Australian Government

Australian Transport Safety Bureau

ATSB TRANSPORT SAFETY REPORT
Aviation Occurrence Investigation – AO-2008-003
Final

Electrical system event
25 km NNW of Bangkok International Airport, Thailand
7 January 2008
VH-OJM
Boeing 747-438

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Numerous figures adapted from images provided by the aircraft operator, aircraft manufacturer, the generator control unit manufacturer, and Google Earth.

Abstract

On 7 January 2008, a Boeing Company 747-438 aircraft, registered VH-OJM, was being operated on a scheduled international regular public transport service between London, England and Bangkok, Thailand. The aircraft had 346 passengers and 19 crew on board, including four flight crew.

On descent to Bangkok International Airport, the customer service manager notified the flight crew that a substantial water leak had occurred in the forward galley.

The cockpit indications progressively showed a number of electrical power-related malfunctions, and many of the aircraft's communication, navigation, monitoring and flight guidance systems were affected. A number of flight and navigation display and other instruments were available in degraded mode and the standby instruments and instrument landing system were also available. The aircraft's engines and hydraulic and pneumatic systems were largely unaffected and an approach was made to Bangkok in day visual meteorological conditions.

The investigation found the galley leak was from an overflowing drain after a drain line had been blocked with ice that formed due to an inoperable drain line heater. The water flowed forward and through a decompression panel into the aircraft's main equipment centre before leaking onto three of the aircraft's four generator control units, causing them to malfunction and shut down.

The investigation identified a number of safety issues in regard to the protection of aircraft systems from liquids, and other factors including the provision of information to flight crews. In response, the aircraft manufacturer and operator implemented a number of safety actions intended to prevent a recurrence. In addition, the United States Federal Aviation Administration issued a notice of proposed rulemaking to adopt a new airworthiness directive for certain 747-400 and 747-400D series aircraft to install improved water protection. The Australian Transport Safety Bureau has issued two safety recommendations and one safety advisory notice as a result of the investigation.

THE AUSTRALIAN TRANSPORT SAFETY BUREAU

The Australian Transport Safety Bureau (ATSB) is an independent Commonwealth Government statutory agency. The Bureau is governed by a Commission and is entirely separate from transport regulators, policy makers and service providers. The ATSB's function is to improve safety and public confidence in the aviation, marine and rail modes of transport through excellence in: independent investigation of transport accidents and other safety occurrences; safety data recording, analysis and research; fostering safety awareness, knowledge and action.

The ATSB is responsible for investigating accidents and other transport safety matters involving civil aviation, marine and rail operations in Australia that fall within Commonwealth jurisdiction, as well as participating in overseas investigations involving Australian registered aircraft and ships. A primary concern is the safety of commercial transport, with particular regard to fare-paying passenger operations.

The ATSB performs its functions in accordance with the provisions of the *Transport Safety Investigation Act 2003* and Regulations and, where applicable, relevant international agreements.

Purpose of safety investigations

The object of a safety investigation is to identify and reduce safety-related risk. ATSB investigations determine and communicate the safety factors related to the transport safety matter being investigated. The terms the ATSB uses to refer to key safety and risk concepts are set out in the next section: Terminology Used in this Report.

It is not a function of the ATSB to apportion blame or determine liability. At the same time, an investigation report must include factual material of sufficient weight to support the analysis and findings. At all times the ATSB endeavours to balance the use of material that could imply adverse comment with the need to properly explain what happened, and why, in a fair and unbiased manner.

Developing safety action

Central to the ATSB's investigation of transport safety matters is the early identification of safety issues in the transport environment. The ATSB prefers to encourage the relevant organisation(s) to initiate proactive safety action that addresses safety issues. Nevertheless, the ATSB may use its power to make a formal safety recommendation either during or at the end of an investigation, depending on the level of risk associated with a safety issue and the extent of corrective action undertaken by the relevant organisation.

When safety recommendations are issued, they focus on clearly describing the safety issue of concern, rather than providing instructions or opinions on a preferred method of corrective action. As with equivalent overseas organisations, the ATSB has no power to enforce the implementation of its recommendations. It is a matter for the body to which an ATSB recommendation is directed to assess the costs and benefits of any particular means of addressing a safety issue.

When the ATSB issues a safety recommendation to a person, organisation or agency, they must provide a written response within 90 days. That response must indicate whether they accept the recommendation, any reasons for not accepting part or all of the recommendation, and details of any proposed safety action to give effect to the recommendation.

The ATSB can also issue safety advisory notices suggesting that an organisation or an industry sector consider a safety issue and take action where it believes it appropriate. There is no requirement for a formal response to an advisory notice, although the ATSB will publish any response it receives.

TERMINOLOGY USED IN THIS REPORT

Occurrence: accident or incident.

Safety factor: an event or condition that increases safety risk. In other words, it is something that, if it occurred in the future, would increase the likelihood of an occurrence, and/or the severity of the adverse consequences associated with an occurrence. Safety factors include the occurrence events (e.g. engine failure, signal passed at danger, grounding), individual actions (e.g. errors and violations), local conditions, current risk controls and organisational influences.

Contributing safety factor: a safety factor that, had it not occurred or existed at the time of an occurrence, then either: (a) the occurrence would probably not have occurred; or (b) the adverse consequences associated with the occurrence would probably not have occurred or have been as serious, or (c) another contributing safety factor would probably not have occurred or existed.

Other safety factor: a safety factor identified during an occurrence investigation which did not meet the definition of contributing safety factor but was still considered to be important to communicate in an investigation report in the interests of improved transport safety.

Other key finding: any finding, other than that associated with safety factors, considered important to include in an investigation report. Such findings may resolve ambiguity or controversy, describe possible scenarios or safety factors when firm safety factor findings were not able to be made, or note events or conditions which 'saved the day' or played an important role in reducing the risk associated with an occurrence.

Safety issue: a safety factor that (a) can reasonably be regarded as having the potential to adversely affect the safety of future operations, and (b) is a characteristic of an organisation or a system, rather than a characteristic of a specific individual, or characteristic of an operational environment at a specific point in time.

Risk level: The ATSB's assessment of the risk level associated with a safety issue is noted in the Findings section of the investigation report. It reflects the risk level as it existed at the time of the occurrence. That risk level may subsequently have been reduced as a result of safety actions taken by individuals or organisations during the course of an investigation.

Safety issues are broadly classified in terms of their level of risk as follows:

- **Critical** safety issue: associated with an intolerable level of risk and generally leading to the immediate issue of a safety recommendation unless corrective safety action has already been taken.
- **Significant** safety issue: associated with a risk level regarded as acceptable only if it is kept as low as reasonably practicable. The ATSB may issue a safety recommendation or a safety advisory notice if it assesses that further safety action may be practicable.
- **Minor** safety issue: associated with a broadly acceptable level of risk, although the ATSB may sometimes issue a safety advisory notice.

Safety action: the steps taken or proposed to be taken by a person, organisation or agency in response to a safety issue.

GLOSSARY

AAIB	Air Accidents Investigation Branch (United Kingdom)
AC	Alternating current
APB	Auxiliary power breaker
APU	Auxiliary power unit
BCU	Bus control unit
BKK	Bangkok International Airport
BTB	Bus tie breaker
CAA	Civil Aviation Administration (United Kingdom)
CASA	Civil Aviation Safety Authority
CASR	Civil Aviation Safety Regulation
CDU	Control display unit
CRM	Crew resource management
CS	Certification specification
CSM	Customer service manager
DC	Direct current
DCIR	Direct current isolation relay
DR&O	Design requirements and objectives
E&E	Electrical and equipment
EASA	European Aviation Safety Agency
ECAM	Electronic centralised aircraft monitoring
EFIS	Electronic flight instrument system
EICAS	Engine indicating and crew alerting system
EPR	Engine pressure ratio
EWIS	Electrical wiring interconnection systems
FAA	Federal Aviation Administration (United States)
FAR	Federal Aviation Regulations (United States)
FCOM	Flight crew operations manual
FCTM	Flight crew training manual
FDR	Flight data recorder
FL	Flight level
FO	First officer

GCB	Generator control breaker
GCU	Generator control unit
ICAO	International Civil Aviation Organization
IDG	Integrated drive generator
JAR	Joint Aviation Requirements
MEC	Main equipment centre
ND	Navigation display
NM	Nautical mile
NNC	Non-normal checklist
NPA	Notice of proposed amendment
NPRM	Notice of proposed rule making
NTSB	National Transportation Safety Board (United States)
PFD	Primary flight display
PWB	Printed wiring board
QAR	Quick access recorder
QRH	Quick reference handbook
SAFO	Safety alert for operators
SO	Second officer
SSB	Split system breaker
TRU	Transformer rectifier unit
UTC	Coordinated universal time
VOR	Very high frequency omnidirectional radio range

1 FACTUAL INFORMATION

1.1 History of the flight

On 7 January 2008, the Australian Transport Safety Bureau (ATSB) received notification that an electrical systems event had occurred on an Australian-operated Boeing Company 747-438 aircraft at a position 25 km north-north-west of Bangkok International Airport (BKK), Thailand. The aircraft, registered VH-OJM (OJM), was being operated on a scheduled international regular public transport service between London, England and Bangkok, Thailand. The aircraft had 346 passengers and 19 crew on board, including four flight crew. Initial reports suggested that the aircraft had sustained a number of system failures resulting in the loss of all alternating current (AC) electrical power.

On 9 January, the Department of Civil Aviation in Thailand delegated the conduct of the investigation to the ATSB in accordance with International Civil Aviation Organization (ICAO) Annex 13, paragraph 5.1.

1.1.1 Initial descent

At about 0837 Coordinated Universal Time (UTC)[1], while the aircraft was at about flight level[2] (FL) 210 on descent, the customer service manager (CSM) notified the flight crew that a substantial water leak had occurred in the forward galley. The CSM later reported that the water was 'smelly' and had debris in it. The water covered the entire galley floor including inside the cart bays but the CSM was not able to determine a source of the water or any observable flow direction. The CSM also reported that cabin crew had attempted to soak up the water using blankets, and that about four or five blankets were saturated.

At about 0839, the flight crew noticed a bus[3] control unit (BCU) status message on the engine indicating and crew alerting system (EICAS) display, which ceased after about 2 minutes. The aircraft's flight operation manuals describe status messages as a low-level alert.

At about FL 150 during the descent, the flight crew occupied their assigned seats for landing. The captain, who was the pilot flying, occupied the left control seat. The first officer (FO) occupied the right control seat, and the two second officers (SO1 and SO2) occupied the observer seats that were located behind the control seats.

A flight crew member later reported that the weather was good for their arrival with little air traffic.

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[1] The 24-hour clock is used in this report to describe the local time of day, as particular events occurred. Bangkok local time was Coordinated Universal Time (UTC) +7 hours.

[2] Pressure altitude in hundreds of feet, referenced to a nominal air pressure of 1013.25 hPa at sea level. FL 210 is about 21,000 feet above mean sea level.

[3] Bus: a physical electrical interface for the distribution of electrical power to multiple devices.

1.1.2 System malfunctions

Between 0846 and 0852, [4] after passing FL 100 and when the aircraft was turning onto an extended left downwind leg for runway 01 Right (01R), the EICAS, flight displays and automated systems showed faults of numerous electrical and other aircraft systems, including:

- AC buses 1, 2 and 3 not powered
- autothrottle disconnected
- autopilot disengaged
- some fuel pumps not operating
- weather radar not operating
- automatic cabin air conditioning and pressurisation system not operating
- right (FO's) displays blanked
- between three and five pages of messages on the EICAS display
- lower EICAS display blanked.

The CSM contacted the flight crew and advised that the cabin lighting had failed. The SO1 advised the CSM that there was an electrical system problem that the flight crew were attempting to resolve.

The status of AC bus 4 appeared normal. The flight crew reported observing main battery and auxiliary power unit (APU) battery discharge messages on the EICAS. The battery discharge messages were classified in the operator's flight crew operations manual (FCOM) as advisory[5] and did not require crew actions. The operator's quick reference handbook (QRH) stated that these messages indicated that the associated batteries were discharging. The QRH did not provide the flight crew with information about the remaining battery life, nor any recommended crew actions to restore services. The EICAS messages were not time stamped.

The flight crew reported that they actioned several non-normal checklists in response to a number of other messages and annunciations. However, after a period of time the flight crew decided to discontinue actioning the non-normal checklists due to the constant action required in response to the continuous scrolling of the EICAS messages.

The EICAS and overhead panel annunciations indicated that three of the four AC buses remained unpowered. The flight crew reported that they also checked the flight deck circuit breakers, and none of them appeared to be open. The flight crew reported that they did not have sufficient time to refer to the aircraft's manuals to diagnose the problem.

The flight crew stated that the following instruments and systems were available:

- left (captain's) primary flight display (PFD), in a degraded mode, which included attitude, airspeed, altitude, vertical speed and instrument landing system indications
- left navigation display (ND), in a degraded mode

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[4] Refer section 1.6.2 for more detailed timing.

[5] Advisory is the second lowest of four priority levels.

- left control display unit
- upper EICAS display, including landing gear indication
- standby instruments, comprising attitude indicator, airspeed, altitude, and magnetic compass
- right flap position indications
- one radio communications system.

In addition, the flight crew reported that during communications with air traffic control, they noticed that the strength of the radio transmissions were less than normal.

It was also reported that engine pressure ratio (EPR) readings were only available for the No 4 engine. The probe for the measurement of EPR for each engine was powered by the associated AC bus[6].

The company standard operating procedure required the flight crew to declare an emergency to air traffic control (ATC) and to the company as soon as possible following a critical system failure. The flight crew did not declare an emergency (MAYDAY) or urgency (PAN PAN) as the aircraft was being radar vectored to landing and was the next in line to land. The captain reported that he considered that there might be a communication issue with ATC, and took into account that the approach was being conducted in daylight and clear of cloud.

1.1.3 Final approach

The aircraft was radar vectored by ATC onto an extended downwind leg for a 10 NM (19 km) final leg to runway 01R (Figure 1).

The flight crew extended the flaps to 5°. The target minimum speed indicator was set but was not displayed on the captain's PFD. The heading bug[7] was frozen in its last position on the downwind radar vector. The track line on the ND appeared to be indicating correctly. The instrument landing system was operational but identification of the navigation aid was not possible by the usual Morse code.

The FO stated that the runway was in sight and that there was nothing on the EICAS that he considered significant in terms of landing safely. He was particularly looking for any information on anti-skid brakes, as the absence of anti-skid would extend the landing distance required.

The landing gear was selected down with the associated normal landing gear indications. The captain was controlling the aircraft manually. He considered that the situation was manageable as the engines were producing thrust, the gear and flaps were configured, there was no traffic ahead of the aircraft and no reason they should not be able to complete the landing. There were no altitude auto-callouts, as the radio altimeter was not operational.

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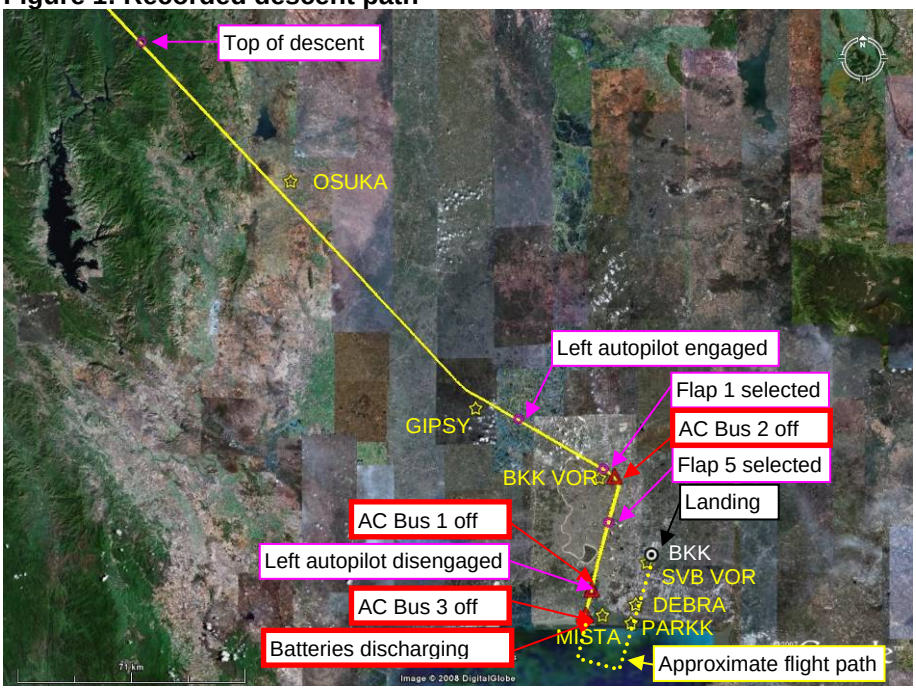
[6] Each AC bus received its primary power from the associated engine (AC bus 1 from No 1 engine and so on).

Figure 1: Recorded descent path[8]



1.1.4 Landing and taxi

The aircraft landed at 0907 with the thrust reversers, spoilers and autobrakes operating normally. The flight crew elected to use partial reverse thrust to avoid over-boosting the engines as the electronic engine controls had entered an alternate mode.

The aircraft taxied off the runway and an announcement was made to the passengers. The flight crew did not seek engineering advice or contact the cabin crew before continuing to taxi to the terminal.

During approach to the terminal the flight crew considered the status of the systems remaining and what other issues were evident. The flight crew noted that the leading edge flaps had not retracted.

The flight crew started the APU but could not bring the APU generators online.

The aircraft was parked at an aerobridge with all four engines running. Ground power was connected but the flight crew was unable to power any aircraft systems from ground power. Engine Nos 1, 2, and 3 were shut down and, when engine No 4 was shut down, all internal lighting failed.

The cabin doors could not be opened because the aircraft remained partially pressurised, so the flight crew opened the pressurisation outflow valve. The doors then opened and the passengers disembarked.

1.1.5 Post-shutdown immediate maintenance activities

The flight crew reported that after the aircraft was parked and the electrical problems were reported to ground crews, a maintenance engineer attempted to

[8] Courtesy of Google Earth.

restore the aircraft's electrical systems by cycling the circuit breakers, but without success. The engineer was also unable to establish ground power.

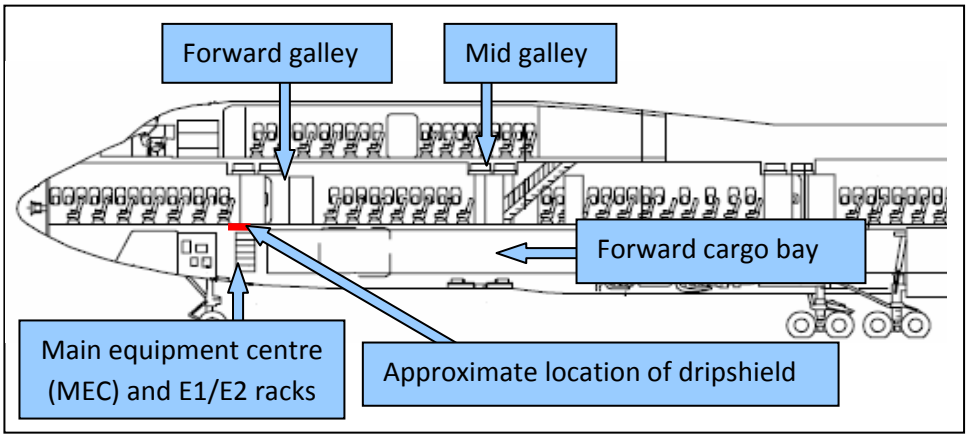
Inspections of the aircraft's main equipment centre (MEC) found cracks around a number of fasteners in a polycarbonate dripshield above the E1/E2 equipment racks[9] (Figure 2 and Figure 3). Water was observed on and around the No 3 generator control unit (GCU). [10]

Inspections identified a minor water leak in the forward galley sink drain. The forward galley ice drawer drain was also blocked. Maintenance personnel reported the presence of water on the floor in the galley area after landing.

Prior to the aircraft's return to service:

- No 2 and No 3 GCUs and both BCUs were replaced
- a temporary repair of the dripshield was carried out
- the batteries were recharged
- the electrical power system was tested
- an inspection and temporary rectification of potential water leak sources was carried out
- various systems were inspected for liquid ingress and/or tested for correct operation.

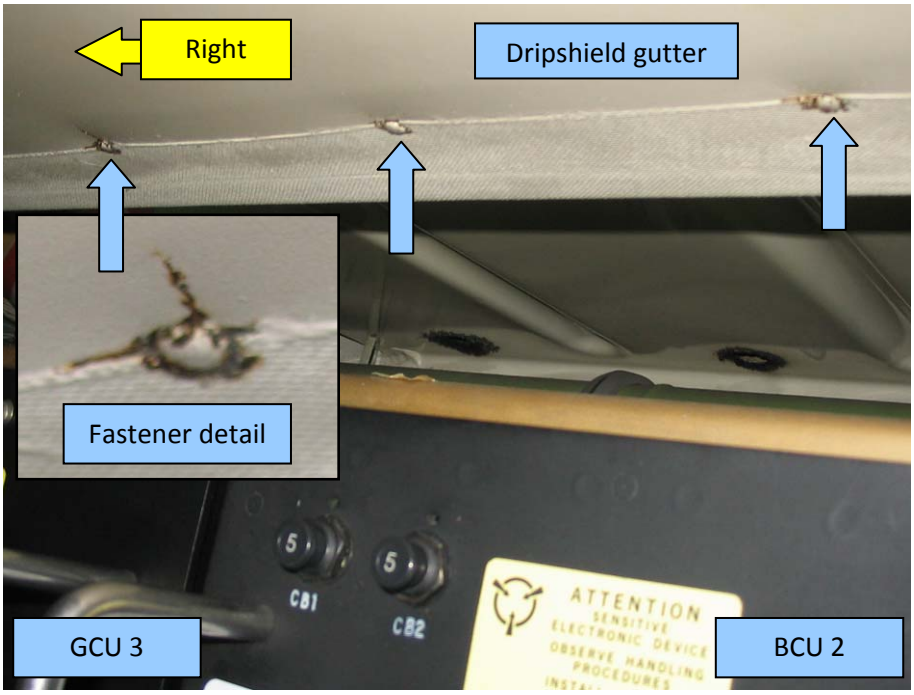
Figure 2: Location of galley and main equipment centre



[9] The aircraft was fitted with several racks for the installation of electronic equipment, mostly in the MEC. E1 and E2 were installed side-by-side at the rear of the MEC. Each housed six rows of equipment with several electrical units per row (Figure 11).

[10] Refer to section 1.4.8 for a description of the aircraft's electrical systems, including the function of the GCUs and BCUs.

Figure 3: Dripshield fasteners, viewed from below



1.2 Injuries to persons

There were no reported injuries to persons.

1.3 Flight crew information

Table 1 summarises the operational experience of the flight crew at the time of the occurrence. All of the flight crew reported that they were well rested prior to the flight.

Table 1: Flight crew experience

	Captain	FO	SO1	SO2
Licence category	ATPL[11]	ATPL	ATPL	CPL[12]
Total flying hours	17,628	9,826	4,393	3,696
Total hours in command	14,888	733	1,849	119
Total 747-400 hours	3,834	2,941	2,385	3,346

[11] Airline Transport Pilot License.

[12] Commercial Pilot License.

1.4 Aircraft information

1.4.1 General information

Aircraft type: Boeing Company 747-438

Serial number: 25245

Year of manufacture: 1991

Registration: VH-OJM

Type Certificate: 10 January 1989

Certificate of Registration: 17 September 1991

Certificate of Airworthiness: 17 September 1991

Total airframe hours: 76,610

Total airframe cycles: 9,754

Last C-check:[13] Completed 20 September 2007

1.4.2 Cockpit layout and instrumentation

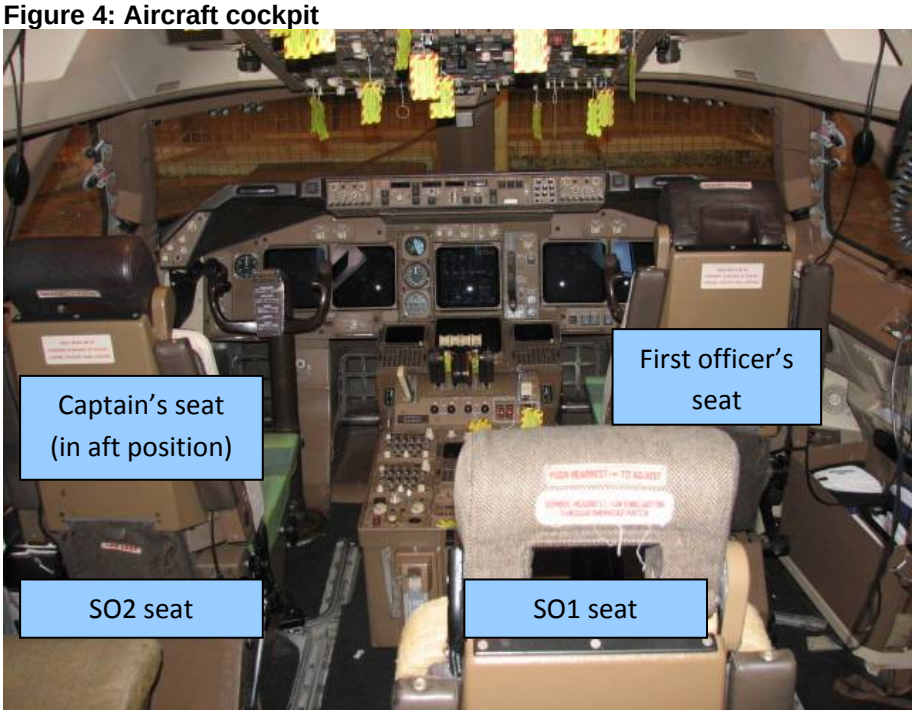
Seating layout

The aircraft's cockpit included two pilot's positions and two SO positions (Figure 4). The captain's seat was on the left, and the FO's seat was on the right. The two SO seats were positioned such that the right SO seat (SO1) was almost central and the left SO seat (SO2) was almost directly behind the captain's seat.

When the captain's seat was occupied, a person in the left SO seat could not easily view the captain's instruments. A person in the right SO seat could view both sets of instruments.

[13] A-, C-, and D-checks are different levels of scheduled maintenance inspections, each level being increasingly comprehensive and at greater intervals. Each level could be split into partial checks, known as A1, A2, and so on, to enable specific inspections to be carried out more or less frequently than others. In addition to other scheduled maintenance inspections, the operator's 747-400 aircraft were scheduled to undergo full A-checks every 1,500 flight hours, full C-checks every 4 years and full D-checks every 12 years, and partial checks for each level twice as frequently.

Figure 4: Aircraft cockpit



Engine indicating and crew alerting system

The EICAS was divided into upper (primary) and lower (auxiliary) displays. The upper EICAS displayed primary engine parameters, crew alert messages, flaps and landing gear status, fuel quantity and environmental control system information. The lower EICAS could display secondary engine parameters, maintenance pages, synoptic displays and/or status messages.

The alert messages were categorised into four levels depending on the urgency and required crew actions:

- Level A (warning) messages in red, requiring immediate crew action.
- Level B (caution) messages in amber, requiring immediate crew awareness and future crew action.
- Level C (advisory) messages in amber and indented, requiring crew awareness and possible future crew action.
- Level D (memo) messages in white, provided as crew reminders or annunciations of normal conditions.

Many messages had an associated entry in the quick reference handbook (QRH), along with the required crew action items. A caret symbol (>) was displayed at the start of messages that did not have any associated actions in the QRH.

Eleven messages could be displayed at once, and were arranged in order of priority with Level A messages shown at the top. The crew could scroll the display to subsequent pages if more than 11 messages were active. A message would be prompted by the detection of a certain condition (such as a fault or undesirable aircraft configuration) and displayed for as long as that condition remained.

Primary instruments

The aircraft's primary instruments were the integrated display units and EICAS displays. There were two integrated display units for the captain and two for the FO. When all displays were operational, they were normally arranged to show primary flight display (PFD) and navigation display (ND) information as shown in Figure 5.

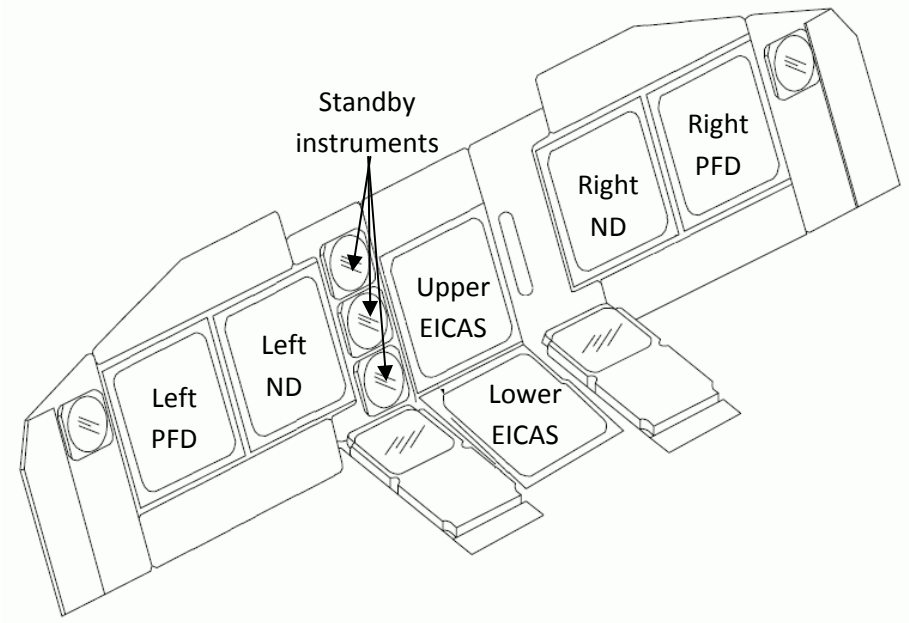
The PFD provided the following information:

- airspeed
- attitude
- heading
- altitude
- vertical speed
- flight mode annunciations
- radio altitude
- guidance cues
- traffic alert and collision avoidance system indications.

The ND provided one of four mode displays, depending on mode selection:

- approach,
- VOR[14],
- map, or
- flight plan.

Figure 5: Instrument panel layout (magnetic compass not shown)



[14] Very high frequency omnidirectional radio range. A type of navigation system using ground-based radio aids.

Standby instruments

The cockpit instrumentation included standby instruments, comprising:

- attitude reference system, airspeed, and altitude instrumentation that was located on the instrument panel
- a magnetic compass, which was located on the centre windshield pillar.

The standby attitude reference system required electrical power for operation and was powered through the main battery bus. It included a failure flag that was displayed when inadequate power or gyro speed was detected. The gyro could maintain enough momentum to be useable for up to about 10 minutes after electrical power was removed or lost.

The standby airspeed indicator was pneumatic and used electrical power for dial illumination.

The standby altitude indicator was pneumatic and used electrical power from the main battery for dial illumination and to facilitate smooth mechanical movement. If electrical power was not supplied, the indicator needle could stick and show incorrect indications.

The standby compass was magnetic and used electrical power for dial illumination.

1.4.3 Forward galley

The forward galley consisted of a wet galley area and a bulkhead, which were about 1 m apart (Figure 6).

The wet area drainage system consisted of sink drains and floor drains, each covered by a perforated grate.

The bulkhead rested on small feet that raised the lower edge slightly above floor level. The lower edge was not sealed.

Immediately forward of the bulkhead was a decompression panel[15] that was installed under a compartment between two passenger seats (Figure 7). The panel comprised a hinged panel that was held shut with a spring, and included a perimeter gap of about 3mm. The panel had been installed as part of the operator's modifications to the aircraft after its initial delivery. The aircraft manufacturer's standard design practice required that decompression panels be located near the cabin sidewalls.

As shown in Figure 7, a polycarbonate assembly was located beneath the floor, comprising a plenum[16] with gutters (not visible in Figure 7) on the front and rear. The assembly forms a dripshield over electrical equipment in the main equipment centre (MEC). See section 1.4.6 *Dripshield and dripshield plenum*.

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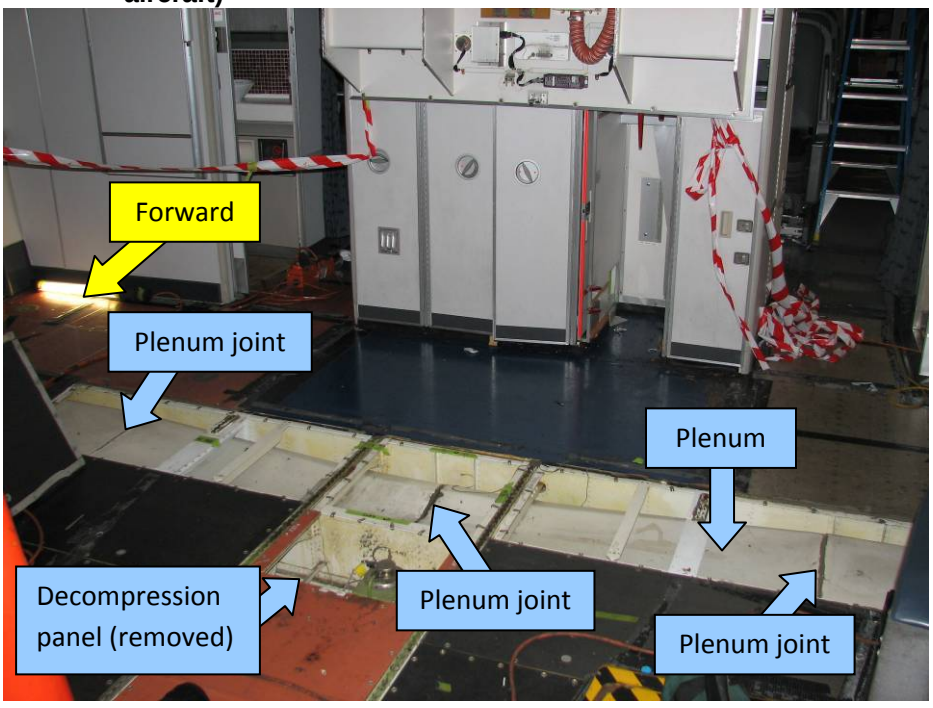
[15] A form of safety valve (in this case consisting of a hinged panel) that opens to relieve air pressure and prevent structural damage in the event of depressurisation. Also known as a blowout panel.

[16] An enclosed space used as an airflow duct for heating or cooling.

Figure 6: Forward galley (typical aircraft)

Figure 7: Forward galley area with bulkhead and floor panels removed (typical aircraft)



Waste water from galleys, galley drains, lavatory washbasins, and drinking fountains was directed overboard through drain masts (Figure 8). The drains were cleaned every 1,500-hourly A2-check.

The drain lines leading to the drain mast were exposed to severe cold near the aircraft's skin due to the normally-experienced sub-freezing temperatures at high altitude. The drain lines leading to the drain masts were fitted with electrical ribbon heaters to prevent icing, and the drain masts were also heated with a separate system (Figure 9). The ribbon heaters were tested for correct operation every D-check.

All of the operator's 747-400 aircraft, including OJM, were originally fitted with a forward drain mast incorporating separate outlet ports for the main and upper deck drains. That drain mast was found to leave waste water marks on the underside of the fuselage, and between 1989 and 1992 the operator subsequently replaced the drain masts on those aircraft with a longer drain mast to reduce the occurrence of the marks. The replacement drain masts only had a single outlet port, so the two drain lines were combined with a rubber Y section.

Figure 8: Simplified aircraft drain system (toilet drains not shown)

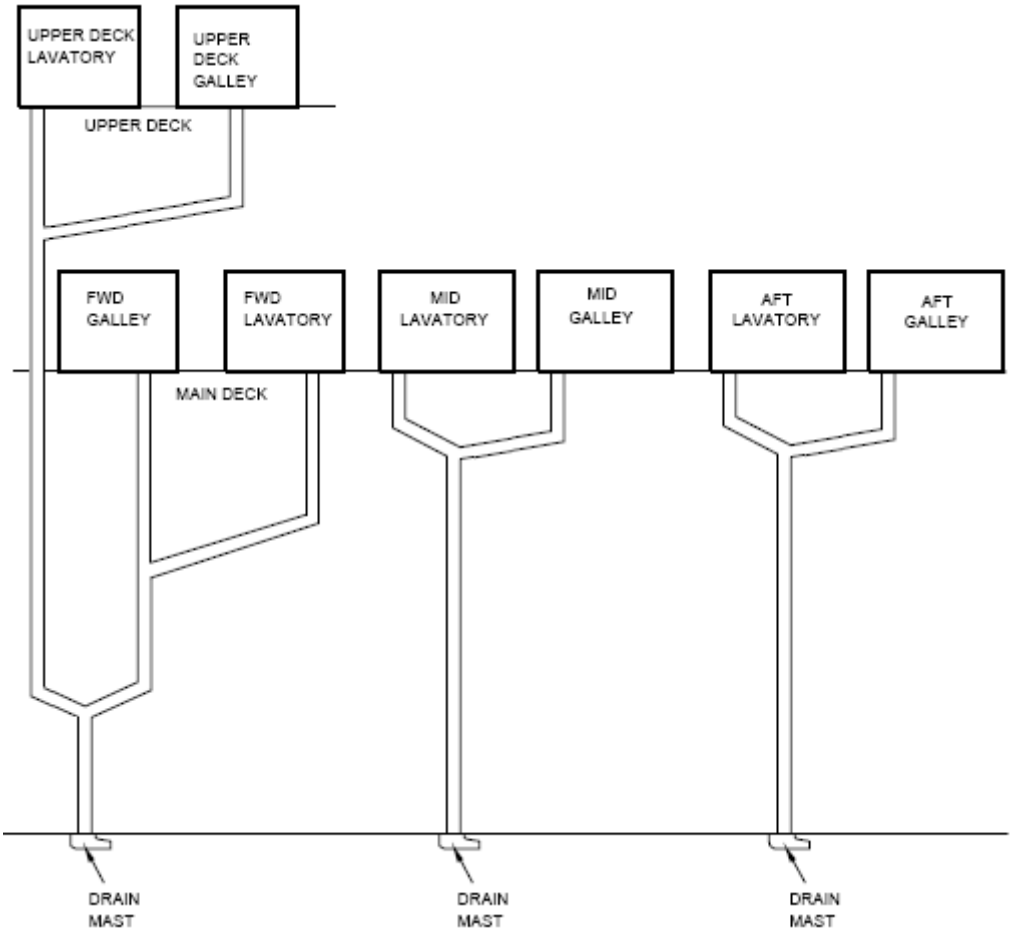
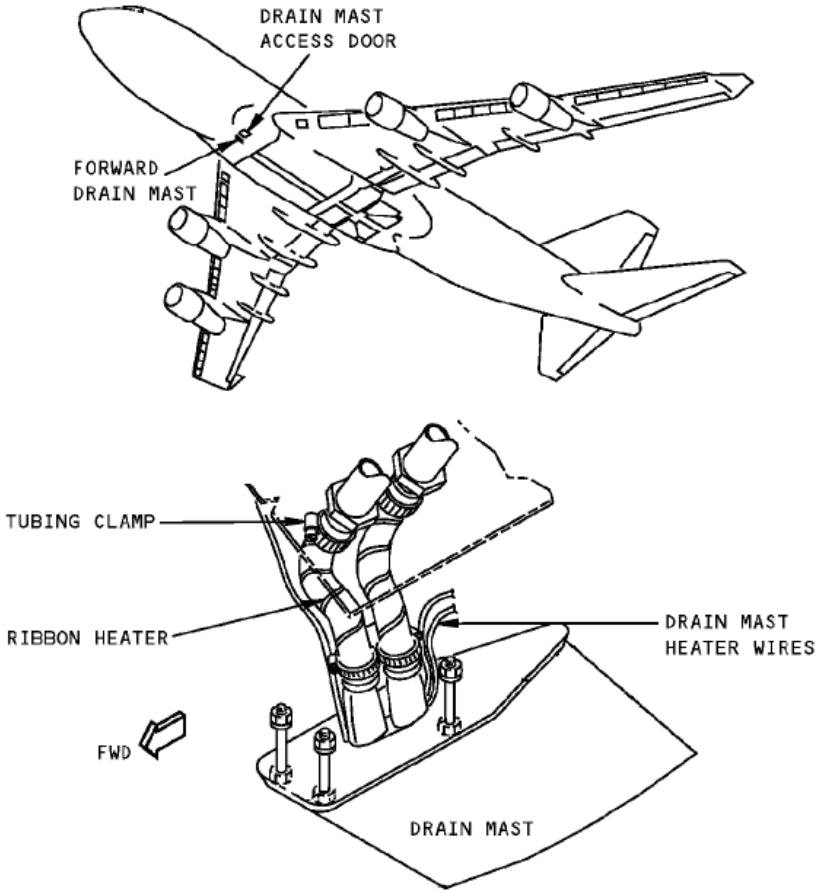


Figure 9: Forward drain mast and ribbon heater (prior to the drain mast modification)



1.4.4 Galley floor sealing

The operator's wet area floor sealing specification P.088 stated that:

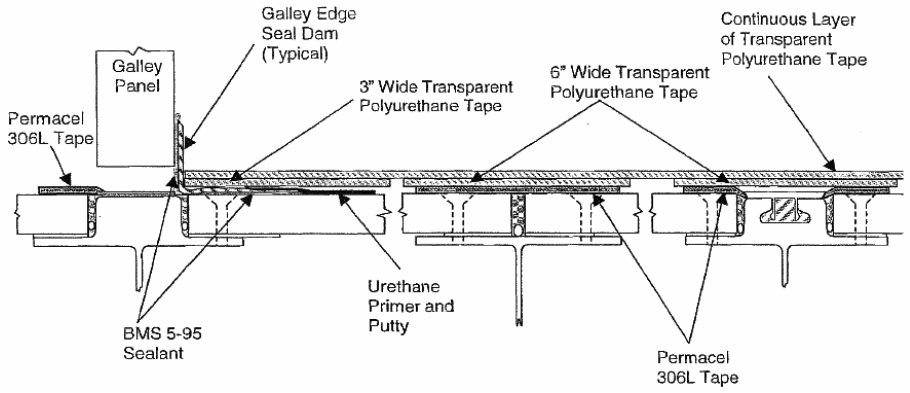
> Wet areas are defined as the floor and substructure beneath galleys, toilet blocks or any nominated wet area and includes an area extending 18 inches [46cm] surrounding these units. This is also extended in a lateral direction to 18 inches [46cm] forward and aft of any main entry door.

The specification for sealing wet area floors around seat tracks is shown in Figure 10. Galley edge seal dams were required around the inside of galley perimeter walls, whereas none were in place around the forward galley bulkhead in OJM.

The aircraft operator reported that it:

- Renewed the wet area floor sealing every partial D-check (6 years). The aircraft underwent a D-check in October 2005.
- Inspected the underfloor area from below for signs of corrosion every partial C-check (2 years). The aircraft underwent a C-check in September 2007.

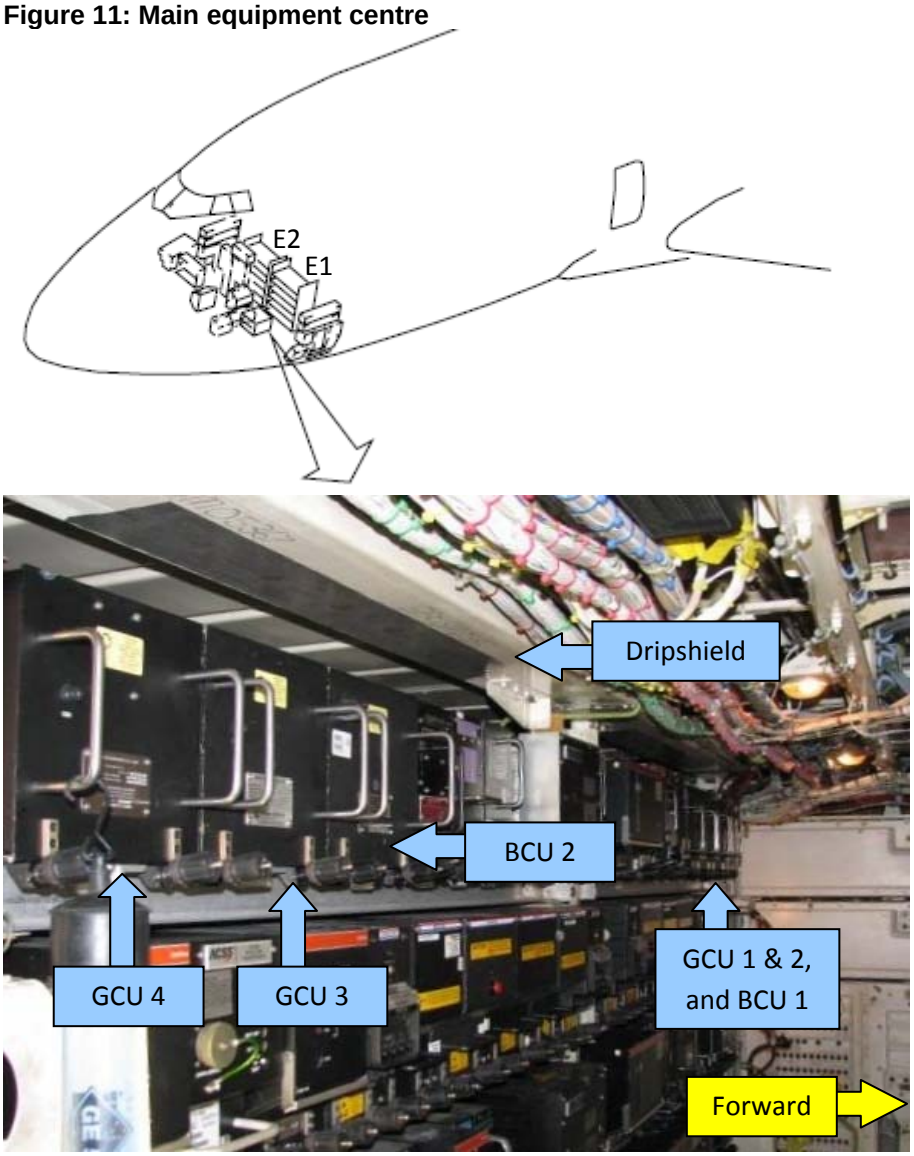
Figure 10: 747-438 wet area floor sealing specification



1.4.5 Main equipment centre

The aircraft's MEC was located below and forward of the forward galley (Figure 2). The MEC contained equipment racks that held much of the aircraft's electrical and avionics equipment. The E1/E2 rack at the aft end of the MEC contained the aircraft's GCUs and BCUs, which were located on the top shelf (Figure 11). A beam was installed that ran laterally across the top of that rack, about 13 cm behind the front faces of the racked equipment.

Figure 11: Main equipment centre



1.4.6 Dripshield and dripshield plenum

The dripshield above the equipment rack incorporated an enclosed exhaust plenum that drew air from above the equipment rack through twenty-four 2.5 cm diameter holes in the bottom of the plenum to reduce the ambient temperature in the MEC (Figure 13). The holes in the underside of the plenum were flush and without a lip.

The dripshield was mounted above the E1/E2 rack in the MEC, and incorporated gutters to collect fluids such as condensation that would otherwise drip into the equipment racks from above, and to divert those fluids to drains on each side of the shield (Figure 12). The drains were connected to plastic tubes that led to the bilge in the bottom of the fuselage, where several small outlets on the aircraft's skin allowed liquid in the bilge to escape.

The plenum and associated dripshield were formed by joining four main sections. The central two sections covered the E1/E2 equipment rack and the upper surface of the plenum was canted inwards towards the centre joint. The outer two sections

extended beyond the equipment rack. The gutter narrowed in the outer sections just beyond the joint.

The gutter was fastened to the lower edge of a floor beam. Four angled braces were installed between the forward lip of the gutter and the floor beam.

The aircraft operator reported that a visual inspection of the E1/E2 rack area was conducted every C-check, but that the process for that inspection did not specifically target any aspect of the dripshield.

Figure 12: Dripshield installation

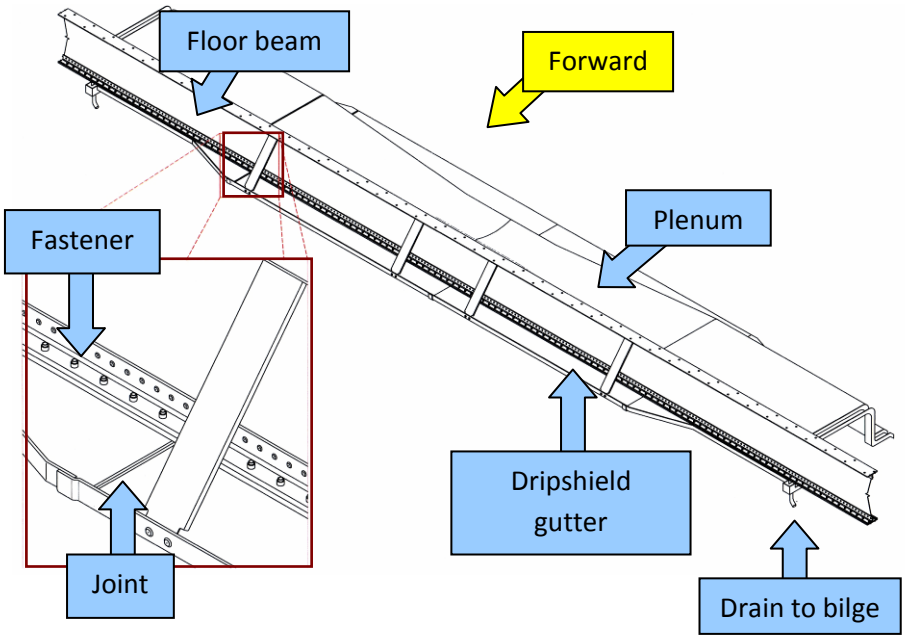


Figure 13: Dripshield showing cutaways of the plenum

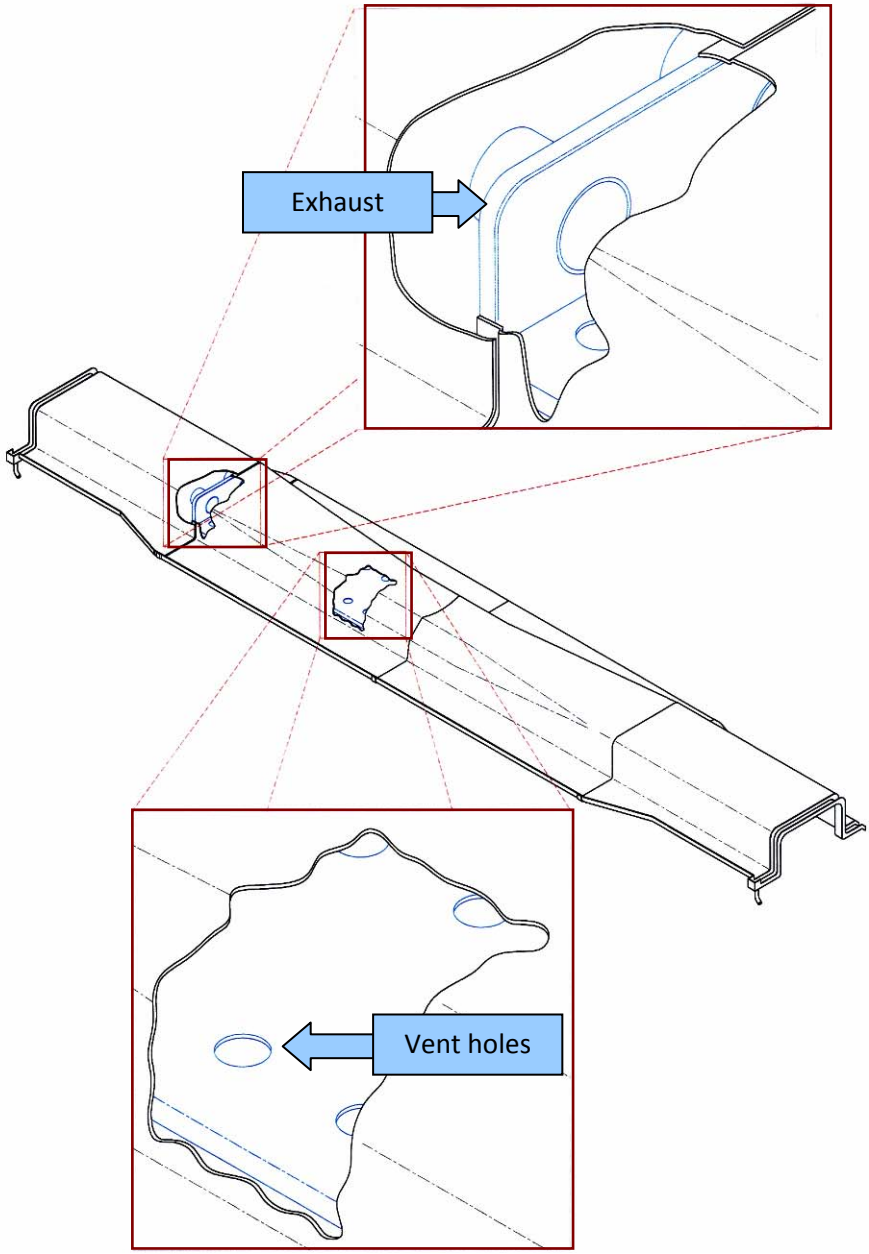


Figure 14: MEC, dripshield, and decompression panel, looking upwards

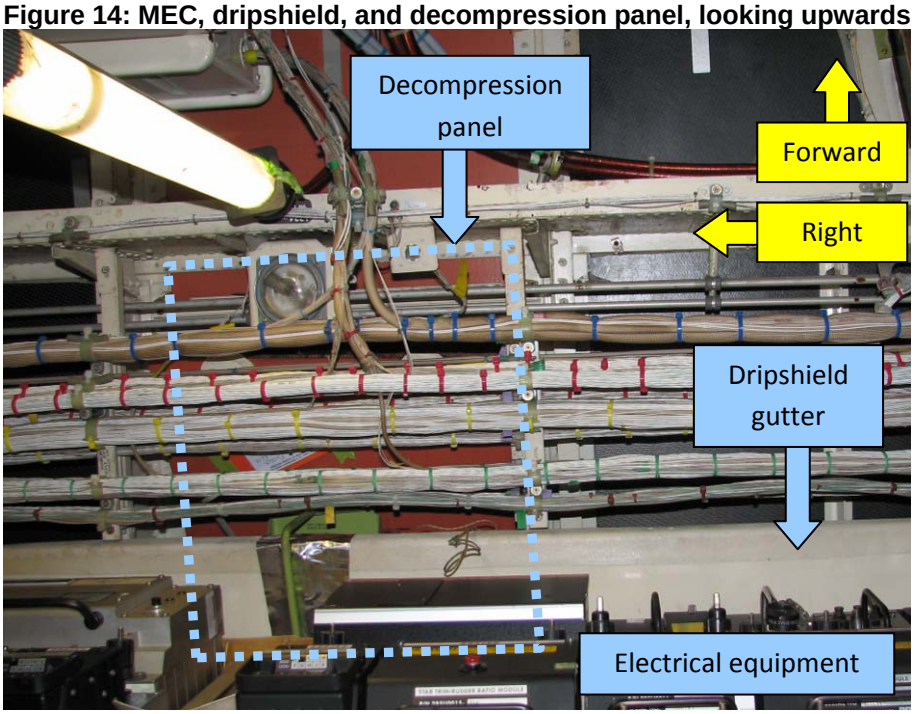
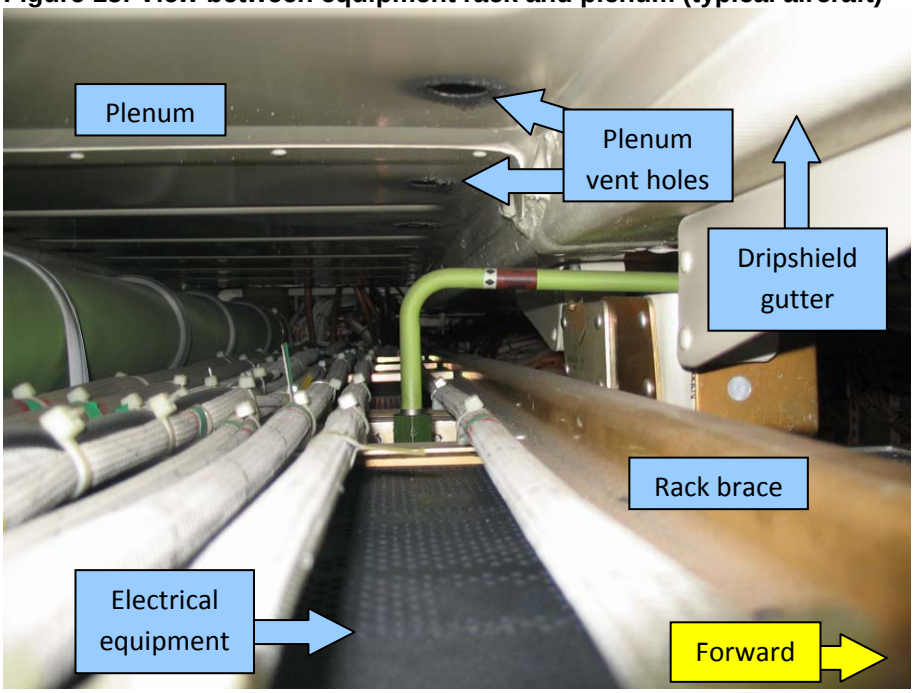


Figure 15: View between equipment rack and plenum (typical aircraft)



1.4.7 Under floor area

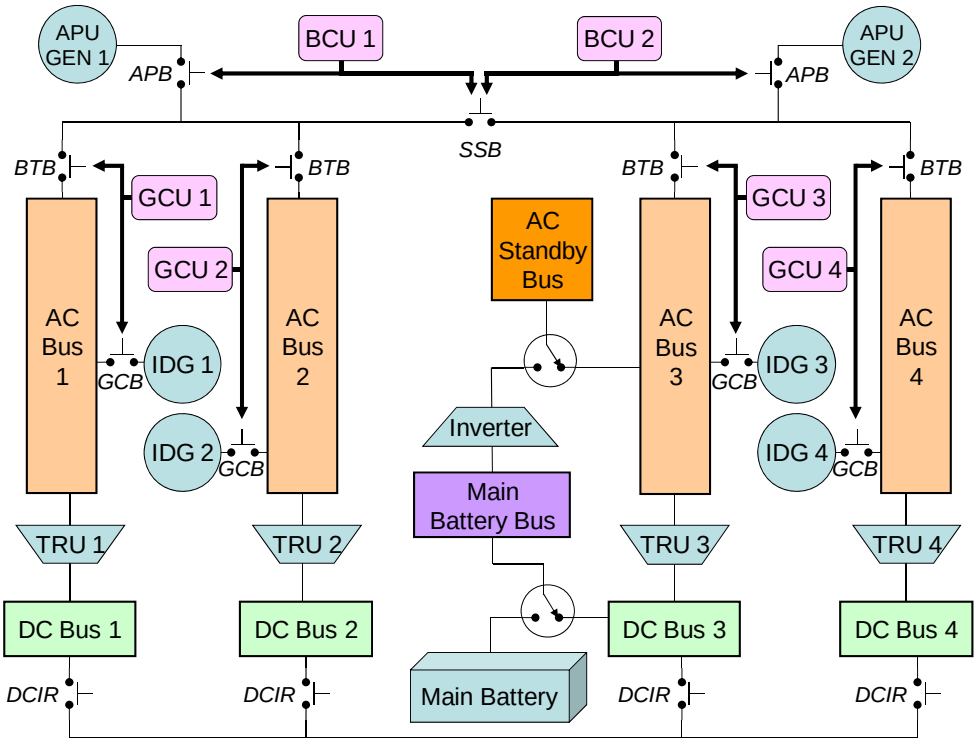
Plastic lining was installed on the lower side of the under floor area between the galley and the cargo bay. The lining was attached to the underside of a steel bracket that had an upturned lip, above an electrical distribution panel and behind the E1/E2 electrical equipment rack. The distance between the lip and the rearmost part of the electrical equipment in the main equipment centre (MEC) was about 30 cm.

1.4.8 Aircraft electrical systems

The aircraft's primary electrical system included four AC buses, four associated DC buses, and two battery buses (Figure 16). Each bus provided power for a particular subset of the aircraft's systems. Many of those systems were duplicated and powered by separate buses to reduce the effect of isolated electrical failures.

The aircraft's engines each included separate electrical systems for engine operation that were independent of the aircraft's main electrical systems.

Figure 16: Simplified electrical system schematic



Each AC bus was normally powered by its associated engine-driven integrated drive generator (IDG) via a generator circuit breaker (GCB). All four main AC buses were normally tied together by the respective bus tie breakers (BTB), and a split system breaker (SSB). Through this system, bus loads were shared between IDGs and power could be transferred between buses in case of a problem with power from one or more IDGs. In addition, a bus could be isolated from the others if it had a problem.

The GCBs and SSB were controlled by the aircraft's four generator control units (GCU) and two bus control units (BCU), which were located in the top rack of the E1/E2 electrical equipment racks in the MEC.

Each DC bus was normally powered by its associated AC bus via a transformer rectifier unit (TRU), and could also receive power from any of the other DC buses via DC isolation relays (DCIR). Each DCIR could be commanded to open by its associated GCU, or by the appropriate selection of a bus isolation switch on the flight deck.

Critical electrical systems were powered by one of the two battery buses, the AC standby bus or the APU standby bus. The battery buses normally received power

from the DC bus 3 and each standby bus normally received power from AC bus 3. In the event of electrical systems failures, the batteries could provide power to critical aircraft systems via the battery buses and standby buses for a minimum of 30 minutes depending on the equipment load demand.

When the batteries were not in use, charge was maintained by battery chargers which received power from either AC bus 1 or from external power sources. When powered, the battery chargers could provide power to the battery buses or augment the available battery power.

If either BCU detected that only one of the four TRUs was operating, both battery buses would be automatically switched to receive power from the batteries instead of DC bus 3. This reduced the load on the remaining TRU.

The aircraft's APU provided auxiliary electrical power and bleed air to the aircraft's systems on the ground and during maintenance. The APU could not be started when the aircraft was airborne.

Key electrical equipment

Many of the aircraft's systems could be powered from different sources, or have redundant systems powered by different sources. Table 2 lists the main electrical equipment and its function on the aircraft.

Table 2: Key electrical equipment

Item	Function
AC Systems with battery backup, and DC battery bus systems	
Air data computer	Calculate and provide air data to other aircraft systems.
Aural warning	Provide aural warnings to flight crews.
Automatic direction finder	Radio navigation.
Cabin pressure outflow valves	Regulate cabin air pressure.
Cargo fire extinguisher	Trigger fire extinguisher in the cargo bays, in case of fire.
Control column stick shaker	Provide tactile warning of impending stall condition.
EFIS[17]/EICAS interface unit	Provide interface for flight crew entry of data into flight computers.
EICAS, upper	Display primary engine parameters, crew alert messages, flaps and landing gear status, fuel quantity and environmental control system information.
Engine driven hydraulic pump shutoff valves	Shut off engine-driven hydraulic pumps in case of fire.
Engine fire extinguishers	Trigger fire extinguisher in engines, in case of fire.
Engine fuel shutoff valves	Allow crew to shut down engines.
Engine speed sensors	Provide engine speed information to cockpit displays.
Fire warning horn/clocks	Provide fire warning to flight crew.

[17] EFIS: Electronic flight instrument system.

Item	Function
Flight control electronics	Power yaw damper, stabiliser trim, rudder ratio, flap control, and control surface locating systems.
Flight deck lights	Flight deck illumination.
Flight management computer system	Flight plan and navigation aid.
Inertial reference system	Inertial navigation.
Interphones	Used for verbal communications between cabin crew stations and the flight deck.
Manual cabin pressure control	Allow manual control and release of cabin pressure.
Modular avionics and warning electronics assembly	Provide flight deck annunciation and warnings for improper aircraft configurations.
Navigation display, left	Provide navigation information to flight crew.
Park brake	Enable parking brake.
Passenger address system	Allow crew to make announcements to the passengers.
Primary flight display, left	Display primary flight information to flight crew.
Satphone	Allow long distance text and voice communication.
Standby altimeter	Display standby pressure altitude (the indicator could operate without power, but unreliably).
Standby attitude indicator	Display standby attitude.
Standby instrument illumination	Illuminate standby instruments.
Transponder	Provide aircraft information and location to air traffic control.
VHF[18] radio	Allow voice communications with other aircraft and air traffic control.
DC Systems without battery backup	
Anti-skid	Control brake pressure to each wheel to prevent skidding.
Autobrake	Provide a smooth application of brakes and constant deceleration after touchdown.
Leading edge flap control	Provide motor power to leading edge flaps (slats).
Stabilator trim	Provide pitch trim.
AC Systems without battery backup	
EICAS, lower	Display secondary engine parameters, maintenance pages, synoptic displays and/or status messages.
Ground proximity warning system	Alert the flight crew about near terrain or windshear conditions.
Landing lights	Illuminate the runway during takeoff and landing.
Navigation display, right	Provide navigation information to flight crew.

[18] VHF: Very high frequency.

Item	Function
Panel lights	Instrument panel illumination.
Primary flight display, right	Display primary flight information to flight crew.
Traffic alert and collision avoidance system	Alert flight crew of the proximity of other aircraft fitted with a similar system to prevent midair collisions.

1.5 Meteorological conditions

Recorded meteorological conditions at Bangkok at the time of the event included high level scattered[19] cloud, temperature 32 ºC, humidity 38%, wind from the north-west at 11 km/h and visibility of 9 km.

1.6 Flight recorders

1.6.1 Recording systems

The aircraft was fitted with a flight data recorder (FDR), a quick access recorder (QAR) and a cockpit voice recorder (CVR). The aircraft's FDR and QAR data were obtained after the event. Both of those components were powered by AC Bus 3 and contained information about aircraft systems behaviour prior to the loss of power to that bus.

The CVR records the total audio environment in the cockpit area. This includes flight crew conversation, radio transmissions, aural alarms, audible control movements, switch activations and engine and airflow noise. The CVR that was installed in OJM retained the last 2 hours of information in solid-state memory, operating on an endless-loop principle.

Cockpit voice recorder systems are designed to operate even when the aircraft is on the ground with the engines shutdown. This allows investigators access to important flight crew conversation or checklist actions before the first engine is started for takeoff or after the last engine is shutdown after landing. The disadvantage is that valuable audio information is quickly overwritten following a non-catastrophic accident or serious incident, where there is a significant interval between an occurrence and when the flight is completed and electrical power is removed from the CVR.

The CVR recordings were not retrieved prior to the aircraft's next flight, and the recordings were overwritten. As a result, the investigation was unable to retrieve the CVR data that was recorded during the incident.

The FDR recorded aircraft flight data and, like the CVR, operated on an endless-loop principle. The recording duration of the FDR that was fitted to OJM was 25 hours and recorded about 300 parameters. An FDR typically records when at least one engine is operating and stops recording when the last engine is shut down.

[19] Cloud amounts are reported in oktas. An okta is a unit of sky area equal to one-eighth of total sky visible to the celestial horizon. Few = 1 to 2 oktas, scattered = 3 to 4 oktas, broken = 5 to 7 oktas and overcast = 8 oktas.

Like the FDR, the QAR recorded aircraft flight data for convenient access by maintenance personnel. The QAR that was installed in OJM stored about 500 recorded parameters.

1.6.2 Recorded data

The recorded data established the sequence of events (Table 3).

Table 3: Recorded sequence of events

UTC (mm:ss)	Flight Level / Altitude	Calibrated airspeed[20] (kts)	Event
0829:16	FL 370	272	Top of descent.
0832:22	FL 308	289	Left autopilot disengaged.
0832:23	FL 308	289	Master warning (active for 1 second).
0833:30	FL 285	286	Abeam waypoint OSUKA.
0840:28	FL 179	240	Left turn abeam waypoint GIPSY.
0842:29	FL 151	240	Left autopilot engaged.
0845:58	10,920 ft	228	Flap 1 selected.
0846:26	10,220 ft	229	Bus tie breaker (BTB) 2 opened.
0846:29	10,120 ft	229	Generator control breaker (GCB) 2 opened and AC Bus 2 status changed from ON to OFF.
0846:30	10,090 ft	229	Auto-throttle disconnected.
0846:36	9,980 ft	229	Autopilot Caution (Right bus) status changed from OFF to ON.
0846:41	9,850 ft	228	Right turn abeam BKK VOR.
0848:21	8,050 ft	211	Flap 5 selected.
0851:18	5,010 ft	186	BTB 1 opened, GCB 1 opened and AC Bus 1 status changed from ON to OFF.
0851:19	5,010 ft	186	Left autopilot disengaged.
0851:19	5,010 ft	186	Master warning (active for four seconds)
0851:26	4,970 ft	187	BTB 3 opened.
0851:32 to 0851:35	4,850 ft	193	Temporary loss of QAR data. BTB 3 closed and GCB 3 opened within this period.
0852:33	4,200 ft	188	Loss of power to AC Bus 3 - FDR and QAR ceased operating for the remainder of the flight.

[20] Indicated airspeed corrected for errors in an aircraft's airspeed indication system.

1.7 Aircraft electrical system examination and testing

1.7.1 GCUs and BCUs

Overview

The aircraft's four GCUs and two BCUs were removed for testing following the incident flight. Water was reported to be present in GCU 3, which controlled the AC bus 3 circuit breakers. No water was reported to be present in any other electrical equipment. Examination and testing revealed that GCUs 1, 2, and 3 exhibited internal corrosion that was consistent with long-term liquid ingress, particularly in respect of a circuit board that was located directly under the edge of an equipment rack brace.

The GCU/BCU manufacturer concluded that an accumulation of conductive contaminants and breakdown of the circuit boards' conformal coating[21] caused the units' monitoring and protection circuits to detect errors and resulted in the automatic shut down of each unit.

Visual examination

Visual external and internal inspections of the units were carried out. The results of that examination are provided in Table 4. Visual examination also identified slight evidence of excessive exposure to humidity on one of the BCU 2 circuit boards.

Table 4: Results of visual inspections of the GCUs and BCUs

Unit	External liquid staining	Internal liquid staining	Internal corrosion
GCU 1	Yes	Yes	Yes (A08 circuit board only)
GCU 2	Possible[22]	Yes	Yes (A08 circuit board only)
BCU 1	Yes	No	No
BCU 2	Yes	Yes (A12 board only)	No
GCU 3	Yes	Yes	Yes (A08 circuit board only)
GCU 4	Yes (very slight)	Yes (very slight)	No

The unit manufacturer's test report stated that the A08 circuit board from the three GCUs '...showed severe corrosion by-products from both the component leads and solder joints.' The A08 circuit board is the second of two boards containing the GCU analogue input/output circuits, and provided bus power monitoring functions including overvoltage, undervoltage, differential protection, load management sense, open phase sense, redundant differential protection, and DC voltage sense circuits.

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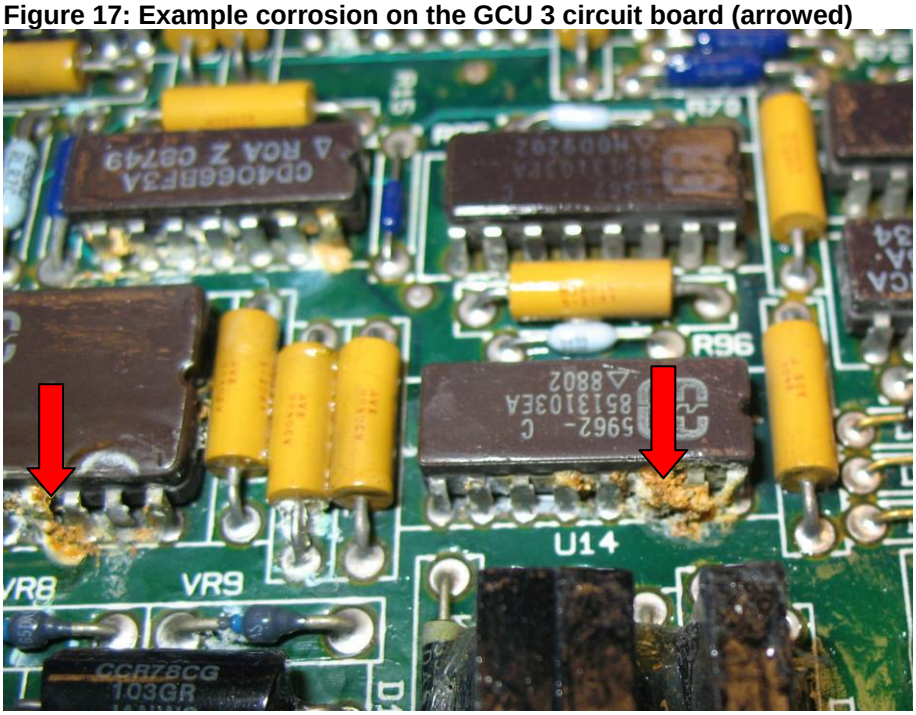
[21] Conformal coating: a protective material, usually transparent, which is used to coat printed circuit boards.

[22] A white, powdery substance that appeared to be due to slight corrosion was present on the underside of the upper connector at the rear of the unit.

The A08 circuit board was located directly underneath the rear edge of an equipment rack brace when the units were installed on the aircraft.

Figure 17: Example corrosion on the GCU 3 circuit board (arrowed)



The test report stated that many of the units exhibited dust on the circuit boards, and that any moisture present could cause the dust to be slightly conductive. The report also recorded that some boards had areas that did not have conformal coating.

Corrosion analysis

Spectral analysis of the contaminants showed strong evidence of residual water and minor evidence of probable carboxylic acid salt and carbonate, consistent with the water containing sugars such as found in beverages.

The unit manufacturer reported that:

> …the condition of the units examined represents the cumulative effects of repeated, long term exposure to liquids and is not the result of a single liquid ingress event. The GCUs and BCUs were repeatedly subjected to an environment which exceeded the hardware design capacity and requirements to resist induced failures by liquid ingress.

Testing

The four GCUs and two BCUs were subjected to the unit manufacturer's acceptance test procedure.[23] Five of the units passed that procedure, although GCU 1 failed a test for a function that was not utilised in the OJM installation.

Recorded data

Examination of data that was recorded in the non-volatile memory of the GCUs and BCUs recorded faults in the four GCUs and one of the BCUs. Some messages were

[23] Acceptance test procedures: a series of tests designed to verify that an item functions as designed.

recorded multiple times, so the number of messages did not necessarily reflect the number of distinct faults. The faults for each unit were associated with a particular circuit board within that unit.

The recorded information included:[24]

- thirteen fault messages from GCU 1, which were associated with the unit's circuit boards A04, A07, A08, and A12
- thirty fault messages from GCU 2, which were associated with boards A05, A07, A08, A09, and A11
- ninety-three fault messages from GCU 3, all except one of which were associated with circuit board A08 - the other fault was associated with circuit board A07[25]
- one fault message from GCU 4, which was associated with board A07
- no fault messages from BCU 1
- three fault messages from BCU 2, which were associated with board A11 (the power supply board).

Some of the recorded faults would have caused internal protection circuits to shut down the units and/or trip one or more of the associated bus circuit breakers. The unit manufacturer reported that some faults indicated that the units had behaved inconsistently with the fault handling design, indicating that the fault detection and handling circuits may have been affected by liquid.

Some of the faults in the GCUs were associated with the function of parts of the circuit boards with corroded components.

1.7.2 GCU and BCU maintenance search

The aircraft operator examined the maintenance records of its 747-400 fleet and identified two previous instances of water in other aircraft's GCUs. One of those aircraft had an associated report of a crack in the dripshield above the GCU. In both instances, water was found inside the aircraft's GCU 3 and maintenance personnel had been alerted to a problem by the presence of an ELEC GEN STATUS 3 message. Corrosion was identified on four of each of the affected unit's circuit cards.

The aircraft operator also conducted a search for maintenance activities on its 747-400 GCUs and BCUs between 1 January 2005 and 28 February 2008. That search identified that:

- a number of activities were carried out on 17 different units encompassing each unit type and location (Table 5) with the following results:
  - the activities involved 11 different aircraft
  - no unit underwent maintenance activities more than twice

[24] The number of fault messages recorded for a particular unit does not necessarily correlate with the extent of physical damage. For example, a unit might have numerous minor faults before shutting down.

[25] GCU circuit board A07 was the first of two boards containing GCU analogue input/output circuits, and included overfrequency, underfrequency, reverse power, overexcitation, underexcitation, underspeed, sync bus protection trip, BCU alive, and shorted permanent magnet generator circuits.

– for at least seven of these activities, no fault was found with the unit.[26]

- the unit installed as GCU 3 during the incident flight was the subject of previous maintenance after being installed as GCU 3 on another aircraft. The earlier fault was logged as 'DURING CRZ MSG ELEC BUS ISLN 3. UNABLE TO RESET. CLEARED AFTER 2HRS, APPEARED MOMENTARILY ON SHORT FINAL.' The source of the fault was not recorded
- at least six of the activities identified a fault in one of the circuit boards on the unit under test. The log for one of these activities recorded that four of the circuit boards were 'very dirty', and found corroded parts on these boards.

The aircraft operator conducted a review of the maintenance documentation for its 747-400 fleet to determine if specific AC power channels exhibited repeat intermittent failures or symptoms that may be attributable to internal corrosion or contamination. As at 25 October 2010, 189 of a total of 210 BCU and GCU units had been inspected. Of those, eight units had reports of corrosion and moisture defects on internal components. In addition three units were reported with unsatisfactory conformal coating. There were no reports of evidence of moisture contamination to the aircraft rack at that time.

On 27 June 2008, the aircraft operator reported that one GCU that was received as part of a maintenance exchange programme[27] and two out of four GCUs obtained as spares showed evidence of internal corrosion and contamination and failed the initial functional electrical test. Maintenance records showed that those units had previously passed acceptance testing by the unit manufacturer.

Table 5: Number of maintenance activities carried out on the operator's 747-400 GCUs and BCUs between 1 January 2005 and 28 February 2008

ITEM	NUMBER
GCU 1	0
GCU 2	4
BCU 1	3
BCU 2	2
GCU 3	9
GCU 4	2
TOTAL	**20**

1.7.3 Other components

Following the aircraft manufacturer's recommendations, the No 2 engine integrated drive generator (IDG) was also removed for testing. The unit passed the acceptance test procedure and was returned to service.

[26] For five of the activities, fault information was not available to the investigation.

[27] The unit manufacturer provided a replacement unit in exchange for one returned for maintenance. The replacement unit may be either new or refurbished and, if refurbished, may not necessarily have been in previous service with the same operator.

After the incident, the aircraft operator removed the aircraft's right flight management computer to inspect for evidence of water ingress or corrosion. The inspection did not identify any evidence of water contamination.

1.8 Immediate aircraft inspection

Maintenance personnel inspected the aircraft on its arrival in Bangkok following the incident. That inspection revealed that the underside of the dripshield gutter had brown liquid stains near the centre of the equipment rack, with faint staining near the right side joint (Figure 18).

The aircraft structure adjacent to the dripshield showed apparent long-term condensation residue. One area of the structure had a clean appearance consistent with water or other fluid having flowed down the side, removing any residue. This area was located underneath the right side of the forward galley bulkhead.

Maintenance personnel tested the drain ports on each side of the dripshield gutter during the inspection. Water that was poured into the drain ports flowed through drain lines on either side of the dripshield into the aircraft's bilge without restriction.

Inspections of dripshields on other aircraft of similar type revealed cracking and splitting of the upper plenum surface and around fasteners in the dripshield gutter.

Subsequent inspections found that a drain line ribbon heater around a drain line to the forward grey water drain mast was inoperative, and that a length of drain line at that location was split (Figure 19). The heater and hose were removed for examination and testing. The drain line heater element was found to be broken at two locations and was inoperable. The examination could not determine the cause of the damage. Tape that had been wrapped around the heater element showed marks consistent with excessive heat damage, although the investigation could not determine whether those marks were collocated with the heater element damage.

Figure 18: Dripshield gutter underside stains, near centre

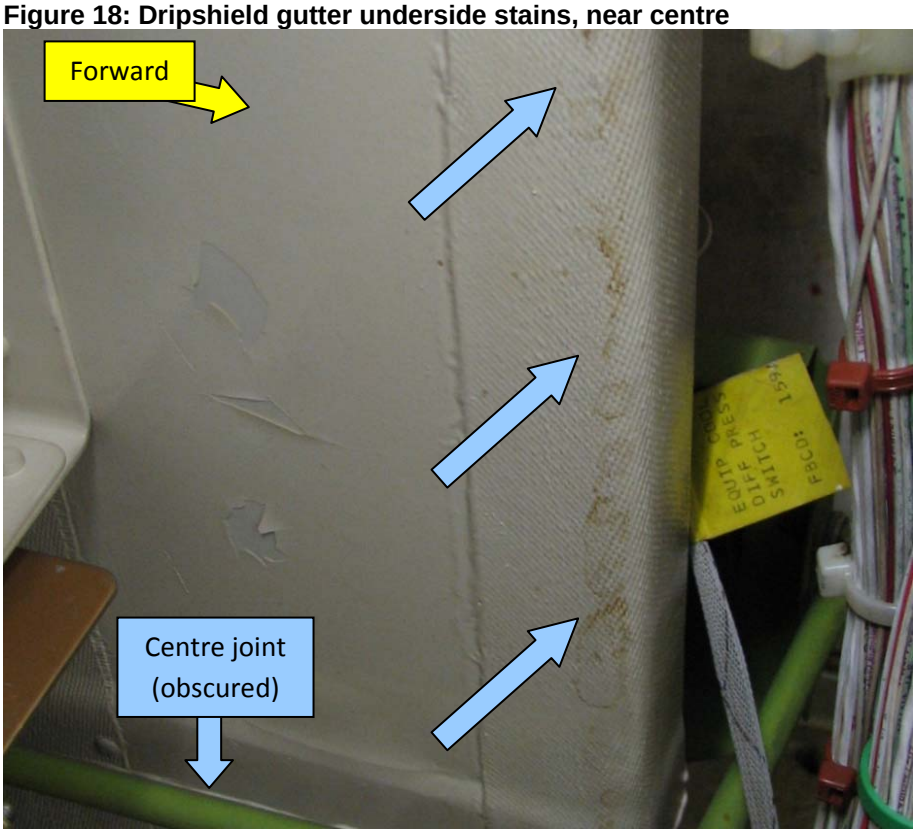
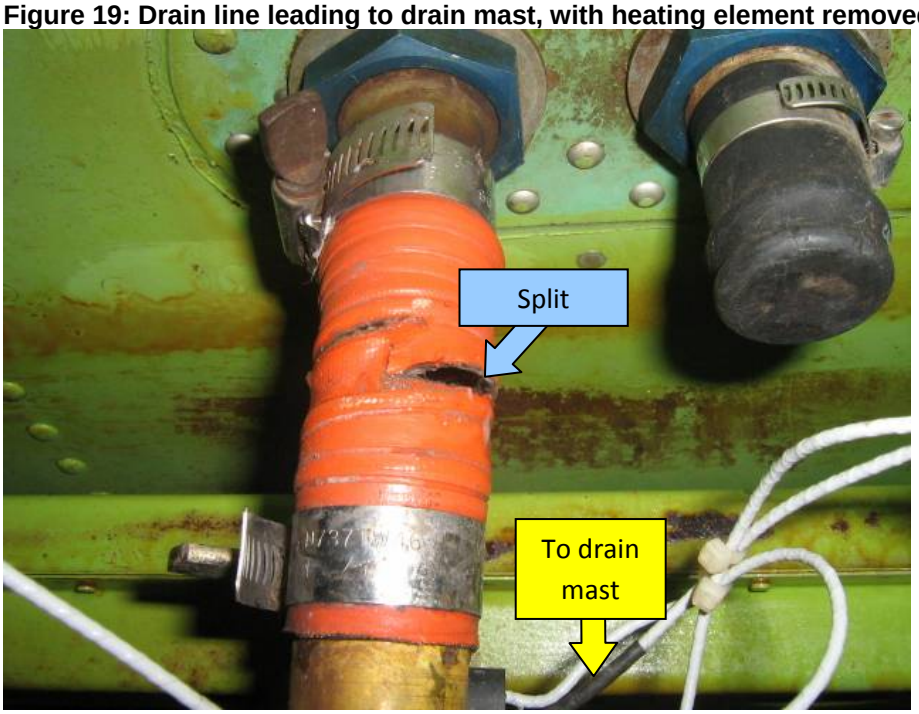


Figure 19: Drain line leading to drain mast, with heating element removed



1.9 Subsequent aircraft inspection

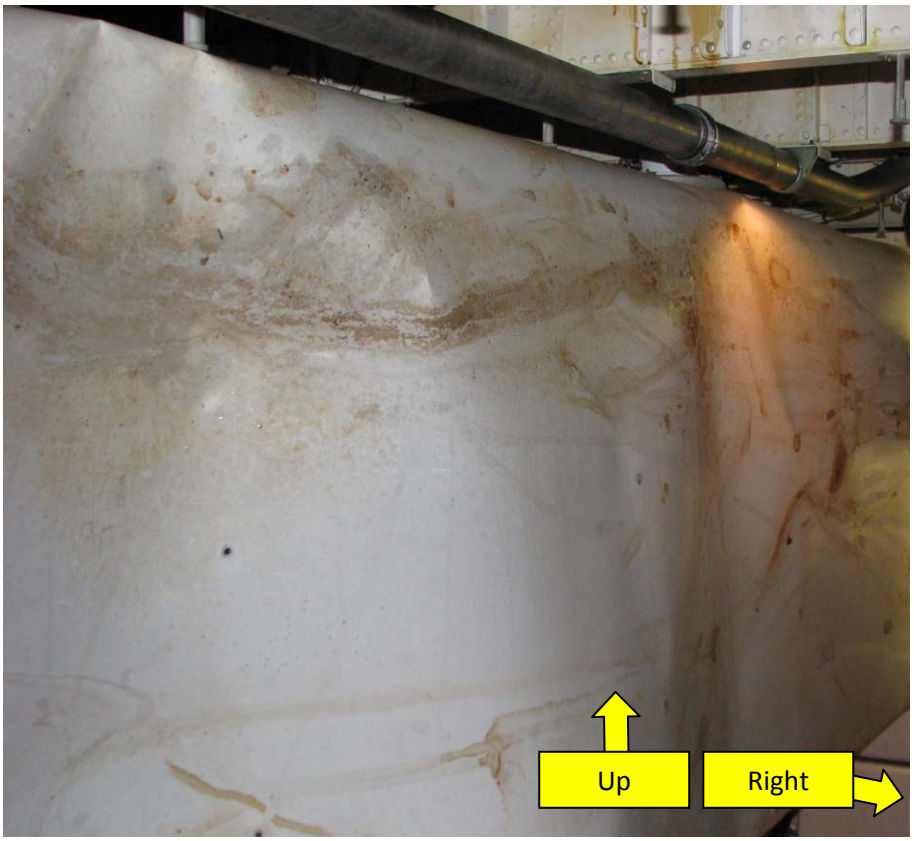
On 9 and 10 March 2008, the aircraft underwent scheduled maintenance, during which the forward galley carpets, flooring, and bulkhead were removed. During this

activity, ATSB investigators inspected the aircraft's forward galley area, MEC, and cargo areas.

1.9.1 Water accumulation

Water accumulation had occurred around the forward galley area prior to the maintenance activity. The carpets immediately aft of the forward galley on both sides of the cabin were saturated. Inspection of the under floor area around the galley revealed several litres of water that had collected in the ceiling lining of the forward cargo bay. That lining had extensive brown liquid staining on its upper surface (Figure 20), although it was not determined whether that staining was due to fluids spilt during maintenance or during the operation of the aircraft. There was no evidence of water spillage from the lining onto the electrical panels at the forward end of the cargo bay, or into the MEC.

Figure 20: Forward cargo lining upper surface

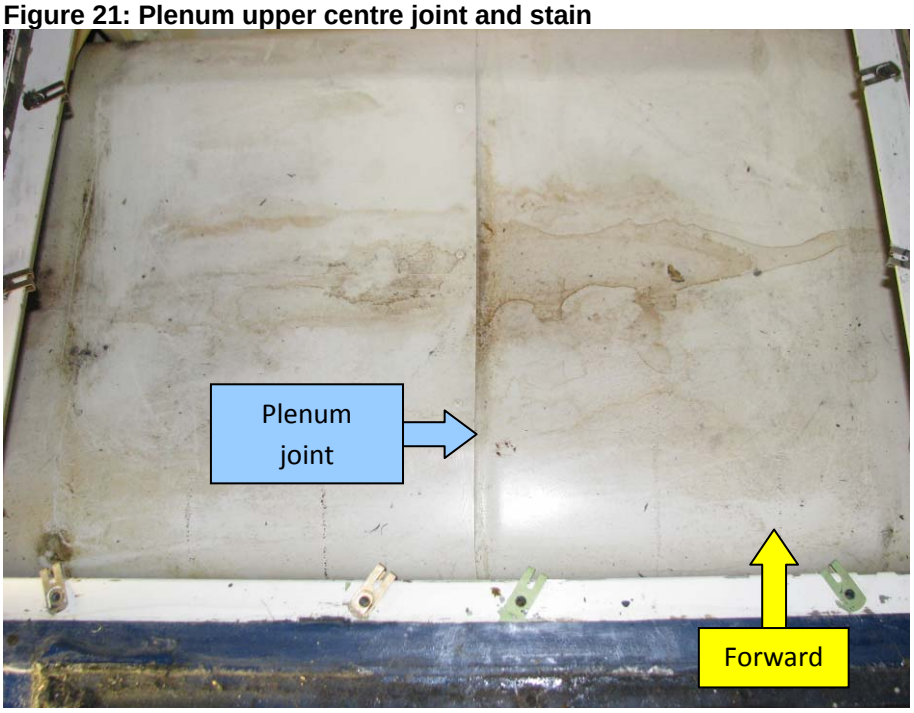


1.9.2 Dripshield

The upper centre joint of the plenum over the E1/E2 equipment racks was sealed at the time of the inspection and appeared watertight (Figure 21). The top of the plenum had brown staining consistent with liquid pooling at the edge of the centre joint. The right joint was slightly split. Internal inspection of the plenum using a borescope showed some dry dust accumulation around the vent holes and did not reveal any liquid staining inside the plenum.

The side of the aircraft structure showed the same evidence of condensation and water flow as seen during the inspections on 8 January (section 1.8), with a clear area on the structure under the right side of the galley bulkhead.

Figure 21: Plenum upper centre joint and stain



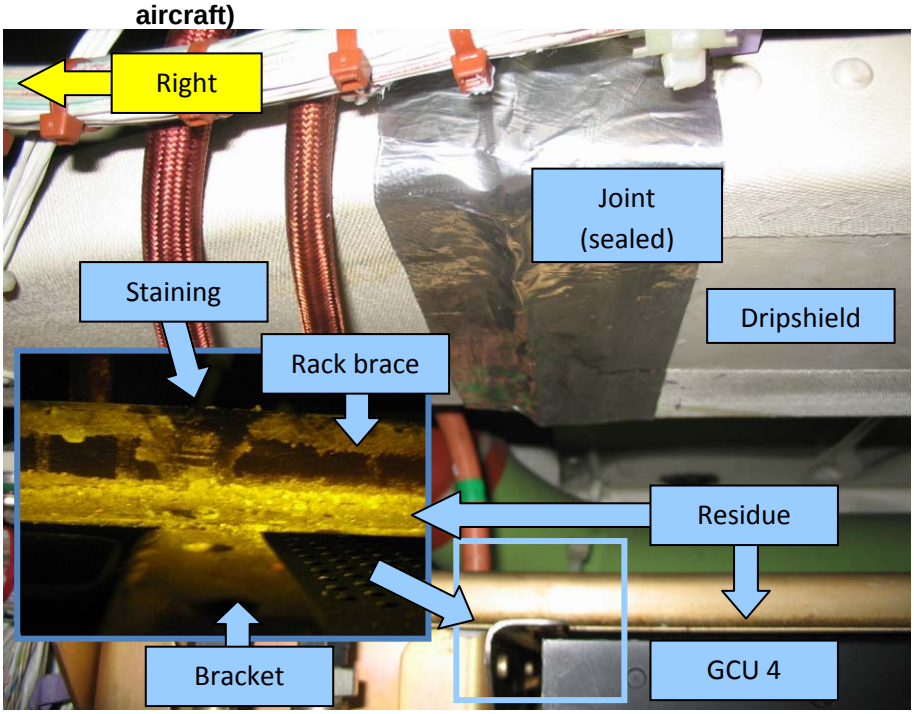
The dripshield gutter joints and some of the fasteners had been sealed at the time of inspection (Figure 22). Testing of a section of dripshield gutter resulted in a very slow leak (less than one drop every 15 minutes) through the unsealed dripshield fasteners, and a fast leak (several millilitres per second) through one of the unsealed dripshield gutter joints. However, the investigation was unable to test the gutter joint in the state that existed at the time of the occurrence.

Figure 22: Dripshield fastener detail, sealant removed

Forensic light inspection of the E1/E2 equipment rack showed staining beneath the right side dripshield joint consistent with liquid flowing from the joint onto the rack brace (Figure 23). The rack brace under the left side dripshield joint did not show any evidence of liquid staining.

The rack brace also showed significant residue on both sides of the E1/E2 equipment rack brace consistent with liquid contact and evaporation. The residue was most concentrated nearest the edges of the rack under the dripshield gutter joint and extended inward to about the area of each BCU. The presence of residue was also evident in photographs of the rack that were taken on 8 and 10 January.

Figure 23: Dripshield joint and drip marks (looking towards the rear of the aircraft)



Tests and inspection of the drainage lines at each end of the dripshield indicated that there was no blockage restricting the flow of liquid through those lines.

1.9.3 Galley sinks and drains

Inspection of the galley drains showed remnants of solid waste in the forward and mid galley sinks. The mid galley sink drain was completely blocked (Figure24).

A damaged drain line beneath the forward galley sink did not leak when tested in place (Figure 25). A metal drain line 'Y' connector in the forward galley was removed and found to be partially blocked by solid waste (Figure 25).

Maintenance personnel found that a drain strainer behind the coffee maker was blocked. The coffee maker and water boiler compartments did not drain as a result.

The ice tray drain line in one of the forward galley cart bays was crushed, consistent with contact by the rear of a service cart (Figure 26).

Figure 24: Galley sinks and solid waste

Figure 25: Forward galley sink drain lines

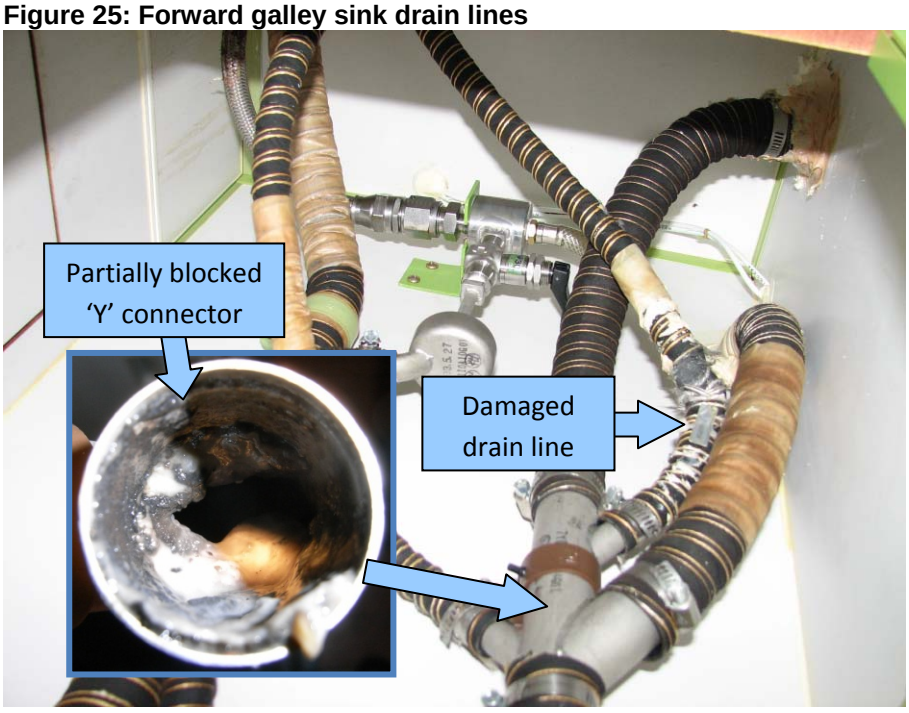
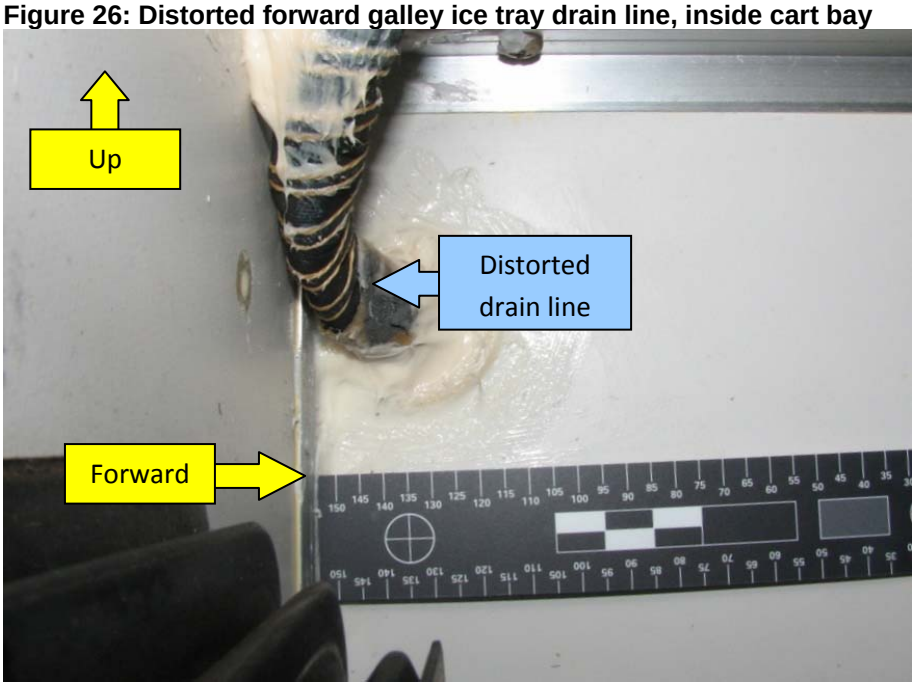


Figure 26: Distorted forward galley ice tray drain line, inside cart bay

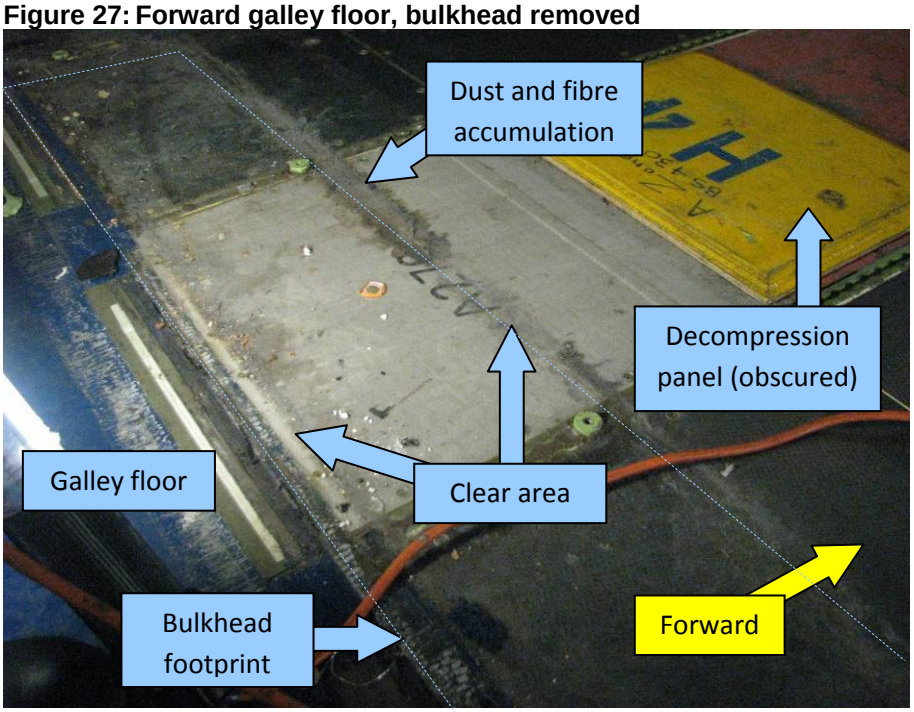


1.9.4 Galley floor

The lower edge of the forward galley bulkhead was not sealed. Inspection of the galley floor after removal of the bulkhead showed a large amount of loose dust and fibre accumulation around the edges of the bulkhead (Figure 27). A decompression panel was installed forward of the bulkhead. An area between the galley floor and that panel was clear of the dust and fibre accumulation, consistent with water flow through that area. The decompression panel door and the area around the panel exhibited liquid stain marks.

The galley floor sealing had partially deteriorated in some areas at the rear of the galley. Corrosion was identified on the floor beams and seat racks behind the galley.

Figure 27: Forward galley floor, bulkhead removed



1.10 Other aircraft inspections

1.10.1 VH-OJK inspections

Scheduled maintenance on another of the operator's 747-438 aircraft, registered VH-OJK (OJK), was observed by the investigation team on 11 January and 6 February 2008. As part of the 6 February activity, carpets and flooring in the forward galley area were removed, as was the forward galley bulkhead.

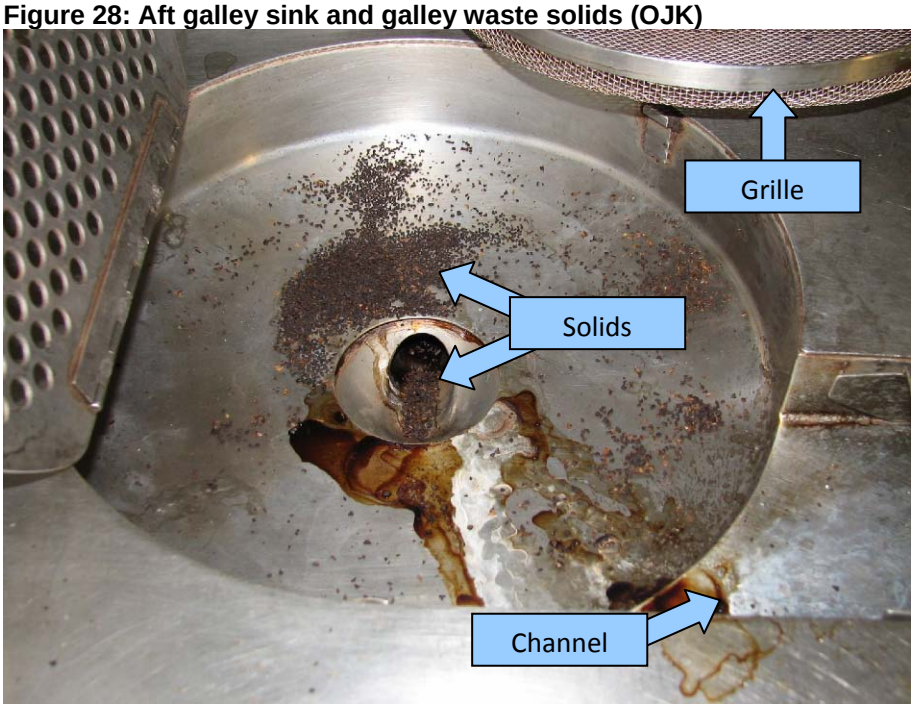
During the 6 February inspection, a water leak occurred in the mid galley as a result of maintenance activity. Water from that leak did not appear to drain into the cart bay drains, and instead rapidly pooled around the mid galley area. Within several minutes, the water had pooled in an area of about two square metres, including the entire galley cart bay.

Inspections of the galley sinks revealed solid waste, which appeared to be coffee grounds, in one of the sinks in the aft galley (Figure 28).

The mid galley bench incorporated a drainage channel leading to a sink. A sink filter grille was in place when inspected, but waste entering the sink from the channel would not be filtered because it would enter the sink underneath the grille.

Examination of the galley floor revealed liquid staining on the floor panels, including the decompression panel (Figure 29).

Figure 28: Aft galley sink and galley waste solids (OJK)



The upper plenum joints on OJK were split and did not appear watertight (Figure 30). There was also a longitudinal crack in the central section of the plenum where a repair had been performed. Damage and distortion in that section of the plenum was consistent with excessive weight being placed on the plenum from above.

The substance used to seal the joints was of a different appearance to that on OJM. An application of light pressure on one side of the left plenum joint indicated that the seal had split.

Although not noted during the inspection on 6 February, a later examination of photographs that were taken at that time showed extensive brown staining on the upper lining in the forward cargo bay of OJK.

Figure 29: Decompression panel (OJK)

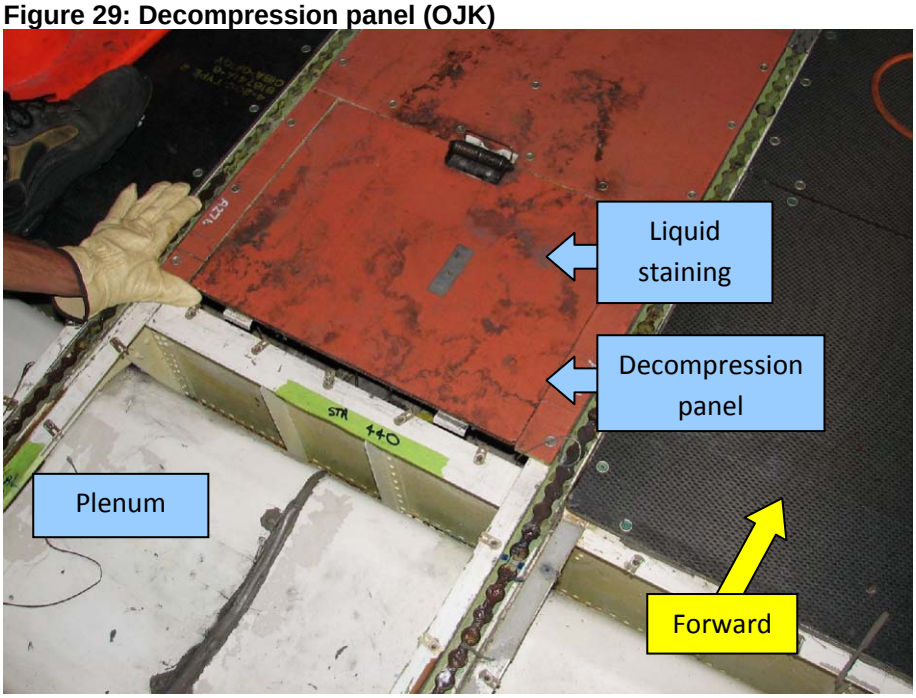
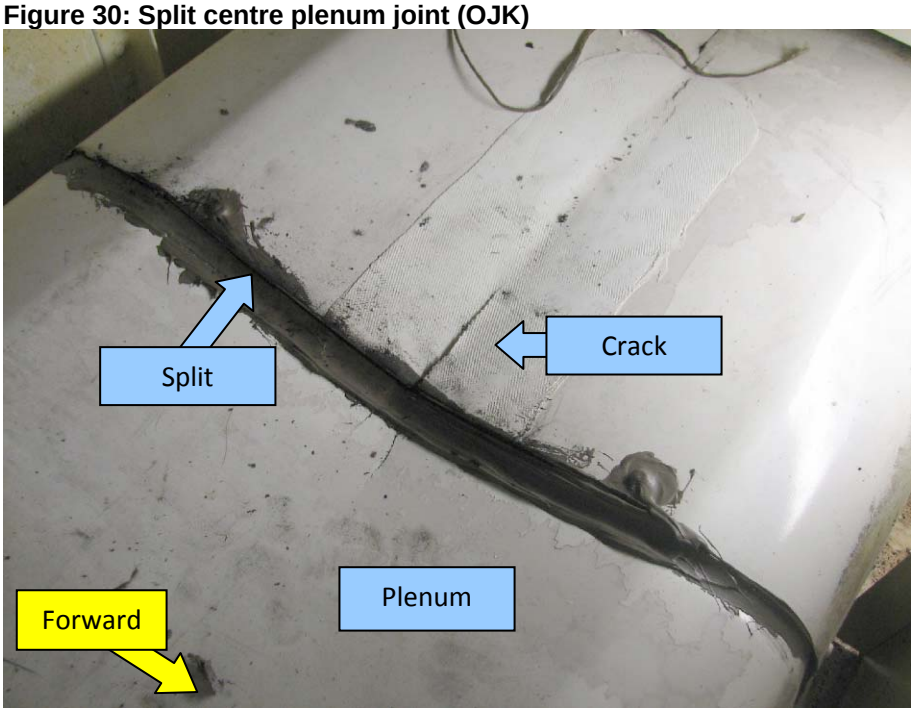


Figure 30: Split centre plenum joint (OJK)

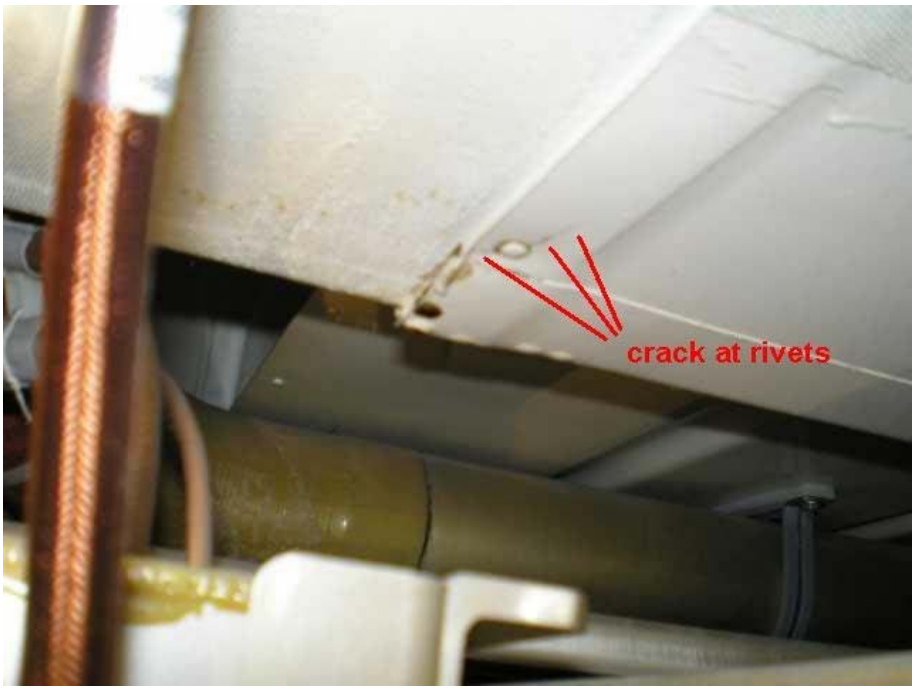


1.10.2 Reports of 747-400 dripshield damage

The aircraft manufacturer has received a number of reports of damaged dripshields in other 747-400 aircraft (examples shown in Figure 31 and Figure 32). At the time of the drafting of this report, the aircraft manufacturer had received 69 reports, 52 of which indicated damage to the dripshield or gutter.

Figure 31: Plenum (unknown 747-400 aircraft)

Figure 32: Dripshield gutter joint (unknown 747-400 aircraft)



1.11 Aircraft design requirements

1.11.1 Aircraft manufacturer

As part of its aircraft development and through-life maintenance program, the aircraft manufacturer used generic design requirements and objectives (DR&O), from which specific design requirements and operational practices for each of its large transport category aircraft were derived. The DR&Os were derived from United States (US) Federal Aviation Regulations (FAR)[28] where applicable. The aircraft manufacturer reported that the DR&Os were constantly updated and revised as part of a 'lessons learned' feedback system.

The aircraft manufacturer's DR&Os included requirements to protect equipment, including electrical equipment, from performance degradation as a result of undesired liquids as follows:

> Equipment whose performance could be degraded by undesired liquids shall be located where the exposure to such liquids is minimized, shall be shielded from such liquids, or shall be protected by a suitable surface finish. Undesired liquids shall be expeditiously drained from critical areas. The equipment and compartment design shall minimize the formation of harmful condensation.
>
> Electrical equipment, components, terminals, connectors, etc. shall be protected from liquids. Special provisions shall be installed to protect electrical and mechanical components located under floor panels or in the vicinity of galleys, lavatories or doors. If any fluid is collected as a result of this protection, it shall be automatically drained each flight. Electrical connector mounting orientation shall minimize fluid penetration.

1.11.2 Aircraft operator

The aircraft operator provided an engineering design guide as a reference for the development and approval of repairs and modifications for its aircraft. The aim of the document was to provide guidelines to ensure effective, consistent and compliant designs.

The design guide did not explicitly require consideration of potential damage (other than structural corrosion) resulting from liquid contact or ingress. When an aircraft modification or change in operation or maintenance practices was proposed, the operator evaluated it through its internal review processes and then requested advice from the aircraft manufacturer. The aircraft manufacturer then assessed the change in accordance with its own processes, taking the operator's specific design and operational requirements into account. The operator could then choose to implement, vary, or cancel the change. Where such changes were covered by regulations they also required approval by the relevant regulatory body, which in Australia is the Civil Aviation Safety Authority (CASA).

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[28] Refer section 1.13.3 and Appendix A.

1.12 Operator crew training and procedures

The operator provided the flight crew with a number of manuals to assist with the operation of the aircraft, including a:

- Quick reference handbook (QRH). One volume of the QRH contained a subset of important information for easy and quick reference, such as during emergencies. The QRH was the primary reference for flight crews when abnormal conditions developed.
- Flight crew operating manual (FCOM). Of two volumes, the FCOM contained aircraft-specific information, including normal and supplementary operating procedures, descriptions of all airplane systems, related controls and indicators, and selected performance data. The FCOM was the secondary reference for flight crews regarding most normal and non-normal flight conditions.
- Flight administration manual (FAM). The single volume FAM contained non-aircraft specific policy, standards and procedures. The FAM was available for in flight reference.
- Flight crew training manual (FCTM).The FCTM was a single volume, aircraft-specific study and reference guide containing general operating method and philosophy, training manoeuvres, and information about flight path control.

At least one printed copy of each of those manuals was always available in the cockpit.

Quick reference handbook

In addition to the crew responses in the case of a number of non-normal events, the QRH included the actions in the event of a single electrical bus malfunction. There were no actions or advice in the event of concurrent, multiple bus malfunctions.

Most of the non-normal checklists corresponded with an EICAS alert message. Chapter 6 of the non-normal checklists identified electrical system issues and the appropriate actions in response. The EICAS messages ‘BATT DISCH MAIN’ and ‘BATT DISCH APU’ were listed in the QRH but did not include any associated instructions or advice. The QRH stated that, if AC bus 1 or 4 was unpowered, the crew should avoid icing conditions and advised that autothrottle, certain navigation modes and, depending on the engine type, either the engine speed or exhaust pressure ratio, would be unavailable.

Flight crew operating manual

The FCOM contained technical information about the electrical system, including the time available on standby power and some of the systems available. There was no guidance in regard to operations on standby power.

The FCOM also included the following advice:

> With the main battery charger unpowered, the main battery can provide power to the main standby bus for a minimum of 30 minutes.
>
> The main standby bus powers individual equipment such as:
>
> • left EIU[29], left CDU[30], left ILS[31], left VOR[32]
>
> • various flight control components
>
> • standby ignition for all engines
>
> • primary EICAS display, standby instrument lights
>
> • left ADC[33], left transponder, left EFIS control panel
>
> …
>
> With the APU battery charger unpowered, the APU battery can provide power to the APU standby bus for a minimum of 30 minutes.
>
> The APU standby bus powers individual equipment such as:
>
> • left FMC[34]
>
> • left ND
>
> • left PFD

and that:

> It is rare to encounter in-flight events which are beyond the scope of the [aircraft manufacturer's] recommended NNCs.[35] These events can arise as a result of unusual occurrences such as a midair collision, bomb explosion or other major malfunction. In these situations the Flight Crew may be required to accomplish multiple NNCs, selected elements of several different NNCs applied as necessary to fit the situation, or be faced with little or no specific guidance except their own judgement and experience. Because of the highly infrequent nature of these occurrences, it is not practical or possible to create definitive Flight Crew NNCs to cover all events.

---

29 EFIS/EICAS interface unit.

30 Control display unit.

31 Instrument landing system.

32 Very high frequency omnidirectional range (navigation system).

33 Air data computer.

34 Flight management computer.

35 Non-normal checklist.

Flight administration manual

The FAM included the following definitions:

> **Emergency:** An emergency is an unpredicted event that may endanger the safety of an aircraft or its passengers and crew.
>
> **Non-Normal/Abnormal:** A non-normal/abnormal event is an unpredicted event that affects the normal operating procedures of the crew or the welfare of the passengers.

In addition, the FAM included the following section regarding emergency and non-normal or abnormal events:

> **22.3 Notification**
>
> **22.3.1 Emergency**
>
> An emergency, as defined above, will be declared and communicated to Air Traffic Control (ATC) or relevant authority as soon as time permits. An emergency should be notified as follows:
>
> **22.3.1.1 Distress**
>
> A condition of being threatened by serious and/or imminent danger and requiring immediate assistance. The distress signal is MAYDAY spoken three times on the air/ground frequency or sent via an Automatic Dependent Surveillance (ADS) Emergency Report. The report should consist of as many of the following elements as possible:
>
> - the name of the station addressed;
> - identification of the aircraft;
> - nature of the distress condition;
> - intention of the Pilot In Command;
> - present position, level and heading.
>
> **22.3.1.2 Urgency**
>
> A condition concerning the safety of an aircraft or other vehicle, or some person on board or within sight, but which does not require immediate assistance. The urgency signal is PAN PAN spoken three times on the air/ground frequency or sent via ATC Datalink Emergency Report. The report should consist of the following elements:
>
> - the name of the station addressed;
> - identification of the aircraft;
> - nature of the urgency condition;
> - intention of the Pilot In Command;
> - present position, level and heading.
>
> Comply with the above notifications if any distress/urgency situation develops or is likely to develop.
>
> …

22.3.3 Non-Normal/Abnormal

A non-normal/abnormal event, as defined above, will be identified as an equipment malfunction or operating situation/difficulty, and notification made to ATC if required, as well as to Company frequency when time permits.

The FAM also provided instructions to flight crew to ensure the consistent application of crew resource management (CRM), which was described in the FAM as '...the effective utilisation and management of all available resources, including information, equipment and people, to achieve safe and efficient flight operations.' The CRM principles and tools included the item 'clear communication', which was defined as the:

- clear, timely and concise communication of intent to other crew members, ground staff and external agencies
- resolution of confusion
- appropriate raising of concern.

Flight crew training manual (FCTM)

The FCTM included the following section:

Approach and Landing on Standby Power

The probability of a total and unrecoverable AC power failure is remote. Because of system design, a NNC for accomplishing an approach and landing on standby power is not required. However, some regulatory agencies require pilots to train to this condition. During training, or in the unlikely event that a landing must be made on standby power, the following guidelines should be considered.

Complete all applicable NNCs and approach preparations. The left navigation radio, CDU, and communications radio are operable on standby power. On some aircraft, the Captain's and/or First Officer's electronic flight instruments are also available.

Note: Refer to Flight Crew Operations Manual (FCOM) Volume 2, Chapter 6, for a list of significant equipment powered by standby power.

The EICAS displays numerous alert messages associated with the loss of all AC power. During the approach, the FLAPS DRIVE message displays after the flaps are selected to 1. The leading edge devices require AC control and cannot be extended on standby power. Use the FLAPS DRIVE NNC to determine the adjusted VREF and landing flap setting.

The control wheel trim switches are inoperative; however, the alternate trim switches on the aisle stand are operable. The right inboard and outboard trailing edge flaps indication is available, but trailing edge flap indication on the left side is not.

Fly the approach on speed. Anti-skid is not available, and with the higher approach speed, any excess speed is undesirable. Auto speedbrakes and thrust reversers are not available.

Flight crew training

The operator's 747-400 flight crew training syllabus did not include the management of multiple electrical bus loss or operations on standby power. Flight crew were trained in handling a single bus loss.

Cabin crew operations manual

The operator's cabin crew operations manual included the following caution in the instructions for the use of coffee plungers:

> CAUTION: DO NOT pour coffee down galley drains, as this will cause blockages. Liquid containing coffee grains is to be disposed of in the galley waste bin. Only clear liquids can be poured down the galley sink.

The manual also included the following instruction in the use of tinned coffee:

> Empty any coffee residue into the galley waste bin. Do not empty into the sink, as coffee grinds will block the drain.

1.13 Emergency response to loss of aircraft electrical power

A complete loss of electrical power is a serious event in an air transport aircraft and has the potential to significantly compromise flight safety.

Many of the primary aircraft systems and flight instruments normally used by a fight crew to control and navigate the aircraft are dependent on electrical power. If power is lost to the primary flight instruments, then the crew must rely on a reduced set of standby instruments (see section 1.4.2). In such a situation, there is an increased possibility that the crew may become spatially disoriented, potentially leading to difficulties in controlling the aircraft.

1.13.1 Spatial disorientation

Spatial disorientation refers to a situation in flight in which the pilot fails to correctly sense the position, motion or attitude of the aircraft and has been described as follows: [36]

> Spatial disorientation to a pilot means simply the inability to tell which way is 'up'.

Spatial disorientation accidents and incidents are often associated with non-instrument rated pilots, and/or with flight at night or in instrument meteorological conditions (IMC). However, multi-crew instrument rated pilots are not immune to spatial disorientation, and such events do occur during the day and in visual meteorological conditions.[37]

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[36] *Pilot's spatial disorientation*. FAA Advisory Circular AC 60-4A, 1983. FAA: Washington, DC.

[37] Previc, F.H. and Ercoline, W.R. (2004). *Spatial disorientation in aviation*. American Institute of Aeronautics and Astronautics: Reston, VA.

Examples of accidents and incidents in which possible spatial disorientation affected flight crews of commercial aircraft include:

- On 7 June 2007, the crew of a Boeing Company 737-500 departing in daylight from London Heathrow Airport lost most of the information displayed on the aircraft's primary flight display. The crew subsequently had difficulties in maintaining control of the aircraft using the standby instruments.
- On 1 January 2007, a Boeing Company 737-4Q8 crashed into the sea off Sulawesi, Indonesia, after the crew lost control of the aircraft in daylight and marginal visual meteorological conditions after becoming distracted by a technical problem.
- On 3 May 2006, an Airbus A320-211 crashed near Sochi, Russia when the captain became disoriented and made nose-down control inputs while performing a go-around at night with the autopilot disengaged.

1.13.2 Distress and urgency radio calls

Civil aviation is a complex system that relies on effective communication and coordination between the different elements of the system to ensure safety. This includes the timely and appropriate exchange of information between pilots and air traffic control.

It is preferable for pilots facing an emergency situation to alert air traffic control as soon as practical. This ensures that the aircraft can be given priority consideration, and other proactive measures taken, such as alerting emergency services if appropriate.

The International Civil Aviation Organization (ICAO) promulgates international standards and recommended practices as annexes to the 1944 Chicago Convention on International Civil Aviation that affect the conduct of civil aviation activities in signatory countries.

ICAO Annex 10 sets the procedures for the international aeronautical telecommunication service. The following definitions and requirements were set under Section 5.3, *Distress and urgency radiotelephony communication procedures*:

> 5.3.1.1 Distress and urgency traffic shall comprise all radiotelephony messages relative to the distress and urgency conditions respectively. Distress and urgency conditions are defined as:
>
> a) *Distress*: a condition of being threatened by serious and/or imminent danger and of requiring immediate assistance.
>
> b) *Urgency*: a condition concerning the safety of an aircraft or other vehicle, or of some person on board or within sight, but which does not require immediate assistance.
>
> 5.3.1.2 The radiotelephony distress signal MAYDAY and the radiotelephony urgency signal PAN PAN shall be used at the commencement of the first distress and urgency communication respectively.

The types of air transport occurrences reported to the ATSB in which the crew have declared a PAN PAN include:

- fumes in the cockpit
- aircraft low on fuel
- aircraft configuration and flight control problems
- uncommanded yaw during cruise flight
- in-flight engine shutdown
- incapacitation of a crew member of a multi-crew aircraft.

An emergency situation in which an air transport aircraft had lost all primary electrical power and was operating on battery power only would normally result in either a PAN PAN or MAYDAY call, depending on the circumstances.

1.13.3 US Federal Aviation Administration safety alert

Following an event on 22 September 2008 in which a Boeing Company 757-223 aircraft overran a runway following a near-complete loss of electrical systems,[38] the US Federal Aviation Administration (FAA) released safety alert for operators 09001, which advised:

> Aircraft Flight Manual (AFM) procedures used by operators generally identify only the time-limited main battery life during conditions described above and usually do not prompt the crew to consider any further action or consequences. Although some operators provide a list of inoperative equipment, few operators give a complete list of the critical systems or components rendered inoperative by complete loss of battery power. In most transport category airplanes, systems such as those for fire protection and detection, flight control, navigation and flight instruments, engine fuel control, braking, auto-flight functions, standby horizon, and others are either fully or partially inoperative with no main battery power. If flight crews do not have appropriate understanding of the effects of lost battery power on critical airplane systems powered by the battery, they may be faced with a rapidly compounding emergency situation.

The FAA recommended that:

> Directors of Safety, Directors of Training, Directors of Operations, trainers and check airmen for operators of transport category aircraft should review Additional, Irregular, Non-Normal and Emergency procedures regarding electrical difficulties for conformance with manufacturer's recommended procedures. Review QRH or other procedural guidance to ensure that the procedures lead to problem resolution rather than complication. In addition, operators should reemphasize or develop procedures that supplement any QRH electrical loss procedure to include consideration of diversion, planning landings on the longest available runway, and preparations for equipment loss. Operators should ensure that their AFM and training reflect accurate abnormal indications and inoperative systems associated with depletion of the main battery.

[38] Refer Appendix B for additional details of this event.

1.14 Airworthiness regulations and guidance

1.14.1 Background

The aircraft was issued a type certificate by the FAA in 1989 that was accepted by CASA under section 21.029A of the Civil Aviation Safety Regulations (CASR). The basis for the FAA type certificate, and of CASA's continuing acceptance of it, was the aircraft's compliance with FAR section (§) 25, which prescribes the airworthiness standards for transport category aircraft in the US.

The FARs addressed electrical system units and the wiring between those units separately, under FAR §25.1309 and §25 subpart H respectively.

Extracts from the FAR are provided in Appendix A.

1.14.2 Regulations and guidance applicable to environmental protection of electrical system units

Under the FAR, the aircraft's GCUs and BCUs are classified as electrical system units. FAR §25.1309, effective from 1 September 1977, require such units to be protected from environmental conditions as follows:

> § 25.1309 Equipment, systems, and installations.
>
> (a) The equipment, systems, and installations whose functioning is required by this subchapter, must be designed to ensure that they perform their intended functions under any foreseeable operating condition.
>
> …
>
> (e) In showing compliance with paragraphs (a) and (b) of this section with regard to the electrical system and equipment design and installation, critical environmental conditions must be considered.

Advisory Circulars are published by the FAA to provide guidance describing acceptable methods of compliance with the FARs. Advisory Circular 25.1309-1A included the following advice on identifying single or common-cause failures that could prevent continued safe flight and landing:

> (3) Some examples of such potential common-cause failures or other events would include rapid release of energy from concentrated sources such as uncontained failures of rotating parts or pressure vessels, pressure differentials, noncatastrophic structural failures, loss of environmental conditioning, disconnection of more than one subsystem or component by overtemperature protection devices, contamination by fluids, damage from localized fires, loss of power, excessive voltage, physical or environmental interactions among parts, use of incorrect, faulty, or bogus parts, human or machine errors, and foreseeable adverse operational conditions, environmental conditions, or events external to the system or to the airplane.

1.14.3 Regulations and guidance applicable to the environmental protection of electrical wiring interconnection systems

In 2007, FAR §25 subpart H introduced separate requirements for equipment that was classified as part of an aircraft's electrical wiring interconnection systems

(EWIS), which comprises the wiring and connectors used between electrical system units.[39] This section was applicable to new aircraft that were approved after 10 December 2007, so did not apply to OJM.

Electrical wiring interconnection system components are specifically required to be protected from water/waste system liquid ingress under §25.1707 of the FAR:

> § 25.1707 System separation: EWIS.
>
> (h) Except to the extent necessary to provide electrical connection to the water/waste systems components, EWIS must be designed and installed with adequate physical separation from water/waste lines and other water/waste system components, so that:
>
> (1) An EWIS component failure will not create a hazardous condition.
>
> (2) Any water/waste leakage onto EWIS components will not create a hazardous condition.

FAA guidance regarding the protection of EWIS is contained in Advisory Circular 25-27, titled *Development of Transport Category Airplane Electrical Wiring Interconnection Systems Instructions for Continued Airworthiness Using an Enhanced Zonal Analysis Procedure*, which includes the following:

> Maintenance material should address the following installations and areas.
>
> …
>
> • Under galleys, lavatories, and cockpit—Areas under the galleys, lavatories, and cockpit are particularly susceptible to contamination from such things as coffee, food, water, soft drinks, lavatory fluids, dust, and lint. Proper floor panel sealing procedures can minimize such contamination in these areas.
>
> • Fluid drain plumbing—Leaks from fluid drain plumbing may lead to liquid contamination of wiring. Service experience may show a need for periodic leak checks or cleaning, in addition to routine visual inspections.
>
> • Fuselage drain provisions—Some installations include plumbing features designed to catch leakage and drain it to an appropriate exit. Blockage of the drain path can result in liquid contamination of wiring. In addition to routine visual inspections, service experience may signal a need to check these installations and associated plumbing periodically to ensure the drain path is free of obstructions.

[39] Refer Appendix A, section 5.2 for the full definition of EWIS.

1.14.4 Regulations applicable to flight crew alerting systems

On 9 July 2009 the FAA published a notice of proposed rulemaking (NPRM) advising of a proposal to amend and expand the US airworthiness standards for flight crew alerting in transport category aircraft. That amendment would affect any such aircraft that were certified after the amendments were in force. The proposed amendments included the following additional requirements:

> FAR § 25.1322 (proposed)
>
> (a) Flightcrew alerts must:
>
> (1) For warning and caution alerts, provide timely attention-getting cues through at least two different senses by a combination of aural, visual, or tactile indications.
>
> (2) Provide the flightcrew with the information needed to identify the alert and determine the correct action, if any.
>
> (3) Be readily and easily detectable and intelligible by the flightcrew under all foreseeable operating conditions, including conditions where multiple alerts are provided.
>
> …
>
> (c) Alert presentation means must be designed to minimize nuisance effects. In particular a flightcrew alerting system must:
>
> (1) Permit each occurrence of attention-getting cues to be acknowledged and suppressed unless they are otherwise required to be continuous.
>
> (2) Prevent the presentation of an alert that is inappropriate or unnecessary.
>
> (3) Remove the presentation of the alert when the condition no longer exists.
>
> (4) Provide a means to suppress an attention-getting component of an alert caused by a failure of the alerting system that interferes with the flightcrew's ability to safely operate the airplane. This means must not be readily available to the flight crew such that it could be operated inadvertently, or by habitual reflexive action. In this case, there must be a clear and unmistakable annunciation to the flight crew that the alert has been suppressed.

On 30 November 2009 the European Aviation Safety Agency published a notice of proposed amendment, advising of a proposal to amend and expand the European Union certification specifications (CS) on the same subject as the FAA NPRM. The proposed amendments were similar to the US amendments but with the following additional requirement:

> CS 25.1322 (proposed)
>
> (c) Warning and Caution alerts must:
>
> 1) be prioritised within each category, when multiple alerts would cause flight crew confusion, or the sequencing of flight crew response is necessary

1.15 Related incidents

The investigation identified a number of other serious incidents between 1995 and 2008 that resulted from water ingress problems during flight. Information on these incidents, as well as other reports involving liquid management issues is at Appendix B.

2 ANALYSIS

2.1 Overview

2.1.1 Effect of electrical systems failures

The aircraft's four engines, hydraulic systems, and pneumatic systems were largely unaffected by the electrical failures due to their independent design, so there was no serious impediment to the aircraft's flight characteristics as a result of the electrical systems failures.

However, many of the aircraft's communication, navigation, monitoring and warning, and flight guidance systems were affected. As a result, once those systems became inoperable or degraded, the flight crew's workload increased considerably for the remainder of the flight with a likely associated reduction in situational awareness.

Had the event occurred more than 30 minutes flying time from the nearest suitable airport, or if there had been a delay prior to landing, numerous flight-critical systems would have subsequently become unavailable. Those systems included:

- communications systems, including radios, interphones, passenger address system, and transponders
- primary flight displays and standby attitude indicator
- warning and caution systems, including ground proximity, traffic and fire warnings
- instrument illumination
- navigation systems
- engine instrumentation.

The loss of these systems would have placed the aircraft at considerable risk, as the flight crew would have been flying by hand with only visual and tactile references, a standby airspeed indicator, a standby magnetic compass and a standby altimeter with degraded reliability to guide them. Communications would have been limited to the use of personal mobile telephones, if available. Additionally, the risk of spatial disorientation would have been particularly acute in instrument meteorological conditions (IMC).

2.1.2 Design, operation, and maintenance

A number of aircraft design and operational characteristics increased the risk that liquid spills or leaks could have resulted in water entering the main equipment centre (MEC) and causing disruption to equipment. Although those issues were relatively minor when considered individually, they had a serious effect on the safety of the flight when combined. The issues included:

- drain line design, operation and maintenance
- drain line heater maintenance

- water integrity sealing around the galleys
- the location of the galley relative to vulnerable equipment
- the location of the decompression panel
- the protection of vulnerable equipment zones such as the MEC
- the localised protection of equipment, particularly dripshield design and maintenance.

The investigation also examined the liquid drain and spill management practices of the aircraft manufacturer and operator. The available evidence did not strongly indicate any systemic issues within the aircraft manufacturer's processes. The operator did not include specific requirements for liquid management in its design guidance documentation, but the investigation considered that the inclusion of such requirements would not have necessarily prevented the incident.

2.1.3 Regulations

The investigation found that there was no detailed regulatory mechanism by which internal liquid hazards to electrical systems units could be considered or monitored throughout the design, operation and maintenance of the aircraft. The United States (US) Federal Aviation Regulations (FAR), and associated design advice provided by relevant Advisory Circulars, specifically addressed the protection of wiring between electrical systems units but not the units themselves. As a result, there was an increased risk of inadequate protection of electrical systems units.

2.1.4 Aircraft operation

Information provided to the flight crew

The fault messages that informed the crew of the battery discharge state were classified as advisory messages, the second lowest of four priority levels, and would have been displayed near the end of several pages of messages that were provided to the crew. In any case, an advisory message only required crew awareness, although it was an indication of the possible need for future crew action. These factors risked the omission of, or delay in the crew's response to, the discharging batteries.

The limited battery power available restricted the amount of time that the aircraft's remaining functional instrumentation and communication systems were available to the crew, which necessitated an expedited descent and landing in order to reduce the risk of those systems failing.

The flight crew manuals did not contain information on means to extend the limited battery life or on managing the aircraft if the batteries were depleted. They did not include information on what critical systems were lost with the loss of each respective bus, or whether some important systems such as wheel brakes and reverse thrust were available on battery power or after the batteries became depleted. As a result, the flight crew relied on their recollection of systems knowledge provided during training to assess and manage numerous failures with a limited amount of time available before the batteries would be depleted. The provision and use of a checklist would increase the consistency of crew actions in such emergencies.

Declaration of an emergency

It is understandable that the crew considered it desirable to land the aircraft as soon as possible. However, a declaration of urgency or emergency would have been appropriate for the situation and should not have substantially increased the flight crew's workload or delayed the landing. Indeed, in any emergency, there is the potential for the involvement of air traffic control (ATC) to result in a reduction in a flight crew's workload.

Although it did not occur in this instance, it is possible that the absence of communication between the crew and ATC regarding the emergency situation could have resulted in the aircraft not being handled by air traffic control as appropriately or expeditiously as possible. This had the potential to affect flight safety.

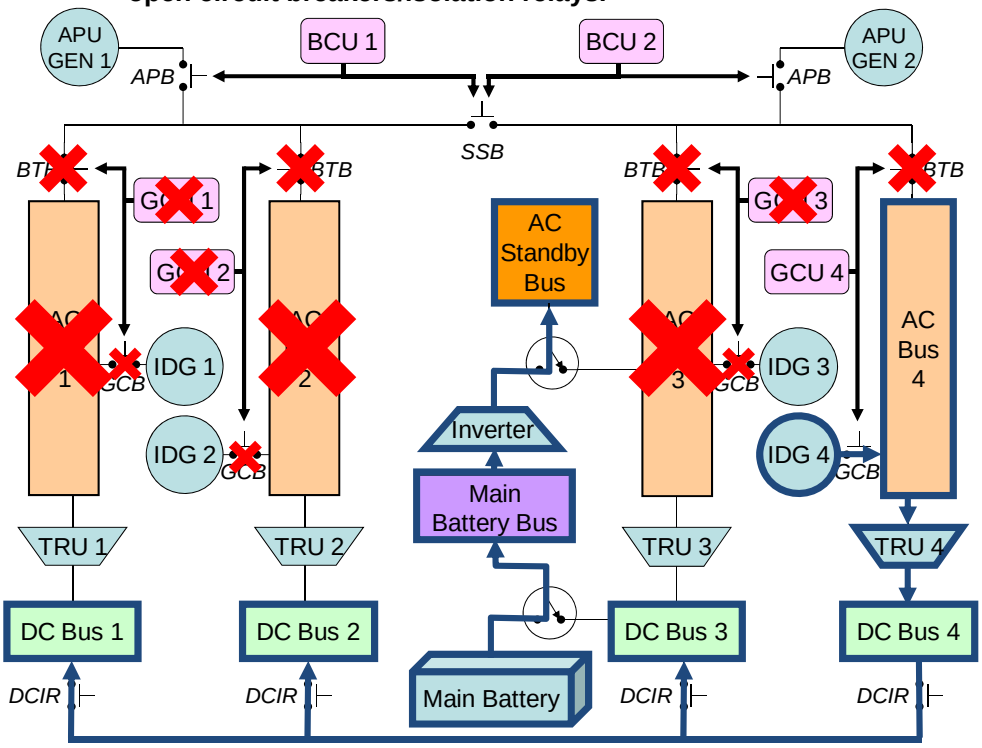
2.2 Electrical power loss

2.2.1 Overview

The aircraft's electrical alternating current (AC) buses and associated direct current (DC) buses were normally capable of supplying continual electrical power to the aircraft's electrical systems; including navigation, communication, and flight guidance systems.

Of the aircraft's four primary AC buses and four primary DC buses, only AC bus 4 and the four DC buses remained powered during the aircraft's final approach and landing (Figure 33). In addition, the aircraft's batteries provided power to the two battery buses and to the AC standby bus via the aircraft's static inverter.

Figure 33: Simplified overview of the aircraft's electrical system configuration at landing. Blue border: active systems; red: inactive systems and open circuit breakers/isolation relays.



2.2.2 Detailed analysis

Alternating current systems

The aircraft's generator control units (GCU) each controlled the generator control breakers (GCB) and bus tie breakers (BTB). Examination of recorded data from the GCUs indicated that GCUs 1, 2, and 3 automatically shut down as a result of internal faults. That automatic shutdown caused the associated GCBs and BTBs for the associated buses to open, resulting in the loss of AC power to each of the associated buses. That data was consistent with flight data recorder (FDR) information showing that the GCBs and BTBs for AC buses 1, 2, and 3 opened during various stages of the incident sequence, and with other indications showing various electrical systems shutting down or entering a degraded mode.

Electrical power could only be transferred from AC bus 4 to any of the other buses when the BTBs associated with both buses were closed. Since the BTBs for buses 1, 2, and 3 were open, the power remaining on AC bus 4 could not be transferred to any of the other buses.

In addition, the GCBs needed to be closed for each integrated drive generator (IDG) to provide power to its associated AC bus. Since the GCBs for AC buses 1, 2, and 3 were open during the event sequence, those buses could not be powered by their associated IDGs.

Direct current systems

The aircraft's DC bus 4 received power from AC bus 4 via the associated transformer rectifier unit (TRU). DC buses 1, 2, and 3 were powered by DC bus 4 via the four DC isolation relays.

During the event, the aircraft's systems that were capable of receiving power from the standby bus, battery buses, AC bus 4, or the DC buses were operable, although some systems operated in a degraded mode. All of the other aircraft systems powered through the AC buses were rendered inoperable.

Battery power

The aircraft's batteries were available to provide power to critical systems for a limited period of time if the primary power sources were lost.

The AC standby bus and APU standby bus normally received power from AC bus 3. Since AC bus 3 was not powered during the aircraft's final approach and landing, the AC standby bus and APU standby bus received power from the main batteries.

The main battery bus normally received power from DC bus 3. The bus control units (BCU) contained logic that transferred the source of battery bus power from DC Bus 3 to the batteries when only one TRU was in operation, as occurred during the incident flight. Since only one TRU was in operation, the BCUs switched the main battery bus to receive power from the main battery. As a result, the main battery also provided power to the AC standby bus.

The battery chargers were not in operation after the loss of power to AC bus 1.

2.2.3 Effect of power loss on electrical equipment

During the final phase of the flight, different electrical systems were affected in a different way depending on which of the various electrical buses could power them. Some systems were operable indefinitely because they were connected to AC bus 4 or one of the four DC buses. Systems that were connected to AC bus 1, AC bus 2, or AC bus 3 either lost power immediately, or remained powered by batteries if they had been connected to one of the standby or battery buses.

Those systems that were powered by batteries were not operable indefinitely due to the limited battery power available.

Table 6 summarises system operability after 0852:33, based on an analysis of the systems associated with each powered electrical bus. In addition to those systems, the aircraft's standby airspeed indicator, standby altimeter, and standby compass would have been operable indefinitely, although the standby altimeter could stick and show erroneous readings if it was unpowered.

Table 6: Effects on electrical equipment

Systems that remained operable indefinitely (DC systems other than battery bus systems, and systems not requiring electrical power)		
Anti-skid	Leading edge flap control	
Autobrake	Stabilator trim	

Systems that were operable for a minimum of 30 minutes (AC systems with battery backup, and DC battery bus systems)		
Air data computer	Engine fuel shutoff valves	Navigation display, left
Aural warning	Engine speed sensors	Park brake
Automatic direction finder	Fire warning horn/clocks	Passenger address system
Cabin pressure outflow valves	Flight control electronics	Primary flight display, left
Cargo fire extinguisher	Flight deck lights	Satphone
Control column stick shaker	Flight management computer system	Standby attitude indicator
EFIS[40]/EICAS[41] interface unit	Inertial reference system	Standby instrument illumination
EICAS, upper	Interphones	Transponder
Engine driven hydraulic pump shutoff valves	Manual cabin pressure control	VHF[42] radio
Engine fire extinguishers	Modular avionics and warning electronics assembly	

Inoperable systems (AC Systems without battery backup)		
EICAS, lower	Landing lights	Panel lights
Ground proximity warning system	Navigation display, right	Primary flight display, right

The systems that were powered by the battery buses, including the AC standby bus, would have been available for a minimum of 30 minutes after battery power was first applied (when AC bus 3 lost power). At that time, the aircraft was on approach and less than 15 minutes from landing. Therefore, the available battery power was not immediately critical to the safe operation of the aircraft. At the end of the taxi to the passenger terminal, the aircraft had been using battery power for about 21 minutes. There was no automated means by which the crew could establish the time at which the aircraft had switched to battery power, or when the 30 minutes would elapse.

If the aircraft had conducted a missed approach, or had been at a different point in the flight when use of battery power was necessary, the amount of battery power

[40] Electronic flight instrument system.

[41] Engine indicating and crew alerting system.

[42] Very high frequency.

available could have been critical to the safe operation of the aircraft. If the batteries had become completely drained, the flight crew would have been unable to achieve radio communications with air traffic control or other aircraft, and may have needed to navigate visually. In addition, other essential electrical systems would have been either unavailable or could have failed progressively as battery power diminished.

2.2.4 Origin of GCU faults

Following the incident, the aircraft's GCUs and BCUs were subjected to an acceptance test procedure, which did not show any failures related to the occurrence. The faults that occurred were therefore transient, and consistent with faults expected as a result of water ingress into the GCUs. The No 3 GCU was found to contain water immediately after the incident.

Post-incident examination of the GCUs revealed corrosion of the internal circuit boards in all three of the GCUs that shut down. Analysis of the corrosion materials observed in GCU 3 showed evidence of long-term exposure to water, including evidence of acids and carbohydrates that are present in beverages such as coffee, fruit juice and soft drinks. Those findings indicated a fluid source originating from the aircraft's galley drains or from spilt liquids in the cabin, and also suggested that liquid ingress had been occurring over an unknown, but extended period of time.

Internal corrosion is difficult to identify without disassembly of the affected unit, although the unit's exterior may be examined for signs of liquid staining and corrosion. A visual examination during regular maintenance activities may have identified liquid ingress and potential for corrosion and enabled maintenance personnel to address the issue.

The aircraft operator reported that some of the used GCUs that had been obtained from the unit manufacturer as replacements or spares exhibited internal corrosion and contamination, indicating that liquid ingress to GCUs has occurred on aircraft operated by other organisations.

The investigation found inconsistencies between the faults recorded by GCUs 1, 2 and 3 and the expected GCU behaviour in response to those faults. Those inconsistencies indicate that some GCU faults may not have been recorded and that some of the recorded faults could have been spurious. As a result, the investigation was unable to conclusively determine the exact nature of the internal faults that occurred in GCUs 1, 2 and 3 or verify whether the units handled those faults in accordance with their design.

The likelihood of spurious voltage and current measurements was high as a result of the number of faults associated with the A07 and A08 circuit boards of the GCUs, along with the corrosion observed on those boards. In addition, the fault associated with the A07 board of GCU 4 indicated that some liquid ingress may have occurred to that GCU.

2.3 Water ingress

2.3.1 Overview

The investigation found that water had probably overflowed from the aircraft's forward galley floor drain as a result of a blockage in that drain, possibly due to ice formation in or near the drain mast. The water flowed forward, through a gap beneath the forward galley bulkhead, and through a gap in the decompression panel into the aircraft's MEC. The water probably entered the dripshield gutter and leaked through the joints at each end of the gutter, and possibly through cracks around the fasteners. The water dripped onto a brace on the top of the equipment rack and travelled along that brace and into the electrical equipment through ventilation holes in the top of the equipment. Water dripping through cracks around the gutter fasteners might have also entered the electrical equipment directly.

The investigation established that the floor sealing around the wet galley was not adequate to prevent water migrating through the seal, although that path was unlikely to result in water entering the GCUs and BCUs due to a 30 cm gap between the cargo ceiling lining and the MEC.

2.3.2 Water sources

The investigation identified several means by which water accumulation could have occurred, including condensation, leakage of water supplies or drains, crushed or blocked drain lines, blocked sinks, and spills.

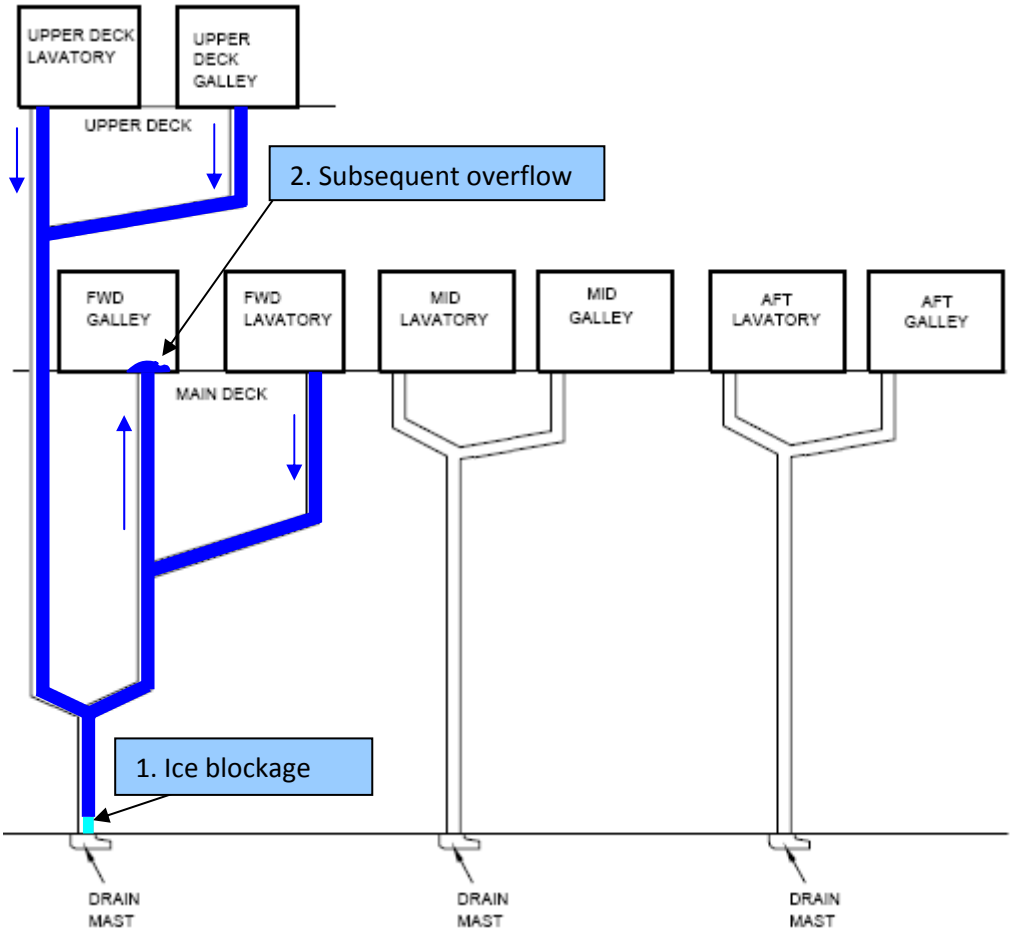
The water almost certainly originated from the floor drains in the forward galley. That would be consistent with the location of the water in the forward galley cart bays, as well as with the customer service manager's (CSM) description of the water.

The ribbon heater that was fitted to the drain lines leading to the drain mast was designed to prevent liquid inside the line freezing due to the sub-freezing temperatures at high altitude. Since the heater was inoperable during the flight, water probably froze inside the drain line and expanded, as evidenced by the split in the drain line. The resulting plug of ice would have prevented water in the forward drain line from exiting the aircraft.

Since the drains and sinks from the aircraft's main and upper deck galleys and lavatories all connected to the same drain mast, liquid entering any of those drains or sinks would not have drained away. As there was no alternate path for the water to escape from the drain system, the water backed up the drain line and exited at the lowest point, which was the forward galley floor drain (Figure 34).

Once the aircraft descended and landed, the associated increasing temperatures caused the ice to melt, and the water in the drain line to empty through the drain mast. Since the blockage had then gone, subsequent testing of the drain function with low volumes of water would not have shown any noticeable restriction.

Figure 34: Forward drain system overflow



2.3.3 Drain line design

The replacement of a two-port drain mast with a single-port drain mast combined the upper and lower deck drains into a single system, decreasing the effectiveness of both systems. Due to the increased volume of waste passing through the drain mast, it was more likely to become blocked. In addition, a blockage occurring below the Y connector would affect both drain systems and potentially cause waste liquid from the upper deck to overflow onto the main deck.

It is reasonable to assume that if a cabin crew member notices a substantial leak in a galley, they would probably stop using the galley sink. However, crew members would not necessarily have known that the forward sinks and drains were interconnected. As a result, the two forward lavatory sinks and the upper galley might remain in use. Any water entering those sinks could then overflow from the main deck drains, potentially without the knowledge of the crew.

2.3.4 Drain line operation and maintenance

During inspections, the investigation found evidence of galley waste solids having been washed down the galley sinks, and a substantial amount of solid waste in a drain line. Although it was probably not sufficient to cause a blockage of the line at the time of the incident, the amount of water required to back up the drain line to floor level would have been substantially reduced by any solid matter in the lines.

The amount of solid matter observed in the drain line connector suggests that a similar amount probably existed in the other parts of the drain system. A blockage could have occurred at any time if some of the solid matter became dislodged.

The aircraft operator's procedures required the heaters on the drain lines leading to the forward drain mast to be inspected for operation every D-check. If a heater failed at any point between checks, it would not have been easily identified by maintenance crews until the next check or after a blockage had occurred. Any such blockage would probably not be easily identified unless it resulted in an overflow that the cabin crew noticed and reported.

2.3.5 Decompression panel

A decompression panel was installed less than 1 m forward of the galley bulkhead, and above and slightly forward of the E1 and E2 equipment racks. In order to operate effectively, it could not be sealed. The panel would have allowed water to pass through the floor relatively unhindered at that location. Inspection of the floor on 9 and 10 March identified dust accumulation around the panel but with a clear area along the aft edge. That inspection also observed dust accumulation underneath the galley bulkhead, but with a clear area around the centre of the galley. Since the bulkhead was installed slightly raised from the floor, liquid could pass underneath it. Those findings were consistent with water on the galley floor passing underneath the bulkhead and into the gaps around the decompression panel.

The location of the decompression panel near the galley increased the risk of liquid from the cabin entering the MEC at a point directly above vital electrical system components.

2.3.6 Floor sealing

The operator's floor sealing process specification required several levels of floor sealing within 18 inches (45 cm) of all wet galleys. However, the CSM reported that water extended beyond this area during the incident flight. The water would have been able to penetrate the unsealed sections of floor.

In addition, the inspections on 9 and 10 March 2008 found a significant volume of water in the forward cargo bay lining. The investigation could not determine how much of this water had penetrated the unsealed sections of the floor, the deteriorated floor sealing around the galley, or both.

The investigation examined the possibility of water washing forwards over the lip where the cargo bay lining joined the bulkhead and into the equipment bay. For water in that location to contact the GCUs or BCUs, it would need to pass over a gap of about 30 cm. It is therefore unlikely that water entered the GCUs through that path.

For the same reason, it is most likely that the water in the cargo lining had migrated through the galley floor sealing, or through the unsealed floor behind the galley and not through the decompression panel.

Any liquids passing through the cabin floors could have an adverse effect on aircraft systems such as electrical systems, flight controls, and the aircraft structure. In particular, water that collected in the cargo lining could pose a serious risk to the

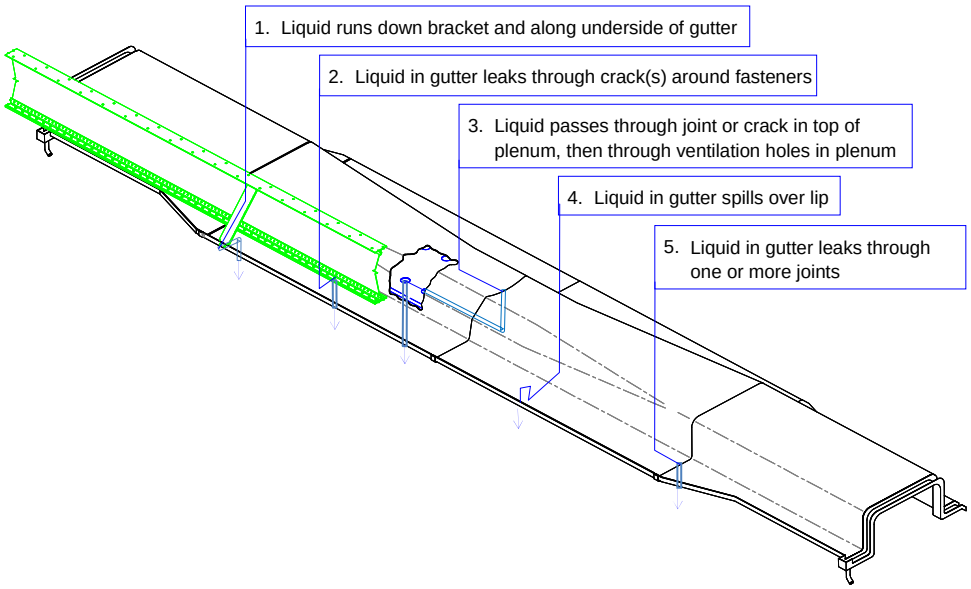
electrical distribution panel behind the E1/E2 racks, and possibly other structures and equipment within the cabin floors and around the cargo bays.

2.3.7 Dripshield

To enter the GCUs from above, water would have had to pass through, bypass, or form condensation on, the dripshield in order to reach the equipment.

During inspections of two 747-400 aircraft, including the incident aircraft, the investigation identified five potential paths by which liquid from above could reach the equipment in the E1 and E2 racks. The investigation concluded that although the drip gutter joints were the most likely path for water to have bypassed the dripshield, all five potential liquid paths posed a substantial risk to the electrical equipment in the E1 and E2 racks (Figure 35).

Figure 35: Potential water ingress paths



The high proportion (52 out of 69) of damaged dripshields or gutters in the worldwide 747-400 fleet indicates that the issue was widespread, even though that particular problem could have been readily identified by a visual inspection during regular maintenance activities. It could be expected that as the aircraft continues to age, the incidence of damage to the dripshields could increase.

During the inspection of OJK on 6 February 2008, it was observed that the upper surface of the plenum was split and cracked, and would probably not have prevented water from entering the plenum. Cracks and splits similar to those seen on OJK have been observed in plenums on other 747-400 aircraft. Although that ingress path did not contribute to the water ingress in OJM, the MEC dripshield and plenum was not sufficiently protective of equipment on other aircraft.

2.3.8 Water ingress into the GCUs

The location of the GCUs on the top of the E1 and E1 electrical systems racks in the aircraft's MEC, combined with the location of many cooling vents in the top of the units, put them at risk of water ingress from above.

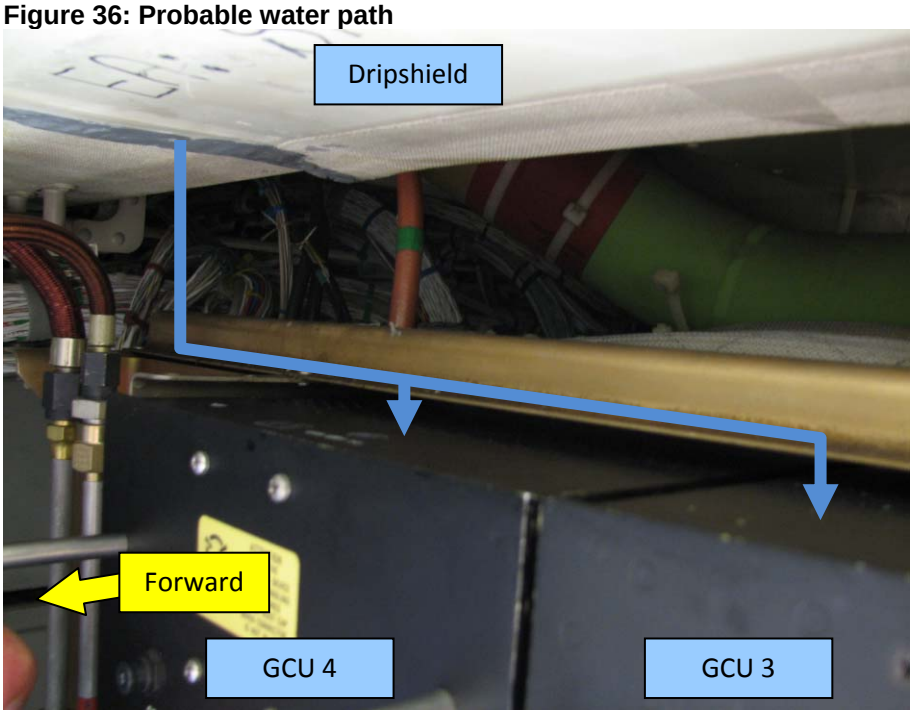
The corrosion that was observed on the A08 circuit board in the three faulted GCUs strongly indicated that water had dripped from the rack brace that was located directly above the A08 board with the GCUs in situ. That was consistent with the residue observed on the rack brace. When the rack brace was examined under forensic lighting, a clear 'drip' pattern was observed at a location directly beneath a joint in the dripshield.

Those findings indicate that the water travelled along the rack brace and onto the electrical equipment at the top of the rack (Figure 36). Water may have also run along the underside of the dripshield gutter, and entered the equipment at other points.

The physical distance between each pair of GCUs reduced the risk of ingress into more than two GCUs, although units on both sides of the equipment rack had failed, indicating that a significant amount of water had passed through the dripshield on both sides. The investigation could not determine why a substantial amount of water had entered GCU 3 and not GCU 4 in sufficient quantity to cause a fault; although it was likely to have resulted from a combination of pre-existing corrosion in GCU 3, the unpredictable nature of water flow, and the variable effect of water on electrical equipment.

The absence of BCU faults may be explained by the more distant location of the BCUs from the edge of the racks relative to the GCUs, which would make water ingress less likely.

Figure 36: Probable water path



2.4 Aircraft design, modification, operation and maintenance practices

The water ingress occurred as a result of several issues with the design, modification, operation and maintenance of some of the aircraft's water protection

and drainage devices. The investigation therefore examined the liquid drain and spill management practices of the aircraft manufacturer and operator.

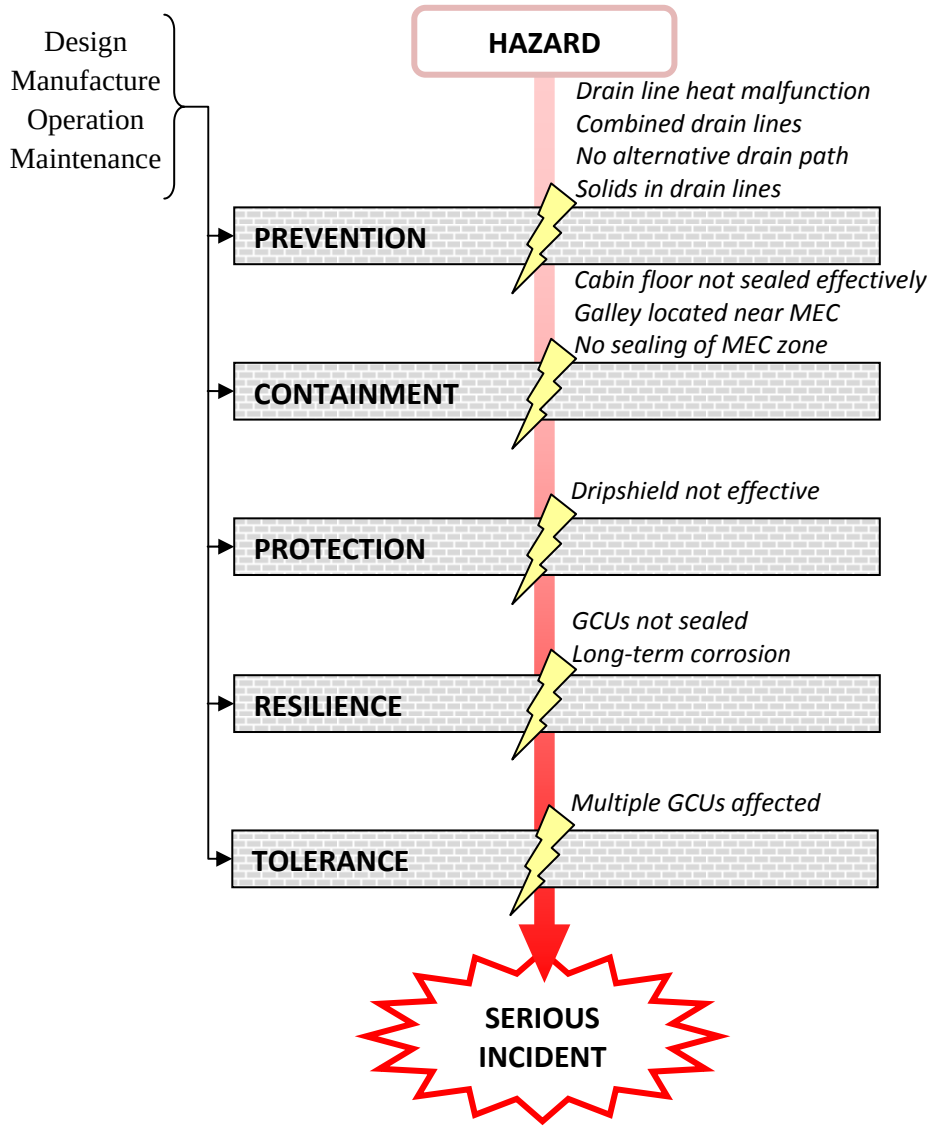
2.4.1 Physical defences

The investigation identified five physical layers of defence to prevent liquids from affecting aircraft safety:

- prevention and containment of spills and leaks, to contain liquids or direct them to low risk areas
- protection (including barriers and by physical remoteness) of vulnerable equipment areas, to prevent liquids from entering high risk areas
- resilience of equipment, to protect equipment from damage by liquid
- fault- and fail-tolerance, to protect systems from single and multiple failures and faults.

In this incident, each of those defences was breached by a different failure or design characteristic (Figure 37).

Figure 37: Breaches of defence



A breach in any single defence could be considered low-risk in view of the other defences that were in place, but the circumstances that allowed that breach to occur could also affect the other defences. As a result, the overall integrity of the system is compromised. Such circumstances could involve a weakness in the principles and policies that drive the design, operation, and/or maintenance of the defences, or a weakness in the implementation of those principles and policies.

2.4.2 Design and change practices

The aircraft manufacturer's documented design objectives included requirements to protect equipment, including electrical equipment, from performance degradation as a result of undesired liquids. The operator's design guide did not explicitly require the consideration of potential damage (other than structural corrosion) resulting from liquid contact or ingress, although there was no evidence to suggest that the operator did not take liquid management into account as part of its unwritten practices. Due to the highly complex nature of the aircraft operator's and manufacturer's system and procedure development processes, and the continual

changes in those processes over the aircraft's life, the investigation was unable to completely determine the extent and effectiveness of the aircraft manufacturer's documented requirements, or of the operator's unwritten practices.

The technical issues identified by the investigation were not likely to have been present, or as serious, at the time of the aircraft's manufacture. Those issues probably arose partly due to a combination of the aircraft's increasing age and from the incorporation of a number of minor modifications over an extended period of time. In addition, the investigation considered that each of the various liquid management issues were relatively minor in isolation, and were unlikely to have been considered a high priority if and when they were initially identified because of the existence of numerous other, independent liquid management devices and processes. For example, if the design process for combining the two forward drain lines had considered the potential adverse effects of the change, it would probably have considered that the galley floor sealing and dripshield would have prevented any spill from having a serious effect on the aircraft. As a result, the design and approval teams for the drain mast modification would probably not have considered that the modification could have contributed to an electrical equipment malfunction, such as occurred in this case.

The available evidence did not strongly indicate any systemic issues within the aircraft manufacturer's processes. The investigation considered that the inclusion of specific liquid management requirements within the operator's documented processes would not have necessarily prevented the incident.

The combination of liquid management issues identified by the investigation highlights the importance of considering the secondary, tertiary and subsequent effects of a change to designs and procedures, and the influence of such changes on both associated and non-associated systems. It is also important for the change review process to consider the specific requirements of a particular operator and aircraft configuration.

Liquid spills and leaks may occur even with the most stringent operational and maintenance procedures. Although there are benefits in addressing spills and leaks directly, consideration should also be given to reducing the vulnerability of high risk components. Specific consideration should be given to various mitigation strategies, including the protection of areas containing vulnerable equipment, the distribution of redundant systems across different locations, the containment of potential liquid sources, and to the protection, resilience and fault tolerance of equipment.

2.4.3 Airworthiness regulations and guidance

The investigation identified a number of other serious incidents involving electrical equipment failures that were attributed to liquid contamination, and which involved four different aircraft types. That illustrates that, although a number of liquid management issues were identified with OJM and other 747-400 aircraft, similar issues may continue to exist in a number of aircraft types.

For the 747-400 aircraft to be deemed airworthy under the US FAR (which is an international airworthiness standard for the aircraft), the installation and maintenance of the GCUs and BCUs only needed to consider 'critical environmental conditions'. Further advice in the associated advisory circular gave 'contamination by fluids' as an example of a potential common-cause failure, but

did not provide any guidance as to how such contamination could arise nor how it could be prevented.

This limited amount of airworthiness regulation and guidance that aircraft manufacturers, operators, and maintenance organisations are required and advised to meet is not commensurate with the potential harm to flight safety posed by liquid contamination.

The broad wording of the regulation and guidance is subject to variable interpretation and makes it difficult to develop appropriate platform-specific requirements, potentially posing a significant adverse effect on an aircraft's safety throughout its life.

The investigation also considered a more recent FAR that was introduced in 2007 that did not apply to OJM, but which required a certain level of physical protection between the electronic wiring interconnection systems (EWIS) and water/waste systems of some other aircraft types. The FAA also provided guidance for the design, inspection and maintenance of EWIS through a number of advisory circulars.

The post-2007 physical protection requirements suggested a higher level of detail to which liquid management could be considered. However, electrical system units such as GCUs and BCUs were not defined as part of the EWIS, so the FAA guidance would not have applied.

The EWIS and electrical system units comprise parts of a complete system but the level of detail in the regulatory requirements and guidance for each is inconsistent.

A similar level of detail within the regulatory requirements and guidance applying to the protection of electrical system units as applied in the case of the EWIS requirements has the potential to reduce the risk of electrical system failure resulting from liquid ingress for current and future aircraft types.

2.5 Aircraft operation

2.5.1 Background

At the time that AC bus 1 became unpowered, the aircraft was turning onto an extended left downwind leg for runway 01 Right and air traffic control (ATC) radar vectoring continued to direct the aircraft to a position on the final leg at 10 NM (19 km).

The flight crew, faced with multiple electrical system failures during the latter stages of the descent into Bangkok, had limited time to assess and respond to those failures before landing. The EICAS battery discharge messages were an indication that primary flight displays and systems could have failed at any point after the next 30 minutes. This time pressure necessitated a prioritising of essential tasks to be completed within the time remaining.

The crew were aware that the aircraft's communication, instrumentation, alerting and navigation systems would not be available once the batteries were exhausted. Any delay before landing could have resulted in further equipment malfunctions and difficulties with communication and navigation. Although the events leading to the application of battery power occurred fairly late in the established approach, the

aircraft landed about 14 minutes later, having used almost half of the 30 minutes assured battery time available.

2.5.2 Flight crew communication of the emergency

The crew could not have predicted whether further failures could have occurred regardless of whether they had known that liquid ingress was a factor. As such there was a possibility that the situation could worsen, resulting in further operational difficulties.

The flight crew's operational instructions required them to make effective use of the resources available, including those external to the aircraft. The flight administration manual (FAM) specifically required crews to transmit a distress (MAYDAY) or urgency (PAN PAN) signal to air traffic control (ATC) if any distress or urgency situation develops or is likely to develop.

The inclusion of cabin crew members and external agencies in the communication loop would have facilitated a coordinated response had the situation worsened, including:

- advising other aircraft in the vicinity of the situation so that consideration and contingency plans could be effected by those flight crews in the event of a:
  - request for assistance by OJM or by ATC
  - radio failure in OJM
  - delay or diversion affecting OJM's arrival and landing.
- enabling preparedness by ATC, including the provision of:
  - prioritisation
  - runway usage planning and allocation
  - contingency planning
  - flow control
  - vertical and/or horizontal surveillance or guidance
  - the protection of assets on the ground
  - aerodrome preparedness for a potential event.
- enabling aerodrome and response agency services to increase their state of response readiness
- enabling cabin crew to prepare the cabin and to brief the passengers.

The time remaining limited the extent to which information could have been passed. However, as outlined in the operator's crew resource management (CRM) procedures, communication duties could have been assigned to another resource, such as one of the two second officers who were on the flight deck.

It is understandable that the crew considered it desirable to land the aircraft as soon as possible. The declaration of an emergency could have been expected to have expedited that arrival. The transmission of an urgency call, particularly if undertaken by one of the second officers, would not have substantially increased the combined flight crew's workload or delayed the landing.

Although it did not occur in this instance, it is possible that an absence of communication between the crew and ATC regarding the emergency situation could have resulted in the aircraft not being handled by ATC as appropriately or expeditiously as possible. This had the potential to have affected flight safety. Similarly, if the situation faced by the crew had deteriorated – for example, due to a missed approach and/or further aircraft equipment failures, or if radio communications between the aircraft and air traffic control had ceased due to lack of electrical power – then the fact that ATC were unaware that operations were not normal may have compromised safety.

2.5.3 Information provided to the flight crew

Manuals

The manuals provided to the flight crew contained information on how to manage the loss of a single electrical bus, and limited information on managing the loss of multiple electrical buses.

The 'BATT DISCH MAIN' and 'BATT DISCH APU' EICAS non-normal message entries in the quick reference handbook (QRH) did not provide the flight crew with information on the time remaining before the battery was exhausted, or any recommended crew actions. Accordingly, the flight crew relied on their recollection of systems knowledge that was provided during training to assess and manage numerous failures with a limited amount of time available before the batteries would be depleted. The various manuals did not contain information on how to extend the limited battery life or to manage the aircraft if the batteries were depleted. They did not include information on what critical systems were lost with each respective bus, or whether some important systems such as wheel brakes and reverse thrust were available on battery power or after batteries became depleted. In the event of a partial or complete electrical power loss, the provision of such information would enable a flight crew to more rapidly and reliably assess the situation and to plan and conduct appropriate responses, and could also reduce flight crew workload.

Flight deck displays

The fault messages that informed the crew of the battery discharge state were classified as advisory messages, the second lowest of four priority levels. The crew would have expected the most important messages to be displayed first on the EICAS, and would have prioritised their responses accordingly.

The display of the battery discharge fault messages near the end of several pages of messages risked their being overlooked, or a delay in the crew's response. Additionally, the absence of any accompanying guidance in the QRH could have lead to inappropriate crew actions or inaction.

The flight crew were presented with a large number of fault messages, many of which resulted from failures that were a direct consequence of other failures, predominantly the loss of electrical bus power. The EICAS did not prioritise the messages within each category in order of the required sequencing of responses. For example, multiple warning messages would be displayed in the order in which the faults arose, but that order did not necessarily reflect the appropriate order in which they should be actioned. This increased the risk that newly displayed messages

could lead a flight crew to lose their place in a checklist, interrupt a checklist inappropriately, or lose track of which checklists had and had not been actioned. Many of the messages would have referred to failures that did not have a significant effect on the safety of the flight, and therefore would have been more distracting than helpful.

A more structured presentation of fault messages would have helped the flight crew to rapidly identify the most appropriate or urgent actions with minimal distraction from unimportant or inappropriate messages.

2.5.4 Landing and taxi

After landing, the flight crew proceeded directly to the terminal without having first established the extent of the aircraft's systems degradation and their effect on taxiing. Some consideration of that risk, including the involvement of engineering and cabin staff may have alerted the crew that the aircraft had not fully depressurised. In the event, that lack of awareness until the cabin crew found that they were unable to open the cabin doors could have had a serious impact on the safety of the aircraft's passengers and crew, should an emergency evacuation have been required.

3 FINDINGS

From the evidence available, the following findings are made with respect to the electrical systems event that occurred 25 km north-north-west of Bangkok International Airport, Thailand on 7 January 2008 and involved Boeing Company 747-438 aircraft, registered VH-OJM, and should not be read as apportioning blame or liability to any particular organisation or individual.

3.1 Contributing safety factors

- Electrical power to the aircraft's alternating and direct current buses 1, 2, and 3 and associated electrical equipment was lost during the flight after generator control units 1, 2, and 3 malfunctioned as a result of past and present waste water ingress.
- Waste water leaked through a decompression panel in the cabin floor, then through dripshields and into electrical equipment after the forward drain line was blocked with ice that formed due to an inoperable drain line heater.
- Maintenance processes did not identify or correct the:
  - deterioration of the dripshield *[Significant safety issue]*
  - corrosion in the generator control units *[Minor safety issue]*
  - inoperability of the forward drain line heater. *[Significant safety issue]*
- The location of the decompression panel and absence of cabin floor sealing above the main equipment centre increased the risk of liquid ingress into the aircraft's electrical systems. *[Significant safety issue]*

3.2 Other safety factors

- The galley drain operation and maintenance processes did not adequately prevent blockage and overflow of the aircraft's drain lines. *[Minor safety issue]*
- The aircraft operator's forward drain mast modification increased the risk of a blockage in the aircraft's forward drain lines.
- The floor sealing around the forward galley was not of sufficient extent to prevent liquids from passing through to the under floor area. *[Minor safety issue]*
- Maintenance processes did not identify or correct the deterioration of the galley floor sealing. *[Minor safety issue]*
- The aircraft operator's documented design objectives did not explicitly require the protection of non-structural systems from liquid contact or ingress. *[Minor safety issue]*
- The United States Federal Aviation Administration regulations and associated guidance material did not fully address the potential harm to flight safety posed by liquid contamination of electrical system units in transport category aircraft. *[Significant safety issue]*

- The priority level of the battery discharge messages that were provided by the engine indicating and crew alerting system did not accurately reflect the risk presented by the battery discharge status. *[Significant safety issue]*
- The flight crew quick reference handbook did not include sufficient information for the flight crew to appropriately manage operations on standby power. *[Significant safety issue]*
- The flight crew did not declare the aircraft's situation to air traffic control or to the cabin crew, which would have enabled them to more effectively prepare for and manage any adverse change in the aircraft's situation.
- The flight crew did not review the aircraft status prior to taxiing to the terminal.

4 SAFETY ACTIONS

The safety issues identified during this investigation are listed in the Findings and Safety Actions sections of this report. The Australian Transport Safety Bureau (ATSB) expects that all safety issues identified by the investigation should be addressed by the relevant organisation(s). In addressing those issues, the ATSB prefers to encourage relevant organisation(s) to proactively initiate safety action, rather than to issue formal safety recommendations or safety advisory notices.

All of the responsible organisations for the safety issues identified during this investigation were given a draft report and invited to provide submissions. As part of that process, each organisation was asked to communicate what safety actions, if any, they had carried out or were planning to carry out in relation to each safety issue relevant to their organisation.

4.1 Equipment protection

4.1.1 Dripshield modifications

Significant safety issue

Maintenance processes did not identify or correct the deterioration of the dripshield.

Action taken by the aircraft manufacturer

In response to this occurrence, the aircraft manufacturer:

- issued a multi-operator message that contained advice and instructions for the inspection and interim repair of main equipment centre dripshields in 747-400 aircraft
- published a service bulletin on 4 November 2009, advising that the following modifications be made to 747-400 dripshields:
  - add raised flanges to the cooling exhaust holes in the plenum to prevent any water inside the plenum from spilling onto equipment
  - install additional drain lines to remove water from the plenum
  - repair and reinforce the dripshield gutter
  - seal and reinforce the plenum interfaces
  - apply a waterproof, fibreglass-reinforced overcoat.
- released a service letter to all operators of the 747-400 aircraft, advising that operators:
  - establish maintenance programs for the drain system based on operator experience on the frequency of blockages and over-flow events
  - visually check the condition of the forward drain mast connection hose or hoses, repeated at an interval based on operator experience
  - perform a visual check and, if necessary, perform a functional test of the forward drain mast

– perform an inspection and clean up of any contaminated areas after liquid is spilled in the galley.

ATSB assessment of action

The ATSB is satisfied that the actions taken by the aircraft manufacturer will, when incorporated, adequately address the safety issue.

Action taken by the United States Federal Aviation Administration

Subsequent to this occurrence, the United States (US) Federal Aviation Administration (FAA):

- adopted airworthiness directive AD 2009-22-14 (effective 8 December 2009), requiring the installation of larger dripshields and drain lines in the electrical/electronic equipment centres of aircraft manufacturer's 747-200C and 747-200F aircraft to prevent water contamination of essential electrical/electronic units. The aircraft manufacturer's procedure referenced by the airworthiness directive was first published on 15 February 2007 and revised on 9 October 2008.
- issued a notice of proposed rulemaking (NPRM) on 5 May 2010 stating:

  > We propose to adopt a new airworthiness directive (AD) for certain Model 747-400 and 747-400D series airplanes. This proposed AD would require installing aluminium gutter reinforcing brackets to the forward and aft dripshield gutters of the main equipment center (MEC); and adding a reinforcing fiberglass overcoat to the top surface of the MEC dripshield, including an inspection for cracking and holes in the MEC dripshield, and corrective actions if necessary. This proposed AD also provides for an option to install an MEC dripshield drain system, which, if accomplished, would extend the compliance time for adding the reinforcing fiberglass overcoat to the top surface of the MEC dripshield. This proposed AD results from a report indicating that an operator experienced a multi-power system loss in-flight of 1, 2, and 3 alternating current (AC) electrical power systems located in the MEC. We are proposing this AD to prevent water penetration into the MEC, which could result in the loss of flight critical systems.

  Comment on the NPRM was required by 6 July 2010.

ATSB assessment of action

The ATSB is satisfied that the actions taken by the US FAA will, when finalised and promulgated, adequately address the safety issue.

Action taken by the aircraft operator

The aircraft operator advised that, as a result of this occurrence, it:

- carried out a fleet inspection of 747-400 dripshields and made temporary repairs in response to any faults found during those inspections – damage was identified in the dripshields of 18 out of 30 aircraft inspected, and consisted of small cracks around the fasteners and cracks in the seals along the three dripshield joints

- commenced a program to conduct a strengthening and sealing modification to the MEC dripshield plenum on its 747-400 aircraft
- conducted permanent repairs on the dripshield gutters of its 747-400 fleet
- changed the MEC equipment area maintenance procedures to specify dripshield inspection criteria and to provide feedback on the long-term suitability of the modifications and repairs.

ATSB assessment of action

The ATSB is satisfied that the actions taken by the aircraft operator adequately address the safety issue.

4.1.2 Extent of galley floor sealing

Minor safety issue

The floor sealing around the forward galley was not of sufficient extent to prevent liquids from passing through to the under floor area.

Action taken by the aircraft manufacturer

In response to this occurrence, the aircraft manufacturer is investigating a number of methods to improve floor sealing in 747-400 aircraft.

ATSB assessment of action

The ATSB is satisfied that the actions taken by the aircraft manufacturer will, when incorporated, adequately address the safety issue.

4.1.3 Maintenance of galley floor sealing

Minor safety issue

Maintenance processes did not identify or correct the deterioration of the galley floor sealing.

Action taken by the aircraft operator

On 11 January 2008, the aircraft operator advised that it would review the effectiveness of the stipulated galley floor sealing maintenance.

Action taken by the ATSB

During the investigation, the ATSB discussed the background for this safety issue and the associated safety risk with the aircraft operator. The potential for a reduction in the associated risk to as low as reasonably practicable by proactive operator safety action was highlighted.

Additional action taken by the aircraft operator

In a response to the draft investigation report, the aircraft operator reported that, since the occurrence, and to provide better understanding and clarification for its maintenance personnel, it had made a number of revisions to its galley floor sealing specification document. The intent of those enhancements was to ensure the correct installation of the galley floor sealing.

ATSB assessment of action

The ATSB is satisfied that the actions taken by the aircraft operator adequately address the safety issue.

4.1.4 Cabin floor sealing above the main equipment centre

Significant safety issue

The location of the decompression panel and absence of cabin floor sealing above the main equipment centre increased the risk of liquid ingress into the aircraft's electrical systems.

Action taken by the aircraft manufacturer

In response to this occurrence, the aircraft manufacturer:

- issued a multi-operator message containing a recommendation that operators review decompression panels that have been relocated after delivery to verify that they do not become a direct water path to the main equipment centre dripshield
- is investigating a number of methods to improve floor sealing in 747-400 aircraft.

ATSB assessment of action

The ATSB is satisfied that, when completed, the actions taken or that are being undertaken by the aircraft manufacturer will adequately address the safety issue.

Action taken by the aircraft operator

The aircraft operator has advised that, in response to this occurrence, it has:

- installed a water barrier gutter at the rear of the forward galley bulkhead on all of its 747-400 fleet
- installed an additional bead of sealant around the first-class seat pods to protect the decompression panel on all of its 747-400 fleet.

ATSB assessment of action

The ATSB is satisfied that the actions taken by the aircraft operator adequately address the safety issue.

4.2 Drain lines

4.2.1 Drain operation and maintenance

Minor safety issue

The galley drain operation and maintenance processes did not adequately prevent blockage and overflow of the aircraft's drain lines.

Action taken by the aircraft manufacturer

In response to this occurrence, the aircraft manufacturer changed the drain overflow troubleshooting procedures to improve the identification of blocked drains.

ATSB assessment of action

The ATSB is satisfied that the action taken by the aircraft manufacturer adequately addresses the safety issue.

Action taken by the aircraft operator

Following this occurrence, the aircraft operator:

- increased the frequency of maintenance to clean and flush the forward galley drain lines to every A-check
- increased the frequency of maintenance to clean behind the ice drawers every A-check
- added procedures to remove and clean the forward galley 'Y' connector during scheduled maintenance
- changed the maintenance procedures to require the replacement of soft galley drain lines on every D-check
- promulgated cabin crew standing orders to provide guidance on the appropriate methods of disposal for different types of liquids
- initiated a review of toilet design, maintenance, and signage to reduce the frequency and impact of blockages - some changes had already been implemented when this report was drafted
- initiated a project to implement high-pressure waste line cleaning
- is investigating a number of proposals to improve galley operation, including the replacement of coffee grounds with coffee bags and the provision of liquid absorption and disposal products
- initiated a review of its fleet's aircraft drain systems to improve reliability, eliminate the risk of blockages, review maintenance practices, eliminate safety risks to engineers, and consider future product selection
- issued service bulletins to modify the drain behind the coffee machine and water boiler to ensure that the drain line is now directed into the galley drain port to prevent water spilling over the top of the galley

- promulgated a cabin standing order and a flight standing order to all 747-400 cabin and flight crews, requiring them to identify, treat and report abnormal water accumulation in galley areas, and modified the cabin crew operating manual accordingly
- promulgated a flight standing order to all flight crew, requiring them to treat and report abnormal water accumulation in galley areas and requiring crews to treat substantial water leaks as airworthiness items (which the operator defined as items that have the potential to affect the aircraft's ability to operate safely if unserviceable).

ATSB assessment of action

The ATSB is satisfied that the actions taken by the aircraft operator adequately address the safety issue.

4.2.2 Drain line heater

Significant safety issue

Maintenance processes did not identify or correct the inoperability of the forward drain line heater.

Action taken by the aircraft manufacturer

The aircraft manufacturer initiated a review of continuing maintenance of 747-400 drain system and ribbon heaters.

ATSB assessment of action

The ATSB is satisfied that the action taken by the aircraft manufacturer adequately addresses the safety issue.

Action taken by the aircraft operator

The aircraft operator:

- conducted a fleet inspection of 747-400 drain mast heaters, drain line heaters and drain mast hoses, and of 30 aircraft inspected, identified 11 failed drain ribbon heaters and four split drain hoses
- performed fleet-wide drain mast heater inspections on 747-300 aircraft, and identified one failed drain ribbon heater of 4 aircraft inspected
- increased the frequency of forward drain mast ribbon heater checks to every A-check. Results of the inspections will be analysed and an appropriate check interval will be established into the system of maintenance in accordance with the findings.

ATSB assessment of action

The ATSB is satisfied that the actions taken by the aircraft operator adequately address the safety issue.

4.3 Electrical equipment maintenance

Minor safety issue

Maintenance processes did not identify or correct the corrosion in the generator control units.

Action taken by the GCU/BCU manufacturer

The GCU/BCU manufacturer implemented procedures for a more thorough inspection of the external chassis of GCUs and BCUs received for repair for signs of liquid contamination, and a circuit card removal and inspection for any suspect units.

The GCU/BCU manufacturer drafted a service information letter to operators and maintenance providers advising that:

> Unexplained EICAS [engine indicating and crew alerting system] messages and aircraft electrical system anomalies may result from the presence of corrosion and contamination within the GCU or BCU circuitry.
>
> Operators suspecting water ingress of the GCU or BCU should remove the units to an avionics repair shop and request a physical inspection and a careful cleaning of the Printed Wiring Assemblies [PWA], the motherboard, and all interconnections to ensure contamination of the circuitry is not present. A test validation is not sufficient to detect corrosion and contamination of the internal circuitry.
>
> Avionic repair stations should examine the NVM [non-volatile memory] of each unit and perform a visual examination of PWAs for corrosion and contamination.

ATSB assessment of action

The ATSB is satisfied that the actions taken and proposed by the GCU/BCU manufacturer adequately address the safety issue.

Action taken by the aircraft operator

The aircraft operator:

- now requires all overhauled GCUs and BCUs to be internally inspected for corrosion, and the environmental protection inspected and reapplied as required in accordance with the manufacturer's standard practices
- conducted a review of tech log reports on their 747-400 fleet to determine if specific AC power buses exhibit repeated intermittent failures or symptoms that may be attributable to internal corrosion or contamination
- is undergoing a scheduled removal of all BCUs and GCUs fitted to 747-400 aircraft to inspect internally for corrosion and environmental protection - this is being performed initially for aircraft that exhibit symptoms on AC bus 3.

ATSB assessment of action

The ATSB is satisfied that the actions taken and proposed by the aircraft operator adequately address the safety issue.

4.4 Fleet reviews

4.4.1 Aircraft manufacturer

Although no safety issue was identified in respect of the fleet reviews, in response to this occurrence, the aircraft manufacturer has proactively:

- initiated a review of the potential applicability of the identified dripshield issues to its other aircraft types, including the 747-8, which is based on the 747-400
- revised the 747-8 design such that:
  - dripshields will be constructed from fibreglass composite instead of polycarbonate
  - the generator and bus control units will be relocated to separate shelves.
- initiated a separate review of all of its aircraft types regarding the design approach for protecting electrical equipment from the effect of large water spills that are in excess of that considered as normal condensation and moisture from the passenger cabin environment. That review includes an examination of the:
  - design requirements and objectives in relation to liquid management, which was expected to be completed in April 2009
  - effectiveness of the 'lessons learned' feedback process.

4.4.2 Aircraft operator

Although no safety issue was identified in respect of the fleet reviews, in response to this occurrence, the aircraft operator proactively:

- changed its procedures to require water spill issues to be reported to engineering
- initiated a 747-400 fleet water spill related-event monitoring program
- conducted a fleet inspection of 747-400 galleys to identify potential water leaks and drain blockages
- initiated regular inspections of its Boeing 767 fleet dripshields, which resulted in a number of issues being discovered - those defects are being managed through a series of temporary and permanent repairs
- initiated regular inspections of its Airbus A330 fleet dripshields.

4.5 Flight crew information and procedures

Significant safety issue

The flight crew quick reference handbook did not include sufficient information for the flight crew to appropriately manage operations on standby power.

Action taken by the aircraft operator

As a result of this occurrence, the aircraft operator:

- evaluated the provision of additional formal guidance to 747-400 flight crew for operations on standby power, including a review of *Section 6 – electrical* of the non-normal checklist within the 747-400 quick reference handbook (QRH). On 30 April 2009, the aircraft operator reported that it did not plan any changes to the QRH unless recommended to do so by the aircraft manufacturer
- has drafted an addition to the 747-400 flight crew operations manual to provide guidance to flight crews on the effect and management of multiple AC electrical bus loss, including battery life, major systems affected, and recommended crew actions.

Action taken by the aircraft manufacturer

In response to this occurrence, the aircraft manufacturer has performed several evaluations for the provision of additional formal guidance to 747-400 flight crew for operations on standby power, including reviews of *Section 6 -Electrical* of the non-normal checklists in the 747-400 QRH. On 29 October 2010, the aircraft manufacturer reported that 'due to the results of these evaluations and the subsequent mitigating changes made to protect the MEC and manage fluid spills, it does not plan any changes to the QRH.' The aircraft manufacturer provided the following justification:

> [The aircraft manufacturer], in conjunction with the FAA, continually reviews and updates the FCTM.[43] The FCTM is provided to Operators who decide when and how to train and distribute the information to their crews. During ATSB's investigation, [the aircraft manufacturer] attempted to develop a Non-Normal Checklist (NNC) which would provide flight crews with guidance when the airplane is on standby power. NNCs are used by the flight crew to cope with non-normal situations. The NNC topics are organized to match that of the Systems Descriptions of the FCOM[44] Vol 2 chapters. Numerous non-normal situations are covered for each system chapter. Although every attempt is made to establish necessary NNCs, it is not possible to develop checklists for all conceivable situations, especially those involving multiple or remote failures. [The aircraft manufacturer] spent a significant amount of time and resources to try and understand the problem and develop a NNC but they were unable to come up with a NNC that would cover the subject event for all 747 configurations in the fleet. Further, [the aircraft manufacturer] believes that one NNC cannot be useful as well as correct for all conditions that might lead to the situation (on standby power).

ATSB assessment of action

The ATSB acknowledges the reviews already undertaken by the aircraft operator and manufacturer and action to amend the operator's operations manual to include guidance to flight crews on the effect and management of multiple AC electrical bus loss, including on battery life. The ATSB recognises that the various crew

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43 Flight crew training manual.

44 Flight crew operating manual.

alerting systems in the 747-400 should inform flight crews of any aircraft systems that are be affected by electrical systems failures.

However, there is currently limited assurance that 747-400 flight crews would be aware of the expected duration of available battery power or of the possible need to expedite appropriate actions such as aircraft diversion that should be undertaken in the event of abnormal or unexpected battery discharge. The inclusion of a note or caution associated with the battery discharge message entry in the QRH to alert crews of the restricted battery life in such cases would help crews select and prioritise the most appropriate actions to recover from the emergency.

ATSB safety recommendation AO-2008-003-SR-108

The Australian Transport Safety Bureau recommends that the aircraft manufacturer undertake further work to address this safety issue.

4.6 Aircraft manufacturer

4.6.1 Battery discharge message priority

Significant safety issue

The priority level of the battery discharge messages that were provided by the engine indicating and crew alerting system did not accurately reflect the risk presented by the battery discharge status.

Action taken by the ATSB

During the investigation, the ATSB discussed the background for this safety issue and the associated safety risk with the aircraft manufacturer. The potential for a reduction in the associated risk to as low as reasonably practicable by proactive manufacturer safety action was highlighted.

Action taken by the aircraft manufacturer

On 29 October 2010 the aircraft manufacturer reported that it had 'reviewed the priority level of the BAT DISCH message that is provided by the EICAS and finds that the current message level "Advisory" is correct.' The aircraft manufacturer provided the following justification:

> [The aircraft manufacturer] believes that the "Advisory" level is correct since an advisory level message typically means that routine crew awareness and corrective action may be required. There is no flight crew action for BAT DISCH MAIN and BAT DISCH APU, these messages only note that the corresponding batteries are discharging when/if electrical loads is sufficient to generate battery drain and the battery is not charging. This situation can occur whenever AC electrical bus 1 is lost, due to the fact the battery chargers are powered by this bus by the way of the ground service bus.

A more important crew alert in a multiple bus loss event, like this investigation, is the EICAS Caution message ELEC AC BUS (X). These messages direct flight crews to the appropriate procedures to attempt to restore electrical power.

ATSB assessment of action

The ATSB recognises that any change in the priority level of the battery discharge messages would contradict the EICAS priority level definitions if no crew actions were associated with the message entries in the QRH. Accordingly, the priority level and QRH should be assessed concurrently. However, the risk presented by the potential for the battery discharge message to be overlooked in the event of multiple EICAS messages remains significant.

Safety Advisory Notice AO-2008-003-SAN-107

The ATSB reminds operators and flight crews of transport category aircraft that although battery discharge may occur routinely, immediate flight crew action may be necessary in the event of abnormal or unexpected battery discharge alerts if the battery discharge status cannot be immediately resolved in-flight. Multiple electrical system failures, including failures of critical flight systems, may occur in the event of battery power depletion.

4.7 Aircraft operator

4.7.1 Design objectives

Minor safety issue

The aircraft operator's documented design objectives did not explicitly require the protection of non-structural systems from liquid contact or ingress.

Action taken by the aircraft operator

As a result of this occurrence, the aircraft operator is planning to include additional guidance on liquid management in its engineering design guide.

ATSB assessment of action

The ATSB is satisfied that the action proposed by the aircraft operator will, when the guidance is included in the operator's engineering design guide, adequately addresses the safety issue.

4.7.2 Flight crew training

Although no safety issue was identified in respect of the operator's flight crew training, in response to this occurrence, the aircraft operator:

- created an 'extensive training module on the electrical system of the 747-400, with dedicated scenarios including the OJM event - these training modules were

designed to increase the depth of system knowledge for new pilots to the aircraft and serve as a refresher to those who have been endorsed for some time'

- included extra flight crew training using standby instruments by degrading the aircraft's electrical system in two steps; initially operating on standby power, and finally using only the standby flight instruments
- promulgated information about the event through discussion items conducted with all 747-400 pilots during their cyclic training program and route (line) checks.

4.7.3 Aircraft instrumentation

Although no safety issue was identified in respect of the aircraft's instrumentation, in response to this occurrence, the aircraft operator initiated a project to install an integrated standby flight display (ISFD) system in its 747-400 fleet to facilitate aircraft navigation in the event of a complete failure of some or all main aircraft indication systems. The ISFD has the capability to provide an integrated, self-illuminating display of the following parameters for up to 150 minutes:

- pitch and roll attitude
- indicated airspeed
- altitude
- heading
- localiser and glideslope deviation.

The modification is planned for completion by the end of 2011. As of 25 October 2010, 15 aircraft had undergone the modification.

4.8 US Federal Aviation Administration

4.8.1 Liquid protection requirements and guidance for transport category aircraft

Significant safety issue

The United States Federal Aviation Administration regulations and associated guidance material did not fully address the potential harm to flight safety posed by liquid contamination of electrical system units in transport category aircraft.

Action taken by the ATSB

During the investigation, the ATSB discussed the background for this safety issue and the associated safety risk with the United States Federal Aviation Administration (US FAA). The potential for a reduction in the associated risk to as low as reasonably practicable by proactive US FAA safety action was highlighted.

The ATSB considers that the risk of ongoing or emerging design, operation and maintenance issues with the potential to result in liquid contamination of electrical system units in transport category aircraft could be significantly reduced over time by improved regulatory guidance and oversight. For example, existing designs and

processes should be monitored for continuing effectiveness while consideration of alternative design principles may be applied to new aircraft designs.

Action taken by the US FAA

The US FAA did not provide comment in response to this safety issue.

ATSB safety recommendation AO-2008-003-SR-109

The Australian Transport Safety Bureau recommends that the US FAA take safety action to address this safety issue.

5 APPENDIX A: APPLICABLE UNITED STATES FEDERAL AVIATION REGULATIONS

5.1 Protection of electrical equipment

Section (§) 25.1309 of the United States Federal Aviation Regulations (FAR) addresses a number of aspects of system installation, including electrical systems such as the aircraft's GCUs and BCUs:

> § 25.1309 Equipment, systems, and installations.
>
> (a) The equipment, systems, and installations whose functioning is required by this subchapter, must be designed to ensure that they perform their intended functions under any foreseeable operating condition.
>
> (b) The airplane systems and associated components, considered separately and in relation to other systems, must be designed so that—
>
> (1) The occurrence of any failure condition which would prevent the continued safe flight and landing of the airplane is extremely improbable, and
>
> (2) The occurrence of any other failure conditions which would reduce the capability of the airplane or the ability of the crew to cope with adverse operating conditions is improbable.
>
> (c) Warning information must be provided to alert the crew to unsafe system operating conditions, and to enable them to take appropriate corrective action. Systems, controls, and associated monitoring and warning means must be designed to minimize crew errors which could create additional hazards.
>
> (d) Compliance with the requirements of paragraph (b) of this section must be shown by analysis, and where necessary, by appropriate ground, flight, or simulator tests. The analysis must consider—
>
> (1) Possible modes of failure, including malfunctions and damage from external sources.
>
> (2) The probability of multiple failures and undetected failures.
>
> (3) The resulting effects on the airplane and occupants, considering the stage of flight and operating conditions, and
>
> (4) The crew warning cues, corrective action required, and the capability of detecting faults.
>
> (e) In showing compliance with paragraphs (a) and (b) of this section with regard to the electrical system and equipment design and installation, critical environmental conditions must be considered. For electrical generation, distribution, and utilization equipment required by or used in complying with this chapter, except equipment covered by Technical Standard Orders containing environmental test procedures, the ability to provide continuous, safe service under foreseeable environmental conditions may be shown by environmental tests, design analysis, or reference to previous comparable service experience on other aircraft.
>
> (f) EWIS must be assessed in accordance with the requirements of §25.1709.

FAR §25.1431 required electrical system units to be protected as follows:

> (a) In showing compliance with §25.1309 (a) and (b) with respect to radio and electronic equipment and their installations, critical environmental conditions must be considered.

5.2 Protection of electrical wiring interconnection systems

From 2007, FAR §25 subpart H defined separate requirements for equipment that was classified as part of an aircraft's electrical wiring interconnection systems (EWIS), which comprises the wiring and connectors used between main electrical system components. This section was applicable to new aircraft approvals after the FAR effectiveness date of 10 December 2007, and so did not apply to OJM.

The subpart defines EWIS as follows:

> § 25.1701 Definition.
>
> (a) As used in this chapter, electrical wiring interconnection system (EWIS) means any wire, wiring device, or combination of these, including termination devices, installed in any area of the airplane for the purpose of transmitting electrical energy, including data and signals, between two or more intended termination points. This includes:
>
> (1) Wires and cables.
>
> (2) Bus bars.
>
> (3) The termination point on electrical devices, including those on relays, interrupters, switches, contactors, terminal blocks and circuit breakers, and other circuit protection devices.
>
> (4) Connectors, including feed-through connectors.
>
> (5) Connector accessories.
>
> (6) Electrical grounding and bonding devices and their associated connections.
>
> (7) Electrical splices.
>
> (8) Materials used to provide additional protection for wires, including wire insulation, wire sleeving, and conduits that have electrical termination for the purpose of bonding.
>
> (9) Shields or braids.
>
> (10) Clamps and other devices used to route and support the wire bundle.
>
> (11) Cable tie devices.
>
> (12) Labels or other means of identification.
>
> (13) Pressure seals.
>
> (14) EWIS components inside shelves, panels, racks, junction boxes, distribution panels, and back-planes of equipment racks, including, but not limited to, circuit board back-planes, wire integration units, and external wiring of equipment.

(b) Except for the equipment indicated in paragraph (a)(14) of this section, EWIS components inside the following equipment, and the external connectors that are part of that equipment, are excluded from the definition in paragraph (a) of this section:

(1) Electrical equipment or avionics that are qualified to environmental conditions and testing procedures when those conditions and procedures are—

(i) Appropriate for the intended function and operating environment, and

(ii) Acceptable to the FAA.

(2) Portable electrical devices that are not part of the type design of the airplane. This includes personal entertainment devices and laptop computers.

(3) Fiber optics.

EWIS components are specifically required to be protected from liquid ingress from water/waste systems under §25.1707 of the FAR as follows:

§ 25.1707 System separation: EWIS.

(h) Except to the extent necessary to provide electrical connection to the water/waste systems components, EWIS must be designed and installed with adequate physical separation from water/waste lines and other water/waste system components, so that:

(1) An EWIS component failure will not create a hazardous condition.

(2) Any water/waste leakage onto EWIS components will not create a hazardous condition.

…

(k) For systems for which redundancy is required, by certification rules, by operating rules, or as a result of the assessment required by § 25.1709, EWIS components associated with those systems must be designed and installed with adequate physical separation.

EWIS are also specifically required to be protected from fuel and hydraulic fluids, heat, chafing, vibration, and other mechanical damage.

6 APPENDIX B: RELATED INCIDENTS

6.1 Serious incidents involving equipment failures that were attributed to liquid ingress

1. On 30 March 2006, the United States (US) National Transport Safety Board (NTSB) published several recommendations following a series of in-flight fires aboard Bombardier CRJ-200 aircraft.[45] The investigation found that the fires originated in a connector in the aircraft's avionics compartment. The NTSB reported that:

   > Various forms of precipitation were present before the departure of each incident flight and when the main cabin door is open on the CRJ-200, the forward cabin floor is exposed to the weather. Water on the floor can then seep into the avionics compartment below, where the contactor is located. Pulling the main entry door into the closed position may also result in water draining into the cabin area and subsequently into the avionics compartment.

   The NTSB recommended that the US Federal Aviation Administration (FAA) require: CRJ-200 operators to provide for the separation of electrical power sources to prevent the simultaneous loss of all electronic flight instrument system displays; require the aircraft manufacturer to develop a means of protecting certain electrical terminals from moisture-induced short circuits; require operators to install that protection once developed; and require the aircraft manufacturer to immediately evaluate the existing abnormal and emergency procedures for the CRJ-200 aircraft to determine whether they adequately addressed the potential fire hazards. These recommendations were classified by the Board as urgent.

2. On 1 April 2003, a US-registered Boeing Company 747-422 had a water leak in the cabin, followed by numerous flight control anomalies. The NTSB investigation[46] reported that circuit breakers on the electrical power supply to the external drain line heaters had been left open following routine maintenance. Post-incident testing showed that, with external drain masts blocked:

   > …water subsequently backed up through the upper deck galley refrigeration air chiller unit and flowed into the main cabin through the ceiling panels on the right side of the aircraft. The water subsequently drained into the canted pressure bulkhead below the main cabin floor, immediately forward of the aft wing spar.

   The NTSB investigation found that the inoperative drain line heaters had contributed to an impeded waste water drain system. Water from the resulting leak subsequently froze and restricted the movement of the aileron control cables.

3. On 7 January 2002, a Republic of Ireland-registered Airbus A300 sustained numerous system failures when on final approach to Copenhagen, Denmark at night in instrument meteorological conditions. The Danish Accident Investigation Board found that water in a potable water tank had frozen while

[45] NTSB Press Release SB-06-17.

[46] NTSB report CHI03IA097.

the aircraft was parked, causing a leak in the potable water system. Water under bleed air pressure then sprayed or leaked into the aircraft's generator control system that was located below the water supply line.

4. On 29 November 2000, a US-registered McDonnell Douglas DC-9-32 sustained numerous electrical system failures including tripped circuit breakers, and an in-flight fire. The fire damaged the aircraft's fuselage, cabin, forward cargo compartment, and an electrical disconnect panel. The NTSB investigation[47] reported that the leakage of lavatory fluid from the aircraft's forward lavatory onto electrical connectors caused electrical shorting that led to the fire. A dripshield was not installed above the connectors.

   The NTSB identified two other incidents of water ingress in the same area on C-9 aircraft, which was a military version of the DC-9:

   > On September 21, 1999, the flight crew of a U.S. Air Force (USAF) C-9A observed several warning lights illuminate and, immediately thereafter, heard numerous circuit breakers pop in succession. Details provided by the USAF indicated that lavatory fluid had leaked beneath the lavatory floor, leading to shorting, arcing, and fire damage to electrical components in the area of the forward cargo compartment. Additionally, on May 26, 2001, the flight crew of another C-9A noticed several warning lights illuminate and heard circuit breakers pop. Investigation revealed damage to electrical components in the forward cargo compartment area, which was caused by shorting and arcing from fluid saturation. Dripshields were installed above the FS [fuselage station[48]] 237 disconnect panels on both airplanes.

   As a result of the 29 November 2000 incident, the aircraft manufacturer issued a service letter stressing the importance of properly servicing and draining lavatory waste tanks and sealing floor panels in areas of probable fluid contamination.

5. On 22 October 1995, a United Kingdom (UK)-registered Boeing Company 737-236 aircraft sustained uncommanded roll and yaw oscillations as a result of water ingress into the aircraft's avionics components. The UK Air Accidents Investigation Branch (AAIB) investigation reported that: [49]

   > The location of the Electronic and Equipment (E&E) Bay, beneath the cabin floor in the area of the aircraft doors, galleys and toilets made it vulnerable to fluid ingress from a variety of sources.

   The report made a number of recommendations, as follows:

   > It is recommended that the FAA:
   >
   > > Require as soon as practical a visual inspection of all Boeing 737 aircraft Electrical and Equipment (E&E) Bays to check for fluid ingress into avionics components, their connectors and associated wiring. Such inspection should involve the minimum disturbance of equipment and connectors commensurate with a thorough examination for contamination. Where such contamination is found, the component should be removed and despatched to workshops for examination.

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[47] NTSB report DCA01MA005.

[48] Fuselage station: a locating system along the longitudinal axis of an aircraft.

[49] AAIB incident report 1/98.

> Require as soon as practical an inspection of the area in and around the E&E Bay for evidence on the structure and fittings of recent fluid leakage such as wet corrosion, staining and crystallised deposits. Such evidence should be investigated to ensure that, where the source of the leak is not apparent or readily rectifiable, no potential exists for it to impinge upon the avionics components, their connectors or wiring. (Recommendation 96-3)

It is recommended that the FAA and Boeing:

> Conduct an urgent review of the measures incorporated into the Boeing 737 to prevent fluid ingress into the E&E Bay, its equipment, connectors and wiring and as necessary require modifications to ensure that the equipment, connectors and wiring are provided with protection consistent with reliable operation.
>
> Conduct a review of the Aircraft Maintenance Manual to ensure that clear and specific instructions are contained therein to enable evidence of fluid ingress, even if not apparently directly impinging on electrical equipment, to be identified during routine maintenance. It should also be ascertained that any routine testing for leaks in the toilet, galley and air stairs systems should be done with the systems functioning fully throughout their normal operational cycle to ensure that any leaks which only occur during, for example, draining or replenishment cycles are detected. (Recommendation 96-4)

It is further recommended that:

> The Boeing Airplane Company promulgate the findings of the E&E Bay Assessment Team to all operators and that the recommendations be actioned through Service Bulletins to maximise the protection from fluid ingress of bay housed electronic components in current aircraft. (Recommendation 97-60)
>
> The CAA[50] with the FAA review FARs[51] and JARs[52] with a view to requiring that the location of electronic equipment be arranged during the aircraft design so as to minimise the potential for contamination by fluid ingress, with the intention of ensuring that the equipment, connectors and wiring are provided with protection consistent with reliable operation less heavily dependant on maintenance practices. (Recommendation 97-61)

On 16 June 1994, the Boeing Company released service bulletin 737-25-1317 requiring the installation of a redesigned dripshield on all 737-300, 737-400 and 737-500 aircraft.

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50 CAA: UK Civil Aviation Administration.

51 Federal Aviation Regulations: Rules that govern aviation activities within the US.

52 JAR: Joint Aviation Requirements, rules that govern aviation activities within certain European countries.

The UK CAA did not accept UK AAIB recommendation 97-61 as follows:

> The type certification basis of the Boeing 737-200 did not contain specific requirements in respect of minimisation of fluid ingress, nor was there any guidance material available at the time of initial certification in July 1968. Guidance material which addressed the issue of fluid contamination was first published in FAA Advisory Circular (AC) 25.1309-1 in September 1982, and hence did not apply to this type.
>
> The Authority is satisfied that the current JARs contain adequate guidance to protect against contamination of electronic equipment by fluid ingress. In particular, ACJ No 2 to JAR 25.1309 and AMJ 25.1309 7e(3) contain specific guidance material. FAA Advisory Circular AC 25.1309-1A paragraph 7e(3) contains equivalent guidance material to that provided in AMJ 25.1309.

6. On 18 July 1995, a US-registered Boeing Company 737-3B7 sustained an uncommanded roll to the left during descent. The NTSB investigation[53] reported that electrical connector plugs and a wiring harness in the aircraft's electronics compartment were contaminated with blue residue and water. The investigation reported that the sources of contamination were water from a leak in the main cabin door drain and from a previous leak from the forward lavatory.

6.2 Serious incidents involving equipment failures that were not attributed to liquid ingress

1. On 22 September 2008, a US-registered Boeing Company 757-223 depleted its batteries in flight and veered off a runway on landing. Preliminary findings by the NTSB[54] indicated that the crew had switched the aircraft to battery power in response to fault messages that were displayed in the cockpit. The crew continued the flight after receiving guidance from the operator's maintenance personnel. The aircraft's batteries were depleted about 100 minutes after takeoff, and numerous aircraft systems were degraded or inoperable as a result. The flight crew reported difficulties with pitch control and the aircraft's brakes. The NTSB's preliminary findings indicated that the information provided by the aircraft's systems and the operator's quick reference handbook (QRH) did not enable the crew to accurately diagnose the problem and act accordingly.

[53] NTSB report MIA95IA187.

[54] NTSB report CHI08IA292.

In a Safety Recommendation published on 24 April 2009, the NTSB reported that: [55]

> On January 13, 2009, the Federal Aviation Administration (FAA) issued Safety Alert for Operators (SAFO) 09001, "Effects of Aircraft Electrical Faults Resulting in Main Battery Depletion," which recommended improved procedures and training for resolving electrical failures without depleting the main battery. The SAFO recommended that directors of safety, directors of training, directors of operations, trainers, and check airmen for operators of transport category aircraft review additional, irregular, non-normal, and emergency procedures for electrical difficulties to ensure that they conform to manufacturers' recommended procedures. SAFO 09001 also recommended that operators:
>
> • Review their QRH or other procedural guidance to ensure that the procedures resolve problems rather than introduce other complications;
>
> • Reemphasize or develop procedures that supplement any QRH electrical loss procedure to include consideration to divert to another airport, plans to land on the longest available runway, and preparation in the event of an equipment loss; and
>
> • Ensure that their airplane flight manual and training accurately reflect abnormal indications and inoperative systems that result when main battery power is depleted.
>
> However, the Board does not consider these improvements to be sufficient because SAFOs are not mandatory nor do they necessarily have a long-term impact. Improved procedures should be specified and required because of the potential severity of loss of battery power.

2. On 25 January 2008, a US-registered Airbus A320 sustained multiple avionics and electrical failures, including the loss of all communications shortly after rotation. The flight returned for landing with several aircraft systems inoperative, including the captain's primary flight display (PFD) and navigation display (ND), the upper electronic centralised aircraft monitoring (ECAM) display, the aircraft's transponder, the traffic alert and collision avoidance system, and the standby attitude indicator. The NTSB's investigation of this incident is ongoing. Preliminary findings indicate that a fault occurred in the aircraft's AC 1 electrical bus, one of the two primary electrical distribution systems for the aircraft, which in turn caused a number of other electrical buses on the aircraft to lose power and the loss of a number of aircraft displays and systems. On 22 July 2008, the NTSB issued six recommendations, including:[56]

> …that the European Aviation Safety Agency and Federal Aviation Administration: Require all operators of A320 aircraft to develop new procedures, if necessary, and to provide flight crews with guidance and simulator training regarding the symptoms and resolution procedures for the loss of flight displays and systems in conjunction with an AC 1 electrical bus failure.

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[55] NTSB Safety Recommendations A-09-41 and A-09-42 and published correspondence.

[56] NTSB Safety Recommendations A-08-53 through A-08-55 and published correspondence.

The NTSB stated in its supporting correspondence:

> The Safety Board notes that the multiple system losses associated with an AC 1 electrical bus failure [in A320 aircraft] can create a challenging situation for crews attempting to identify the nature of the fault and determine the best course of action for correcting the problem. For example, during [the incident flight on 25 January 2008], the crewmembers noted that the multiple messages on the ECAM system, which provides information to the crew regarding failures that have occurred on the aircraft along with recommended corrective actions, were being displayed then removed by the ECAM system so quickly that they were unable to interpret and address the error messages.
>
> …
>
> The Safety Board is concerned that the blanking of electronic displays and failure of multiple aircraft systems can pose a significant safety risk during all phases of flight but especially when an airplane is operating close to the ground (such as during takeoff and landing) or during approach operations under instrument conditions. The Board is especially concerned about a failure under such circumstances because of the increased pilot workload and potential for crew distraction associated with managing the failure.
>
> …
>
> The Safety Board's investigation also found that not all operators have informed their pilots or provided training regarding the symptoms and resolution for an AC 1 electrical bus failure. In some cases during these events, experienced A320 pilots were unable to rapidly identify the nature of the fault to initiate corrective action… Crew attempts to troubleshoot unusual or unforeseen systems problems, especially during critical phases of flight, may lead to more serious problems or even loss of aircraft control.

The NTSB reported that prior to May 2007, 49 incidents similar to the 25 January 2008 occurrence had taken place in which the failure of electrical buses on A320 family aircraft resulted in the loss of flight displays and various aircraft systems. Ten of those events resulted in the loss of five of the aircraft's six main cockpit displays, and a further seven events resulted in the loss of all six displays.

3. On 15 September 2006, a UK-registered Airbus A319 sustained an electrical failure that caused numerous aircraft systems to become degraded or inoperative, including the aircraft's transponder and radios. The aircraft landed without further incident. The investigation[57] identified a fault in the aircraft's No 1 GCU, resulting in a loss of the left electrical bus, and found contributing factors relating to the manual diversion of power between buses. The AAIB made 14 recommendations as a result of the investigation.

4. On 22 October 2005, a UK-registered Airbus A320 sustained an electrical failure that resulted in five out of the six flight displays going blank. In addition, the autopilot and autothrust systems disconnected, the very high frequency radio and intercom became inoperative, and most of the cockpit lighting extinguished. After troubleshooting the problem, the flight crew was able to restore power to the displays and most of the affected systems by reconfiguring the electrical system to provide power from the AC 2 electrical bus. The AAIB investigated

[57] AAIB incident report 4/2009.

this incident,[58] but was unable to determine the contributing factors due to a lack of available evidence. The AAIB made 13 recommendations, including:

> Safety Recommendation 2007-062: It is recommended that the European Aviation Safety Authority should, in consultation with other National Airworthiness Authorities outside Europe, consider requiring training for flight by sole reference to standby instruments for pilots during initial and recurrent training courses.

6.3 Other incidents

As a result of this occurrence, the aircraft operator reviewed the technical logs of its 747-400 fleet and identified various periods of 'galley, drain system, and/or toilet performance difficulties including water leaks and/or poor water pressure issues'. That included a number of incidents on OJM.

In addition, the aircraft manufacturer reported that a number of electrical-water ingress events have occurred on various 747 freighter and combi[59] aircraft. Those aircraft have an electrical equipment bay in the same location as 747 passenger aircraft, but with a different equipment rack and dripshield design. The aircraft manufacturer had published a multi-operator message providing instructions for checking and repairing the dripshields on those aircraft.

A review of reported water-electrical incidents confirmed that this problem is not aircraft type specific. A number of those incidents follow.

On 16 June 2010, during the scheduled maintenance of a Boeing Company 747-438, water contamination of electrical equipment in the E2 rack was observed. No in-flight effects were reported. The operator reported that the top surface of the MEC dripshield plenum was cracked, and water staining indicated that the final stages of the water contamination path was from the main deck floor onto the top surface of the plenum, through the cracks in the top surface of the plenum, and through the air distribution holes in the bottom surface of the plenum.

On 11 July 2009, a flight deck toilet overflowed in a Boeing Company 747-438 due to a solenoid fault. The aircraft's upper deck floor was soaked and water leaked through the ceiling into the main deck. The aircraft diverted as a precaution due to the possibility of water leakage into the main equipment centre and main holds. Subsequent inspections found no damage to electronic systems.

On 26 February 2009, a substantial amount of water pooled on the main deck of a Boeing Company 747-438, aft of the overwing galley. Inspections identified that the forward drain mast heater was not operational.

On 17 February 2008, an Airbus A330 sustained a leak from a galley drain.

On 14 February 2008, a Boeing Company 747-438 sustained a leak from a galley drain.

On 6 February 2008, an Airbus A330 sustained a leak due to a blocked galley drain.

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[58] AAIB incident report 2/2008.

[59] Combi: a combination freighter and passenger aircraft.

On 26 July 2004, a Boeing Company 717-200 sustained a leak from the hand basin in the aft lavatory that resulted in an electrical short in nearby interphone wiring.

7 APPENDIX C: SOURCES AND SUBMISSIONS

Sources of Information

The sources of information during the investigation included the:

- flight crew of VH-OJM (OJM)
- customer service manager of OJM
- aircraft operator
- aircraft manufacturer
- aircraft maintenance providers
- generator control unit (GCU) and bus control unit (BCU) manufacturer
- the United States (US) Federal Aviation Administration (FAA).

Submissions

Under Part 4, Division 2 (Investigation Reports), Section 26 of the *Transport Safety Investigation Act 2003* (the Act), the Australian Transport Safety Bureau (ATSB) may provide a draft report, on a confidential basis, to any person whom the ATSB considers appropriate. Section 26 (1) (a) of the Act allows a person receiving a draft report to make submissions to the ATSB about the draft report.

A draft of this report was provided to the Civil Aviation Safety Authority, the flight crew and customer service manager of OJM, the aircraft operator, the aircraft manufacturer, the aircraft maintenance providers, the GCU and BCU manufacturer, the US National Transportation Safety Board and Federal Aviation Administration, and the Department of Civil Aviation in Thailand.

Submissions were received from the aircraft manufacturer, the aircraft captain and the aircraft operator. The submissions were reviewed and, where considered appropriate, the text of the report was amended accordingly.

Electrical system event
25 km NNW of Bangkok International Airport, Thailand
7 January 2008
VH-OJM
Boeing Company 747-438