Wait** 2 minutes unless the smoke or fumes are increasing. This allows time for the smoke or fumes to clear.

19 Choose one:

- **Smoke or fumes continue or are increasing:**
  PACK 3 control selector ......................... OFF
  **Wait** 2 minutes unless the smoke or fumes are increasing. This allows time for the smoke or fumes to clear.
  ►►Go to step 20

- **Smoke or fumes are decreasing:**
  ►►Go to step 24

►►Continued on next page◄◄
8.14


Smoke, Fire or Fumes continued

20 Choose one:
- Smoke or fumes continue or are increasing:
  PACK 3 control selector ........ NORM
  PACK 1 control selector ........ OFF
  R ISLN valve switch ............... On
  ➤➤ Go to step 21

- Smoke or fumes are decreasing:
  L ISLN valve switch ............... On
  ➤➤ Go to step 21

21 PACK 2 control selector ............... NORM

22 Wait 2 minutes unless the smoke or fumes are increasing. This allows time for the smoke or fumes to clear.

23 Choose one:
- Smoke or fumes continue or are increasing:
  ISLN valve switches (both) ........ On
  PACK 1 control selector ........... NORM
  Consider an immediate landing.
  ➤➤ Go to step 24

- Smoke or fumes are decreasing:
  ➤➤ Go to step 24

Continued on next page
Smoke, Fire or Fumes continued

24 Do **not** accomplish the following checklists:

- HL7419, HL7420, HL7430 - HL7616
- CARGO DET AIR
- ELEC UTIL BUS L, R
- FUEL OVRD 2, 3 FWD
- FUEL PRESS CTR L
- FUEL PUMP 2, 3 FWD
- HL7616
- HUMID FLT DK
- TEMP ZONE
- TRIM AIR OFF

**Go to the Smoke or Fumes Removal checklist on page 8.44, if needed**
FREIGHTER - Smoke or Fumes Removal (April 1, 2011)

8.44

Smoke or Fumes Removal

HL 7413 - HL 7415, HL 7419, HL 7420, HL 7436 - HL 7616

Condition: Smoke or fumes removal is needed.

Objective: To remove smoke or fumes through the smoke override valve, or the smoke evacuation port.

1. Do this checklist only when directed by the Smoke, Fire or Fumes checklist.

2. Do not delay landing in an attempt to complete the following steps.

3. EQUIP COOLING selector . . . . . . . . . . . . . . . . . . . . . . . . OVRD
   This attempts to discharge the smoke or fumes overboard by using the equipment cooling override mode.

▼ Continued on next page ▼
Smoke or Fumes Removal continued

4 Choose one:

- Smoke or fumes does not continue and is not severe:
  
  Go to the Smoke, Fire or Fumes checklist on page 8.11 and do the remaining steps.

- Smoke or fumes continues or is severe and the smoke or fumes source is determined to be on the flight deck:
  
  Pull the smoke evacuation handle. Pulling the smoke evacuation handle when smoke or fumes source is not on the flight deck may bring the smoke or fumes into the flight deck.

  Go to the Smoke, Fire or Fumes checklist on page 8.11 and do the remaining steps.

- Smoke or fumes continues or is severe and the smoke or fumes source is determined to be in the cabin:
  
  Go to step 5

5 LDG ALT switch ................. Push to MAN

MAN landing altitude mode shows on EICAS.

Continued on next page
6. LDG ALT selector ............... Set between 8000 and 8500
7. EQUIP COOLING selector ............... NORM
8. Start a descent. Level off at the lowest safe altitude or 8,500 feet, whichever is higher.
9. OUTFLOW VALVES MAN switches (both) ...... NORM
10. OUTFLOW VALVES manual control ............... Hold in OPEN until the outflow valve indications show fully open

11. Do not accomplish the following checklists:
    - CABIN ALT AUTO
    - LANDING ALT
    - OUTFLOW VLV L, R

Go to the Smoke, Fire or Fumes checklist on page 8.11 and do the remaining steps.
● FREIGHTER - Ditching (April 1, 2011)

**Ditching**

Condition: Airplane ditching and evacuation are needed.

1. Plan to jettison fuel as needed to reduce the VREF speed.
2. Do **not** arm the autobrakes.
3. Plan to ditch with the gear up.
4. Use flaps 30 and VREF 30.
5. **Checklist Complete Except Deferred Items**

**Deferred Items**

--- Descent Checklist ---

Recall ........................................... Checked

Autobrake ........................................... OFF

Landing data .............. **VREF 30, Minimums**

Approach briefing ................. Completed

--- Approach Checklist ---

Altimeters .................................

\[\text{\textbullet Continued on next page} \]

Ditching (April 1, 2011) 1/3
When below 5,000 feet:

- GND PROX GEAR OVRD switch ........ OVRD
- GND PROX TERR OVRD switch ........ OVRD
- PACK control selectors (all) ............ OFF
- OUTFLOW VALVES MAN switches (both) ............ ON
- OUTFLOW VALVES manual control ........ Hold in CLOSE until outflow valve indications show fully closed
- Passenger signs ............ ON
- HL7604
- MAIN DECK SIGNALING switch ........ Push

When on final approach:

- Omit the landing checklist.
- Landing gear lever ............ UP
- FLAP lever ............ 30
- Advise the cabin of imminent touchdown.
- Maintain airspeed at VREF 30.
- Rotate to a touchdown attitude of 10 to 12 degrees.

After impact:

- FUEL CONTROL switches (all) ........ CUTOFF
- Engine fire switches (all) .... Pull, rotate to the stop and hold for 1 second

Continued on next page

Ditching (April 1, 2011) 2/3
Deploy the slide/rafts and evacuate the airplane.
APPENDIX 10: Results of Tests and Research

1. 3D Hardware Wreckage Reconstruction

2. 3D Software Wreckage Reconstruction

3. Dangerous Goods Chemical Properties Test & Analysis

4. Dangerous Goods Leakage Test in Pressurized Environment

5. Measure the Electrostatic Energy of Packaging the Cargo

6. Test of the Flight Vibration Condition Using Tri-axis(X/Y/Z) Vibration Machine

7. Fire Dynamics Simulation

8. Additional Analysis & Tests
   
   a. Dangerous Goods Packaging Materials Fusible Test
   
   b. Paint Flammable Gas Leakage Check
   
   c. Insulation Test
   
   d. Chemical Reaction of Amines Liquid Corrosive N.O.S. & Lithium-ion Batteries
1. 3D Hardware Wreckage Reconstruction

- 3D reconstruction Procedures
  - Phase 1: Development procedure
  - Phase 2: Wreckage selected
  - Phase 3: Support structure design
  - Phase 4: Support structure Assembly
  - Phase 5: 3D scanning data decimate
  - Phase 6: Aligning of multiple Wreckage
  - Phase 7: Wreckage 3D assembly
  - Phase 8: Analysis of Structures

- Support structure and mounting: Section 46 reorganization around a fire trail. From the STA 1480 is to the STA 2484 in the full length is 25.5m, 6.5m, and the largest width of the length of the structure of the whole fuselage. That the aircraft is on the second floor of the cargo compartment to 1m in height from the ground. To allow the attachment of the wreckage by placing a circular structure that is 1m intervals to maintain the elliptical shape of the aircraft.

![3D reconstruction section and the wreckages](image_url)
10. Results of Tests and Research

3D H/W reconstructed wreckages analysis: STA 1700 ~ 2000 in the vicinity of some tearing and appears to the outside of the spout form below to receive a column as shown by the pressure and heat damage of the explosion in wreckages #1134 and #1123. This location is the main cargo compartment of the aircraft ML/MR, PL/PR area. Aluminum alloy fuselage was damaged by the heat was some melted Refine torn up due to the shape of the crown form of explosive Dangerous Goods.

3D H/W reconstructed wreckages analysis: Some of the wreckage #511 of STA 2205 melt a hole in the vicinity of the melting of the heat received and appears to down a cup shape, corresponding to RR area that 250 inches rearward from the main cargo compartment appeared PR area.
Appendix 10. Results of Tests and Research

3D H/W reconstructed wreckages analysis: The state is heavily tanned inside of the top of the main cargo compartment with dangerous goods ML area wreckage #1134. Showed inside and outside that a colored state is loaded in the cargo hold PR area by Dangerous Goods of blue photoresist. This is thought to be the blue liquid flies in the plane ripped a hole in the state already has the upper body by the fire.

<Fig.165> Melted by heat of fire plane right outside

<Fig.166> Colored wreckage #1134, left)outside, right)inside
2. **3D Software Wreckage Reconstruction**

- **3D Software Wreckage Reconstruction Simulation Procedures**
  - Phase 1: Development of 3D S/W procedure
  - Phase 2: modeling & data configuration
  - Phase 3: Wreckage selected
  - Phase 4: Wreckage 3D scanning
  - Phase 5: Wreckage 3D digitizing process
  - Phase 6: 3D scanning data decimate
  - Phase 7: Aligning of multiple datasets
  - Phase 8: 3D S/W reconstruction with reference frame
  - Phase 9: Wreckage 3D assembly
  - Phase 10: Analysis of results

- Modeling and 3D Scan Data written: Guidelines for Reference Frame CAD Data written to the target, Use the "GSD Application" in the CATIA V5 model creation, Area division is divided into seven Area for the STA 1480 ~ STA 2436. Using 3D Scanning Camera TU-50, Scanning is complete, We make below Fig.

![Fig.167] S/W Reconstruction Result(1): Left View(Up), Right View(down)
3. Dangerous Goods Chemical Properties Test & Analysis

- Flash point test is applied to a total 7 Dangerous Goods

<tab.32> Flash point test results of 7 Dangerous Goods

<table>
<thead>
<tr>
<th>Dangerous Goods</th>
<th>Test Result</th>
<th>Remarks</th>
</tr>
</thead>
<tbody>
<tr>
<td>Photo-resist/IC 8132 (KUPR-A58-2.9cP)</td>
<td>47.5°C</td>
<td></td>
</tr>
<tr>
<td>Photo-resist/IC 8110, 8121 (HIK-128C-1.7cP)</td>
<td>47°C</td>
<td></td>
</tr>
<tr>
<td>Photo-resist/LCD R4650</td>
<td>1st 48°C, 2nd 49°C, 3rd 50°C</td>
<td>Repeat three times</td>
</tr>
<tr>
<td>Photo-resist/LCD B4650</td>
<td>45°C</td>
<td></td>
</tr>
<tr>
<td>Photo-resist/LCD B5120</td>
<td>42°C</td>
<td></td>
</tr>
<tr>
<td>Paint (TF-4200EB-451)</td>
<td>12°C</td>
<td></td>
</tr>
<tr>
<td>Amines Liquid Corrosive N.O.S.</td>
<td>Does not flash in more than 150°C</td>
<td></td>
</tr>
</tbody>
</table>

- Ignition point test is applied to a total 2 Dangerous Goods

<tab.33> Ignition point test results

<table>
<thead>
<tr>
<th>Dangerous Goods</th>
<th>Ignition point test result</th>
</tr>
</thead>
<tbody>
<tr>
<td>Photo-resist/LCD</td>
<td>273°C</td>
</tr>
<tr>
<td>Paint(TF-4200EB-451)</td>
<td>264°C</td>
</tr>
</tbody>
</table>

- Spark Ignition test is applied to a total 7 Dangerous Goods
  
  - Before Spark Ignition tests, Measurement of VOCs to a small amount of sample injected into 10ml transparent closed container results.
### VOCs Measurement Results of Dangerous Goods

<table>
<thead>
<tr>
<th>Dangerous Goods</th>
<th>VOCs Measurement Results</th>
</tr>
</thead>
<tbody>
<tr>
<td>Photo-resist/IC 8132 (KUPR-A58-2.9cP)</td>
<td>VOCs Measured</td>
</tr>
<tr>
<td>Photo-resist/IC 8110, 8121 (HIK-128C-1.7cP)</td>
<td>VOCs Measured</td>
</tr>
<tr>
<td>Photo-resist/LCD R4650</td>
<td>VOCs Measured</td>
</tr>
<tr>
<td>Photo-resist/LCD B4650</td>
<td>VOCs Measured</td>
</tr>
<tr>
<td>Photo-resist/LCD B5120</td>
<td>VOCs Measured</td>
</tr>
<tr>
<td>Paint (TF-4200EB-451)</td>
<td>VOCs Measured</td>
</tr>
<tr>
<td>Amines Liquid Corrosive N.O.S.</td>
<td>VOCs Measured</td>
</tr>
</tbody>
</table>

- Spark Ignition tests Results

#### Spark Ignition tests Results (after 2hr. rest)

<table>
<thead>
<tr>
<th>Dangerous Goods</th>
<th>Spark Ignition tests Results</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>after 30min'</td>
</tr>
<tr>
<td>Photo-resist/IC 8132 (KUPR-A58-2.9cP)</td>
<td>Does not ignite</td>
</tr>
<tr>
<td>Photo-resist/IC 8110, 8121 (HIK-128C-1.7cP)</td>
<td>Does not ignite</td>
</tr>
<tr>
<td>Photo-resist/LCD R4650</td>
<td>Does not ignite</td>
</tr>
<tr>
<td>Photo-resist/LCD B4650</td>
<td>Does not ignite</td>
</tr>
<tr>
<td>Photo-resist/LCD B5120</td>
<td>Does not ignite</td>
</tr>
<tr>
<td>Paint (TF-4200EB-451)</td>
<td>ignite</td>
</tr>
<tr>
<td>Amines Liquid Corrosive N.O.S.</td>
<td>Does not ignite</td>
</tr>
</tbody>
</table>

- Additional testing of the paint on the spark ignited, rest times after 5min., 10min., 15min., 30min., after 1hr.,

#### tests Results of Additional testing of the paint.

<table>
<thead>
<tr>
<th>Elapsed time</th>
<th>Whether the spark ignition</th>
</tr>
</thead>
<tbody>
<tr>
<td>5min.</td>
<td>Does not ignite</td>
</tr>
<tr>
<td>10min.</td>
<td>ignite</td>
</tr>
<tr>
<td>15min.</td>
<td>ignite</td>
</tr>
<tr>
<td>30min.</td>
<td>ignite</td>
</tr>
<tr>
<td>after 1hr.</td>
<td>ignite</td>
</tr>
</tbody>
</table>
4. Dangerous Goods Leakage Test in Pressurized Environment

- To confirm dangerous goods leakage for loaded Dangerous Goods Receptacles in pressurized environment.
  - Implement a pressurized environment test equipment (chamber)

<Fig.168> pressurized environment test equipment

- Through Test Results, Confirmed that it does not leak flammable liquid or gas in air transport (pressurized environment, 8,000ft below) Dangerous Goods.
- Do check the possibility of Dangerous Goods leaks of flammable substances in the (32,000ft ~ 34,000ft) pressure of cruising altitude of cargo.

<tab.37> Flammable gas leaks of dangerous goods in air transport environment

<table>
<thead>
<tr>
<th>Dangerous Goods</th>
<th>Pressure conditions</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>73~77kPa</td>
<td>below 30kPa</td>
</tr>
<tr>
<td>Photo-resist/LCD</td>
<td>No detect</td>
<td>Detected</td>
</tr>
<tr>
<td>Photo-resist/IC</td>
<td>No detect</td>
<td>Detected</td>
</tr>
<tr>
<td>Paint</td>
<td>No detect</td>
<td>Detected</td>
</tr>
</tbody>
</table>
5. Measure the Electrostatic Energy of Packaging the Cargo

- Measure the electrostatic energy of packaging the cargo package
  - Date: 2014 January 10
  - Site: Cargo Terminal
  - Temperature and Humidity: 0.7℃~6℃, 52.5~68.3% RH

<table>
<thead>
<tr>
<th>Type</th>
<th>Measured temperature</th>
<th>Measured humidity</th>
<th>Remarks</th>
</tr>
</thead>
<tbody>
<tr>
<td>Type-A</td>
<td>6℃</td>
<td>52.2% RH</td>
<td>nonconductor</td>
</tr>
<tr>
<td>Type-B</td>
<td>14℃</td>
<td>65% RH</td>
<td>nonconductor</td>
</tr>
<tr>
<td>Type-C</td>
<td>0.7℃</td>
<td>68.3% RH</td>
<td>conductor</td>
</tr>
</tbody>
</table>

The actual measured temperature and humidity for electrostatic energy measurements.

- The MIE values of the specific gas, which can cause dangerous goods. Can be compared to a standard to determine whether the electrostatic potential energy with MIE values of the specific gas is derived.
  - Photo-resist/IC 8132
### Appendix 10. Results of Tests and Research

- **Photo-resist/IC 8110, 8121**

<table>
<thead>
<tr>
<th>molecule name</th>
<th>molecular formula</th>
<th>M I E (mJ)</th>
</tr>
</thead>
<tbody>
<tr>
<td>ethly acetate</td>
<td>(CH_3COOC_2H_5)</td>
<td>1.42</td>
</tr>
<tr>
<td>Propylene</td>
<td>(C_3H_6)</td>
<td>0.28</td>
</tr>
<tr>
<td>cyclohexane</td>
<td>(C_6H_{12})</td>
<td>0.22</td>
</tr>
<tr>
<td>methane</td>
<td>(CH_4)</td>
<td>0.28</td>
</tr>
<tr>
<td>carbon monoxide</td>
<td>(CO)</td>
<td>0.3</td>
</tr>
</tbody>
</table>

- **Photo-resist/LCD R4650**

<table>
<thead>
<tr>
<th>molecule name</th>
<th>molecular formula</th>
<th>M I E (mJ)</th>
</tr>
</thead>
<tbody>
<tr>
<td>ethly acetate</td>
<td>(CH_3COOC_2H_5)</td>
<td>1.42</td>
</tr>
<tr>
<td>Propylene</td>
<td>(C_3H_6)</td>
<td>0.28</td>
</tr>
<tr>
<td>ether</td>
<td>(C_2H_5OC_2H_5)</td>
<td>0.19</td>
</tr>
<tr>
<td>ethylene</td>
<td>(CH_2)</td>
<td>0.07</td>
</tr>
</tbody>
</table>

- **Photo-resist/LCD B4650**

<table>
<thead>
<tr>
<th>molecule name</th>
<th>molecular formula</th>
<th>M I E (mJ)</th>
</tr>
</thead>
<tbody>
<tr>
<td>ethly acetate</td>
<td>(CH_3COOC_2H_5)</td>
<td>1.42</td>
</tr>
<tr>
<td>Propylene</td>
<td>(C_3H_6)</td>
<td>0.28</td>
</tr>
<tr>
<td>ether</td>
<td>(C_2H_5OC_2H_5)</td>
<td>0.19</td>
</tr>
<tr>
<td>ethylene</td>
<td>(CH_2)</td>
<td>0.07</td>
</tr>
<tr>
<td>cyclohexane</td>
<td>(C_6H_{12})</td>
<td>0.22</td>
</tr>
<tr>
<td>methane</td>
<td>(CH_4)</td>
<td>0.28</td>
</tr>
<tr>
<td>carbon monoxide</td>
<td>(CO)</td>
<td>0.3</td>
</tr>
</tbody>
</table>

- **Photo-resist/LCD B5120**
Appendix 10. Results of Tests and Research

**<tab.43> Minimum ignition Energy (MIE) value of Photo-resist/LCD B5120 gas**

<table>
<thead>
<tr>
<th>molecule name</th>
<th>molecular formula</th>
<th>MIE (mJ)</th>
</tr>
</thead>
<tbody>
<tr>
<td>ethyl acetate</td>
<td>CH₃COOC₂H₅</td>
<td>1.42</td>
</tr>
<tr>
<td>Propylene</td>
<td>C₃H₆</td>
<td>0.28</td>
</tr>
<tr>
<td>ether</td>
<td>C₂H₅OC₂H₅</td>
<td>0.19</td>
</tr>
<tr>
<td>ethylene</td>
<td>CH₂</td>
<td>0.07</td>
</tr>
<tr>
<td>cyclohexane</td>
<td>C₆H₁₂</td>
<td>0.22</td>
</tr>
<tr>
<td>methane</td>
<td>CH₄</td>
<td>0.28</td>
</tr>
<tr>
<td>carbon monoxide</td>
<td>CO</td>
<td>0.3</td>
</tr>
</tbody>
</table>

- Paint TF-4200EB-451

**<tab.44> Minimum ignition Energy (MIE) value of Paint TF-4200EB-451 gas**

<table>
<thead>
<tr>
<th>molecule name</th>
<th>molecular formula</th>
<th>MIE (mJ)</th>
</tr>
</thead>
<tbody>
<tr>
<td>butanol</td>
<td>C₄H₁₀O</td>
<td>0.26</td>
</tr>
<tr>
<td>methylcyclohexane</td>
<td>C₇H₁₄</td>
<td>0.27</td>
</tr>
<tr>
<td>methanol</td>
<td>CH₄O</td>
<td>0.14</td>
</tr>
<tr>
<td>methane</td>
<td>CH₄</td>
<td>0.28</td>
</tr>
<tr>
<td>ethane</td>
<td>C₂H₆</td>
<td>0.26</td>
</tr>
</tbody>
</table>

- Type-A : Analysis of the results of the Minimum ignition Energy (MIE) derived from the charged Dangerous Goods.

- The minimum of the measured Type-A, which can be determined that the average, have at least one or more high electrostatic energy than the MIE of vaporized components from the maximum energy is dangerous goods.

- Type-B : Analysis of the results of the Minimum ignition Energy (MIE) derived from the
charged Dangerous Goods.

![Graph](image1)

**<Fig.171 > Type-B with MIE**

- The minimum of the measured Type-B, which can be determined that the average, have at least 2 or more high electrostatic energy than the MIE of vaporized components from the maximum energy is dangerous goods.

**Type-C**: Analysis of the results of the Minimum ignition Energy(MIE) derived from the charged Dangerous Goods.

![Graph](image2)

**<Fig.172 > Type-C with MIE**

- The minimum of the measured Type-C, which can be determined that the average, have at least 4 or more high electrostatic energy than the MIE of vaporized components from
the maximum energy is dangerous goods.

☐ 2nd Measure the electrostatic energy of packaging the cargo package

- Date : 2014.April.9-10
- Site : Cargo Terminal, Aircraft Cargo Compartment
- Cargo Terminal : after electrification elapsed time, after 15min., after 30min.

- Ground test measurements

<table>
<thead>
<tr>
<th>after electrificationElapsed time</th>
<th>goods</th>
<th>quantity of electric charge(nC)</th>
<th>electrostatic energy(mJ)</th>
<th>Temp.(℃)</th>
<th>Humidity(%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Shortly after electrification</td>
<td>1</td>
<td>18.2 0.27, 11.3 0.17, 31.0 0.47</td>
<td>10.3 71.8, 10.5 71.7, 10.5 76.3</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>2</td>
<td>16.2 0.24, 14.1 0.21, 15.9 0.24</td>
<td>11.1 68.5, 11.1 68.6, 11.2 68.4</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>3</td>
<td>17.5 0.26, 11.3 0.17, 23.0 0.35</td>
<td>11.5 67.4, 11.3 67.4, 11.4 67.2</td>
<td></td>
<td></td>
</tr>
<tr>
<td>after 15 min.</td>
<td>1</td>
<td>× x 10.5 74.5, × x 10.3 76.4, × x 10.6 75.3</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>2</td>
<td>10.0 0.15, × x 10.4 75.5, 10.6 0.16, 10.2 75.9</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>3</td>
<td>× x 10.5 74.3, × x 10.5 75.2, × x 10.4 75.8</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>after 30 min.</td>
<td>1</td>
<td>× x 10.4 71.5, × x 10.6 72.8, × x 10.5 74.5</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>2</td>
<td>× x 11.5 64.9, × x 10.4 73.3, × x 10.5 74.3</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>3</td>
<td>16.5 0.25, × x 10.0 77.7, 10.5 74.0, 10.5 74.3</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

<Fig.173 > result of quantity of electric charge at Cargo Terminal

- 8 kinds of cargo loaded on aircraft, after electrification 35min. ~ 1hr 35min.
## Results of Tests and Research

- Test measurements In Aircraft Cargo Compartment

<table>
<thead>
<tr>
<th>after electrification Elapsed time</th>
<th>goods</th>
<th>Packing</th>
<th>quantity of electric charge (nC)</th>
<th>electrostatic energy (mJ)</th>
<th>Temp. (°C)</th>
<th>Humidity (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>35 min.</td>
<td>JR</td>
<td>Total Package</td>
<td>x</td>
<td>x</td>
<td>14.3</td>
<td>23.1</td>
</tr>
<tr>
<td>1 hr. 20 min.</td>
<td>GR</td>
<td>Total Package</td>
<td>x</td>
<td>x</td>
<td>16.7</td>
<td>19.3</td>
</tr>
<tr>
<td>1 hr. 35 min.</td>
<td>T</td>
<td>Total Package</td>
<td>x</td>
<td>x</td>
<td>10.7</td>
<td>15.5</td>
</tr>
<tr>
<td>1 hr. 15 min.</td>
<td>SL</td>
<td>2nd Package</td>
<td>x</td>
<td>x</td>
<td>11.2</td>
<td>14.2</td>
</tr>
<tr>
<td>1 hr.</td>
<td>PR</td>
<td>Total Package</td>
<td>x</td>
<td>x</td>
<td>22.7</td>
<td>13.2</td>
</tr>
<tr>
<td>1 hr.</td>
<td>ML</td>
<td>Total Package</td>
<td>x</td>
<td>x</td>
<td>22.7</td>
<td>15.0</td>
</tr>
<tr>
<td>1 hr. 20 min.</td>
<td>RL</td>
<td>Total Package</td>
<td>x</td>
<td>x</td>
<td>18.7</td>
<td>9.6</td>
</tr>
<tr>
<td>1 hr. 20 min.</td>
<td>GL</td>
<td>Total Package</td>
<td>15.4</td>
<td>0.23</td>
<td>17.8</td>
<td>8.0</td>
</tr>
</tbody>
</table>

*Fig.175 > result of quantity of electric charge at Cargo Compartment*
6. Test of the Flight Vibration Condition Using Tri-axis(X/Y/Z) Vibration Machine

- According to the data transmitted by the ACARS of AAR991 1.32G logged in Incheon airport runway shows a vertical takeoff airplane accelerometer. Typically, the B747 aircraft during take-off vertical acceleration is about 1.15G, 1.32G takeoff is recorded as G is estimated to be greater than normal operation.

- Charger and dangerous in a similar condition to determine the type of cargo loaded on the airplane. Performing the test by using the vertical acceleration whether or not the loaded condition and the motion of the cargo, such as the 3-axis vibration machine in a 1.3G or greater.

<Fig.176> the direction of specimen installed on the vibration machine

- Test conditions apply of vibration machine
  - Waveform generation performed according to the Random-motion Test method.
  - Table is also a 3-axis simultaneous excitation
  - Tests once, The total test time is 30 seconds, Maintained for more than 25 seconds strong motion time.

- Test result : Confirmed that changes according to unverified very thin possibility of cargo loaded on the airplane to take off by the acceleration of the group is thinking of moving cargo is loaded on the 3-axis vibration machine.
7. Fire Dynamics Simulation

- Should adopt the FDS_5 (Fire Dynamics Simulator) model as an analysis tool for the fire simulation.

- Fire simulation procedure
  - Calculate the area and grid settings
  - Cargo compartment and cargo geometric modeling
  - Thermal boundary conditions set
  - Ventilation settings
  - Measurement equipment, control settings
  - Set around like pressurization, the temperature in the hold, gravity environment conditions
  - Ignition sources selected according to the scenario
  - Simulation execution, and results analysis

Scenario 1: sources of ignition at position ML

- Represents the trend leaning towards the front, but the direction of movement of the flame. Scenario 2 less than the heat release rate of the overall size.

- Propagation delay progression of peripheral sources of ignition are also different scenario 2 depending on the ignition source location. The farther away from the source of ignition is showing similar progress.

![Image](image_url)

(a) Smoke detector alarm sequence

(b) Smoke propagation path (the more red the first detection)

<Fig.177> After the fire, the smoke spread in the ML area
Scenario 2: sources of ignition at position PR

- Check that the first smoke and flames spread to the front than the rear.
- Refine the first detection of smoke in the front side MR, ML section area than the PL and PR in the STA position as an ignition source.

(a) Smoke detector alarm sequence

(b) Smoke propagation path (the more red the first detection)

<Fig.178> After the fire, the smoke spread in the PR area

<Fig.179> Left), the thermal distribution of heat in the body even if the PR section also ignite and damage, Right) Heat distribution in the section A-A’ for PR area of main cargo compartment
8. Additional Analysis & Tests

a. Dangerous Goods Packaging Materials Fusible Test

Performing a test administered by the polystyrene form was used as packaging for liquid dangerous goods loaded on the airplane dangerous goods. Polystyrene form $990cm^3$ (1.1cm×15cm×10cm×6pieces), addition liquid Dangerous Goods 40cc. Test Result : Paint, Photo-resist/IC, Photo-resist/LCD are chemical respond rapidly.

b. Paint Flammable Gas Leakage Check

Measured at the internal & external closure of the paint firmly locked state with the flammable gas leaks whether VOCs meter for the case was allowed to stand 2 hours, then kept at room temperature for 2 hours in a refrigerator, and if placed in a sealed plastic bag and the paint container.
Appendix 10. Results of Tests and Research

Fig.182> Ensure that you are ready to paint flammable gas leakage in closed closure, Left) In Refrigerator rest, 5℃, 2hrs, Right) At room temp. 18℃, after 2hrs, in Laboratory

- VOCs (Volatile Organic Compounds) Test Result:
  - At room temp. 18℃, after 2hrs, in Laboratory: Flammable gas(VOCs) Detect
  - In Refrigerator rest, 5℃, after 2hrs: Flammable gas(VOCs) non-detect, Odor weakly detect.

c. Insulation Test

- Dangerous Goods in the airplane is located on the same palette, lithium-ion battery with a liquid Dangerous Goods also tested for insulation and electrical conductivity of liquid Dangerous Goods.

<tap.45> Electro Insulation test Result for Dangerous Goods

<table>
<thead>
<tr>
<th>Dangerous Goods</th>
<th>Isolated / non-isolated</th>
<th>Electrical conductivity</th>
</tr>
</thead>
<tbody>
<tr>
<td>Photo-resist/IC 8132 (KUPR-A58-2.9cP)</td>
<td>non-isolated</td>
<td>Very weak (water level)</td>
</tr>
<tr>
<td>Photo-resist/IC 8110, 8121 (HIK-128C-1.7cP)</td>
<td>non-isolated</td>
<td>Very weak (water level)</td>
</tr>
<tr>
<td>Photo-resist/LCD R4650</td>
<td>non-isolated</td>
<td>Very weak (water level)</td>
</tr>
<tr>
<td>Photo-resist/LCD B4650</td>
<td>isolated</td>
<td>Not at all</td>
</tr>
<tr>
<td>Photo-resist/LCD B5120</td>
<td>non-isolated</td>
<td>Very weak (water level)</td>
</tr>
<tr>
<td>Paint (TF-4200EB-451)</td>
<td>isolated</td>
<td>Not at all</td>
</tr>
<tr>
<td>Amines Liquid Corrosive N.O.S.</td>
<td>non-isolated</td>
<td>Very weak (water level)</td>
</tr>
</tbody>
</table>

d. Chemical Reaction of Amines Liquid Corrosive N.O.S. & Lithium-ion Batteries

- A lithium-ion battery for car completely soaked in Amines Liquid Corrosive N.O.S 30 minutes after checking in ambient temperature 18 ℃ environment of the lithium-ion
battery damage result is not at all. Between the Amines Liquid Corrosive N.O.S with lithium-ion battery has not chemical and electrical reactions occur at all.

<Fig.183> A lithium-ion battery soaked in Amines Liquid Corrosive N.O.S