AIRCRAFT ACCIDENT REPORT 1/2014

AAIB

Air Accidents Investigation Branch

Report on the accident to Airbus A330-343, G-VSXY London Gatwick Airport 16 April 2012

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This report contains facts which have been determined up to the time of publication. This information is published to inform the aviation industry and the public of the general circumstances of accidents and serious incidents.

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Air Accidents Investigation Branch
Farnborough House
Berkshire Copse Road
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Hampshire   GU11 2HH

January 2014

The Right Honourable Patrick McLoughlin
Secretary of State for Transport

Dear Secretary of State

I have the honour to submit the report by Mr R D G Carter, an Inspector of Air Accidents, on the circumstances of the accident to Airbus A330-343, registration G-VSXY at London Gatwick Airport on 16 April 2012.

Yours sincerely

Keith Conradi
Chief Inspector of Air Accidents

Contents

GLOSSARY OF ABBREVIATIONS USED IN THIS REPORT

AAIB	Air Accidents Investigation Branch
ACARS	Aircraft Communications Addressing and Reporting System
AGI	Aircraft Ground Incident
AMCS	adaptive microprogrammed control system
APU	Auxilary Power Unit
ASDA	Accelerate Stop Distance Available
ATC	Air Traffic Control
ATP	Acceptance Test Procedure
BEA	Bureau d'Enquêtes et d'Analyses
BITE	Built-In Test Equipment
CAA	Civil Aviation Authority
CAN	Controller Area Network
CAP	Civil Aviation Publications
CIDS	Cabin Intercommunication Data System
CMS	Central Maintenance System
CVR	Cockpit Voice Recorder
DAR	Digital ACMS Recorder
DME	Distance Measuring Equipment
EASA	European Aviation Safety Agency
ECAM	Electronic Centralised Aircraft Monitor
FCOM	Flight Crew Operations Manual
FDR	Flight Data Recorder
FEDC	Fire Extinguishing Data Converter
FIN	Functional Item Number
FSM	Flight Service Manager
ft	feet
FWC	Flight Warning Computer
hrs	hours (clock time as in 1200 hrs)
ICAO	International Civil Aviation Organization
ILS	Instrument Landing System
KHz	kilohertz
km	kilometre(s)
kt	knot(s)
LDA	Landing Distance Available
LDCC	Lower Deck Cargo Compartment
lbf	pounds force
m	metre(s)
MCDU	Multifunction Control and Display Unit
MEL	Minimum Equipment List
MHz	megahertz
MLW	Maximum Landing Weight
MTOW	Maximum Takeoff Weight
NITS	Nature, Intention, Time, Special Instructions
NVM	Non-Volatile Memory
PA	Public Address
PCB	printed circuit board
PET	Polyethylene terephthalate
PF	pilot flying
POB	Persons On Board
RFFS	Rescue and Fire Fighting Service
RH	relative humidity
RTF	radiotelephony
RTO	Rejected Takeoff
RVP	Rendezvous Point
SDF	Smoke Detection Function
SDS	Smoke Detection System
SEM	Scanning Electron Microscope
SEP	Safety Equipment Procedures
SMS	Safety Management System
SOP	Standard Operating Procedure
TC	Terminal Controller
TODA	Takeoff Distance Available
TOI	Temporary Operating Instruction
TORA	Takeoff Run Available
TOW	Takeoff Weight
TSD	Troubleshooting Data
UK	United Kingdom
UTC	Co-ordinated Universal Time (GMT)
°C,M,T	degrees Celsius, magnetic, true
%/m	Percentage obscuration per metre

Air Accidents Investigation Branch

Aircraft Accident Report No: 1/2014 (EW/C2012/04/05)

Registered Owner and Operator:	Virgin Atlantic Airways
Aircraft Type:	Airbus A330-343
Nationality:	British
Registration:	G-VSXY
Place of Accident:	London Gatwick Airport
Date and Time:	16 April 2012 at 1131 hrs

Synopsis

The Air Accidents Investigation Branch (AAIB) was notified of this occurrence by Virgin Atlantic Airways shortly after it happened and the investigation was started the same day.

The occurrence was initially classified by the AAIB as a Serious Incident. However, when it became clear that two passengers had incurred injuries defined as Serious, the occurrence was reclassified as an Accident, in accordance with ICAO Annex 13 and the United Kingdom's 'Civil Aviation (Investigation of Air Accidents and Incidents) Regulations 1996'. This classification as an Accident does not reflect the state of the aircraft, which sustained only very minor damage, during the evacuation.

In accordance with established international arrangements, the Bureau d'Enquêtes et d'Analyses (BEA) in France, representing the State of Design and Manufacture of the aircraft, appointed an Accredited Representative and was supported by a team which included advisors from Airbus, the aircraft manufacturer, and Siemens, systems manufacturer. The aircraft operator has co-operated with the investigation and provided expertise as required. The Civil Aviation Authority (CAA) and the European Aviation Safety Agency (EASA) have been kept informed of developments.

The aircraft was operating a flight from London Gatwick Airport to McCoy International Airport in Orlando, USA with three flight crew, 10 cabin crew and 304 passengers on board including three infants. Early in the flight the crew received a series of smoke warnings from the aft cargo hold and the commander elected to return to London Gatwick. The crew carried out the appropriate emergency drills, including the discharge of the fire extinguishers in the aft cargo hold, but the smoke warnings continued. The aircraft landed safely, the crew brought it to a halt on the runway and endeavoured to establish the extent of any fire. This produced conflicting evidence and, with smoke warnings continuing, the commander ordered an emergency evacuation.

The passengers all left the aircraft within 90 seconds but two injuries, classed as 'Serious', were incurred. Subsequent examination of the aircraft and its systems showed that the smoke warnings had been spurious.

The investigation identified that injuries were sustained during the evacuation of the aircraft. The evacuation was initiated based on the commander's assessment of the available sources of information, including the repetitive and intermittent nature of the aft cargo smoke warnings.

The investigation identified the following causal factor for the intermittent cargo smoke warnings:

(i) A latent fault on the T1 thermistor channel of smoke detector 10WH, in combination with a CAN Bus fault and possible high levels of humidity in the cargo compartment due to the carriage of perishable goods, provided circumstances sufficient to generate multiple spurious aft cargo compartment smoke warnings.

The investigation identified the following contributory factors for the intermittent cargo smoke warnings:

(i) The thermal channel fault in 10WH was not detected prior to the event by the internal smoke detector temperature monitoring.

(ii) The proximity of the fire extinguisher nozzles to the smoke detectors.

1 Factual Information

1.1 History of the flight

1.1.1 The departure and climb from London Gatwick Airport

G-VSXY was operating a flight from London Gatwick Airport to McCoy International Airport in Orlando, USA with three flight crew, 10 cabin crew and 304 passengers on board including three infants. The flight took off from Runway 08R at 1048 hrs with the commander operating as the pilot flying (PF) and turned towards the south-west.

At 1103 hrs the aircraft was near Bournemouth en route to waypoint LORKU[1] and climbing through FL187 when a SMOKE AFT/BULK CARGO SMOKE Master Warning was displayed for seven seconds on the ECAM[2] Engine and Warning Display. After a short pause, the warning returned for nine seconds. The third crew member advised the commander that he would go into the cabin to see if he could detect any smoke or fire. The commander contacted the operator's engineering department on the radio to see whether the aircraft had sent any failure messages over ACARS[3] but, as he was explaining what had happened, the warning activated again. He ended his discussion with the engineering department and told the co-pilot that they would need to return to London Gatwick Airport.

The co-pilot, who had recently been instructed by London Control to contact Brest ATC, informed the controller that the aircraft "HAD A TECHNICAL PROBLEM" and required routing towards London Gatwick Airport. The controller misunderstood this transmission, gave the crew their routing through her airspace and asked for their requested cruising flight level. The commander declared a PAN and asked for vectors back to London Gatwick Airport stating that there was "SMOKE IN THE CARGO HOLD". As he made his transmission, the smoke warning reappeared for five seconds. The controller said that she would call him back shortly to which the commander replied that he was turning the aircraft back towards London Gatwick Airport. The controller acknowledged this message and gave him a frequency to call London Control. The aircraft was levelled at FL220 and began a left turn onto a heading of 045ºM.

1 LORKU: an ATC waypoint located approximately 14 nm north of Alderney.
2 ECAM: Electronic Centralised Aircraft Monitor.
3 ACARS: Aircraft Communications Addressing and Reporting System, a digital datalink between aircraft and ground stations.

1.1.2 The return to London Gatwick Airport

The crew carried out the actions displayed on the ECAM display for the SMOKE AFT/ BULK CARGO SMOKE warning, which involved discharging fire extinguishing agent into the aft cargo hold, and contacted London Control. The smoke warning appeared again for five seconds as the fire extinguishing agent was being discharged. Eighteen seconds after discharge, the smoke warning activated again and this time it remained on for a period of 2 min and 53 seconds.

With the aircraft being flown by the co-pilot, the commander said "FSM TO THE FLIGHT DECK" on the PA[4] system to instruct the Flight Service Manager (FSM) to report to the flight deck for a briefing. As part of the briefing, the commander told her that after landing "IF THERE IS NO INDICATION FROM AIR TRAFFIC CONTROL WE WILL TAXI IN BUT IF THERE IS ANY SIGN THAT THERE IS SMOKE WE MAY HAVE TO EVACUATE BUT NOT UNTIL YOU HEAR MY INSTRUCTIONS". The FSM repeated the content of the briefing and left the flight deck. The third crew member, who had by now returned to the flight deck, informed the commander that he had been unable to detect any sign of fire or smoke in the cabin. During the period in which the events in this paragraph occurred, the smoke warning activated intermittently a further two times, each time for 11 seconds.

After making contact with London Control, the co-pilot requested a descent and confirmed with ATC that it would be an overweight landing because the aircraft type was unable to jettison fuel. During the descent, the commander made an announcement to the passengers advising them that there had been "AN INDICATION" in the cockpit and they were returning to London Gatwick Airport. The crew prepared for landing and carried out the '*OVERWEIGHT LANDING*' checklist. As the aircraft routed towards the airport, the smoke warning activated another three times.

At 1124 hrs the aircraft was established on the ILS approach for Runway 08R and began its final descent. At 8 nm from the runway, the flight crew transferred to the Tower frequency and the commander advised the controller that the aircraft would stop on the runway to allow the airport's Rescue and Fire Fighting Service (RFFS) to inspect it. He then briefed the co-pilot and third crew member that if necessary they would conduct an evacuation on the runway. He then added "AS SOON AS WE LAND I AM GOING TO SAY CABIN CREW STANDBY. WHEN WE HAVE STOPPED". Figure 1 shows the track flown by the aircraft along with the locations where the aft cargo compartment smoke warnings were triggered.

[4] Public Address.

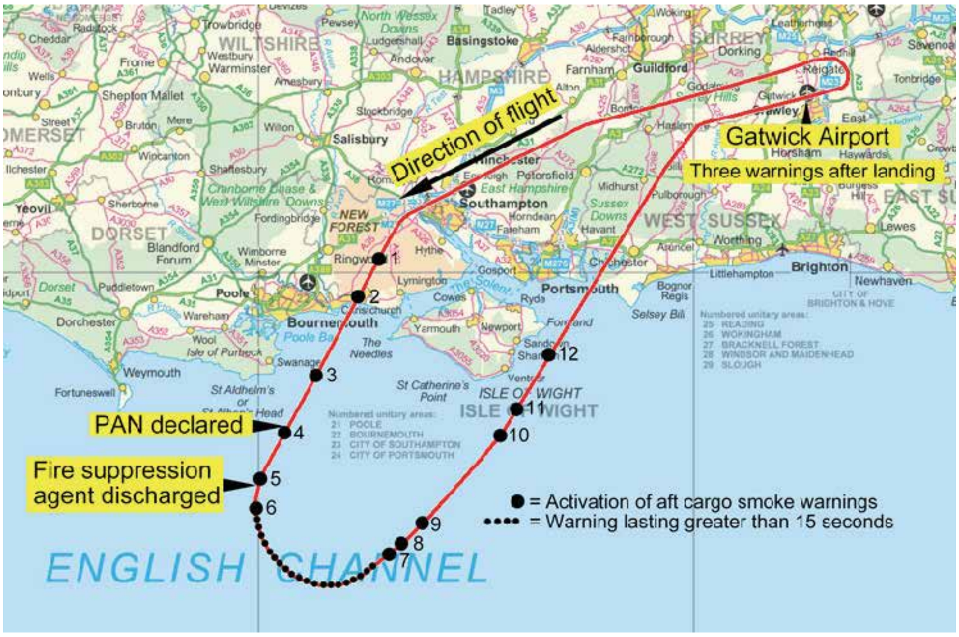


Figure 1

Flight track showing the activation of aft cargo smoke warnings (times in Figure 9)

1.1.3 The landing and evacuation

As the aircraft descended through 950 ft agl, the commander disconnected the autopilot in order to fly a manual landing. The aircraft touched down at 1127 hrs at 158 kt and above the certificated maximum landing weight. The commander used maximum reverse thrust and medium autobrake to slow the aircraft and it came to a halt approximately 1,630 m from the threshold of Runway 08R. He gave the order "CABIN CREW REMAIN SEATED" over the PA system and set the parking brake at 1127:57 hrs with the engines at idle and the APU running (it had been started shortly before landing).

The Tower controller instructed the crew of G-VSXY to contact the RFFS on frequency 121.600 MHz but the commander was unable to make contact and so he returned to the Tower frequency. He asked the controller if there were any signs of smoke from the rear of the aircraft and the controller replied "I DON'T SEE ANY SMOKE FROM HERE...... ALL APPEARS TO BE NORMAL AT THIS STAGE".

The aircraft was then contacted by the RFFS, callsign 'Fire 1', on frequency 121.600 MHz who said "I UNDERSTAND YOU MIGHT HAVE HAD SMOKE IN THE COCKPIT, CAN YOU TELL ME THE CONDITIONS ON BOARD?" The commander explained that the smoke warning was from the aft cargo hold, that there had been numerous warnings and that they had discharged the extinguishing agent into the compartment. He also asked whether there was any smoke coming from the rear of the aircraft.

Fire 1 said he would do an inspection but first he required the commander to confirm that the parking brake was set, the radar was off, and the engines were at idle. While Fire 1 was speaking, the Tower controller said "IT LOOKS LIKE THERE MAY JUST BE A LITTLE BIT OF SMOKE AT THE BOTTOM OF THE LEFT-HAND ENGINE". The commander answered Fire 1, confirming what had been asked, and then asked the co-pilot what the Tower controller had said. Before the co-pilot could answer, Fire 1 asked for the taxi lights to be turned off and the smoke warning was triggered again.

The commander advised Fire 1 that there had been another smoke warning and that there might be a need to evacuate although not immediately. Fire 1 acknowledged this message and confirmed that all exits were clear. The co-pilot told the commander that the controller might have seen some smoke but, although the commander was alarmed by what he heard, he said that they would be remaining on board for the moment. He asked Fire 1 to inspect the rear of the aircraft. When Fire 1 reached the rear of the aircraft he said to the commander "THERE APPEARS TO BE NOTHING UNTOWARD BUT YOU'VE GOT THE DRAFT FROM THE ENGINES THAT MAY BE DISSIPATING ANYTHING. I AM UNABLE TO TELL". While he was saying this, the smoke warning sounded once more and the commander said to Fire 1 "WE ARE STILL GETTING WARNINGS WE UNFORTUNATELY WILL HAVE TO EVACUATE THE AEROPLANE". Fire 1 advised that all fire appliances were clear. The commander declared a MAYDAY on the Tower frequency advising that the aircraft was being evacuated and, just as he finished transmitting, the smoke warning activated again. The crew ran through the ON GROUND EMER / EVACUATION checklist at 1131 hrs and evacuated the aircraft.

1.1.4 Information from flight crew interviews

At first, the commander had thought the smoke warning was probably a spurious fault. After it had triggered three times, however, he decided that it would be prudent to carry out the appropriate checklist items and return to London Gatwick Airport. The co-pilot stated that he was "very aware" that the warning continued even after the checklist actions had been carried out.

After the aircraft came to a halt, the commander wanted to maintain control of the cabin and so instructed the cabin crew to remain seated. He said that it was a difficult decision to evacuate the aircraft but, when the warning continued, he decided that evacuation was the safest course of action.

The commander commented that pilot training might predispose pilots to make decisions to evacuate in such circumstances. In order to train for an evacuation, simulator sessions often end with the aircraft on the ground with a fire or smoke warning which remains and crews are expected to evacuate the aircraft.

1.1.5 Information from cabin crew interviews

1.1.5.1 Events while airborne

When the commander summoned the FSM to the flight deck, his PA was unclear to nearly all of the cabin crew, most of whom only heard the word "FLIGHTDECK". Some crew interpreted the message as an instruction for the third flight crew member to return to the flight deck. The cabin crew member standing outside the flightdeck was the only person who understood the PA but it was said so fast it took a second for her to realise what had been said. She told the FSM what the message had actually been and then passed the message by cabin interphone to the crew at the rear of the aircraft.

When the FSM left the flightdeck after her briefing from the commander, she expected to find half of the cabin crew waiting for a briefing at the galley by the L1[5] door. In fact, they were waiting at the galley by the L2 door and the FSM had to summon them to her location by PA to give them their briefing.

1.1.5.2 Events on the ground

After landing, the commander made the PA "CABIN CREW REMAIN SEATED" which led them to believe that an evacuation would not be necessary[6]. They were taken by surprise, therefore, when the commander subsequently gave the instruction to evacuate.

During the evacuation, the slide at the R4 door did not inflate properly and so the cabin crew member at that door redirected passengers towards the L4 door. Otherwise, cabin crew members reported that the evacuation was conducted in accordance with Standard Operating Procedures (SOPs) although many reported that the speed of descent down the slide was higher than expected. One stated that it was "more violent than in training"; another that "the slide is a lot faster [than expected] and can really hurt"; and another that "the slide experience was very fast and painful".

Passengers were generally quiet throughout the evacuation, which had come as a surprise to the cabin crew. Some passengers stopped to try and bring their bags with them and had to be told to leave them behind. Passengers evacuated at a good rate although some hesitated at the door and needed encouragement to jump onto the slide. Most passengers were cautious when they reached the doors and most did not jump onto the slides in pairs. Many passengers were seen to land awkwardly at the bottom of the slide and one lady was observed to fall onto the tarmac after which passengers following

[5] Doors are referred to as follows: L and R refer to the side of the aircraft; and 1 to 4 refers to the number of the door working rearwards from the front of the aircraft.

[6] See paragraph 1.17.1 for an explanation of the specific meaning of alert and stand down PAs.

behind collided into her. At one exit, the fireman at the bottom of the slide asked the crew to slow down the rate that passengers were leaving until the blockage at the bottom of the slide could be cleared. One man was injured at the bottom of a slide and was being attended by paramedics, which slowed the evacuation until he could be moved.

After the evacuation, the FSM was asked by the police to assemble her crew and stay together as a group away from the passengers.

1.1.6 Information from the Airport Fire and Rescue Service (RFFS)

After the aircraft landed, two fire vehicles entered the runway and followed it until it stopped. The RFFS had been told that the aircraft had smoke in the cockpit and therefore the vehicles positioned towards the front of the aircraft. RFFS procedures required Fire 1 to contact the commander to establish the facts of the incident, to understand his or her intentions, and to give advice. After hearing from the commander that the problem was, in fact, possible smoke in the aft cargo hold, Fire 1 repositioned a vehicle to the rear.

Following the decision to evacuate, the RFFS manned the escape slides to assist passengers and limit injuries. A number of passengers landed awkwardly at the bottom of the slides and many toppled forward onto the concrete suffering minor injuries. Passengers on the slides were very close to each other and many did not have time to clear the area at the bottom of the slide before being hit by the following passenger. At the bottom of one slide, a fireman tried to protect those already lying on the floor from those coming down the slide by lying across the bottom of the slide.

An airport vehicle near to the aircraft was broadcasting the message "COME THIS WAY" to passengers at the bottom of the slides to direct them to the evacuation area on the grass to the right side of the aircraft. When all the passengers had evacuated the aircraft, the RFFS searched it to confirm that there was no one left on board.

The RFFS was equipped with thermal imaging cameras to look for sources of heat. Such devices are only able to see heat spots that are detectable on the outside of the aircraft skin and are unable to see through pallets within the cargo hold to potential heat spots deeper within. A 'high loader' vehicle was brought to the aft cargo bay and three cargo pallets were removed to create space for a thorough inspection. Once sufficient space had been created, it was discovered that there was no smoke present and that there were no heat spots.

It was also noted by the RFFS that there was smoke rising from the brakes on the left and right landing gear.

Fire 1 commented that when extinguishers are operated in the confined space of a cargo hold it will inevitably trigger the fire detector.

1.1.7 Information from Air Traffic Control

The ATC planner for the area in which G-VSXY had its smoke warning received a phone call from the Brest controller advising that the aircraft had "smoke on board" and was diverting back to London Gatwick Airport. This information was passed on as "smoke in the cockpit" to the London Terminal Controller (TC) and the Watch Manager at the airport who declared a Full Emergency for an aircraft with smoke in the cockpit. The planner stated subsequently that he had just completed his Training in Unusual Circumstances and Emergencies (TRUCE) and the training scenario included an aircraft with a suspected fire on board. In addition, the garbled sounding RTF led him to believe that the pilots were using oxygen masks and that therefore there was smoke in the cockpit.

At 1132 hrs, one minute after the evacuation commenced, the incident commander on the ground asked for the emergency to be upgraded to an Aircraft Ground Incident (AGI) and, at 1133 hrs, the runway was closed[7]. When an AGI is declared by ATC, it serves to alert and provide support from off-airport emergency services. His request was relayed to the ATC Watch Manager by a phone call from the fire station watch room. Due to background noise on the phone line, the message was misunderstood and the Watch Manager believed that the RFFS was asking whether ATC was going to upgrade the emergency to an AGI. The Watch Manager answered that this was not necessary because "if it's already a Full Emergency we don't need to upgrade". At 1137 hrs, the incident commander called ATC on the radio to request that the incident be upgraded to an AGI because of the need for local authority fire service support and the Watch Manager declared an AGI at 1139 hrs.

The procedures for declaring an AGI, which presumed that the incident had not led on from a previous event, required the nature of the problem to be promulgated by ATC on both the 'crash line' and 'emergency line'. There were no procedures within the orders to upgrade to an AGI from a Full Emergency and, in this case, the Watch Manager did not include the nature of the problem when he made his upgrade call on the crash line and he did not make a follow-up call on the emergency line. Consequently, airport and off-airport agencies were not informed during these calls, that the aircraft had been evacuated on the runway and had to be informed separately.

[7] The airport was reopened using Runway 08L at 1300 hrs.

1.1.8 Information from the airport operator

Airfield Operations vehicles were used to escort other agencies' vehicles from the Rendezvous Points (RVP) to the aircraft, and the Operations vehicles' 'matrix boards' and loudspeakers were effective in conducting passengers away from the aircraft. The incident highlighted that local police officers were prevented from driving airside and were required to wait for an escort from the RVP.

The responding agencies considered it would have been better to have had an early indication of POB[8], having only received the message "POB to be advised". Also, the message they received was that there was smoke in the cockpit, which set a different context for the responders to that of a warning light indicating a fire. A message was passed that there were 30 smoke inhalation injuries, which was not accurate.

1.2 Injuries to persons

Injuries	Crew	Passengers	Others
Fatal	0	0	0
Serious	0	2	0

1.3 Damage to aircraft

A number of fuselage skin panels were dented or punctured as a result of the deployment of the evacuation slides.

1.4 Other damage

None

1.5 Personnel information

1.5.1 Commander

Age:	49 years	
Licence:	Airline Transport Pilot's Licence	
Instrument Rating:	Valid until 30 April 2013	
Medical:	Class One issued on 7 December 2011	
Flying experience:	Total all types	15,619 hours
	Total on type	155 hours
	Last 90 days	109 hours
	Last 28 days	17 hours

[8] Persons On Board.

1.5.2 Co-pilot

Age:	37 years	
Licence:	Airline Transport Pilot's Licence	
Instrument Rating:	Valid until 28 February 2013	
Medical:	Class One issued on 6 September 2011	
Flying experience:	Total all types	9,680 hours
	Total on type	355 hours
	Last 90 days	155 hours
	Last 28 days	75 hours

1.6 Aircraft information

1.6.1 General information

Manufacturer:	Airbus SAS
Type:	A330-343
Aircraft Serial No:	1195
Year of manufacture:	2011
Total airframe hours:	4,718 hours
Total airframe cycles:	617 flight cycles
Last Maintenance Check:	6A check on 15 March 2012
Certificate of Registration:	G-VSXY/R1
Issuing Authority:	Civil Aviation Authority
Date of issue:	24 February 2011
Certificate of Airworthiness:	Issued by the European Aviation Safety Agency on 10 February 2011
Airworthiness Review Certificate:	Expiry 23 February 2013
Engines:	2 Rolls Royce RB211 Trent 772B-60 turbofans

G-VSXY's certificated Maximum Takeoff Weight (MTOW) was 233,000 kg and the certificated Maximum Landing Weight (MLW) was 187,000 kg. The Takeoff Weight (TOW) on departure from London Gatwick was 231,044 kg and the weight on landing was 225,090 kg. The overweight landing did not result in any apparent damage to the aircraft but the tyres and brakes were replaced as a precaution.

The A330 is a long range aircraft. It is of conventional layout, powered by two pylon-mounted engines, one under each wing. G-VSXY was maintained by the airline's own EASA-approved maintenance organisation.

1.6.2 G-VSXY cabin layout

Figure 2 shows the cabin layout for G-VSXY, with twin passenger aisles and a total of eight doors equipped with escape slides.

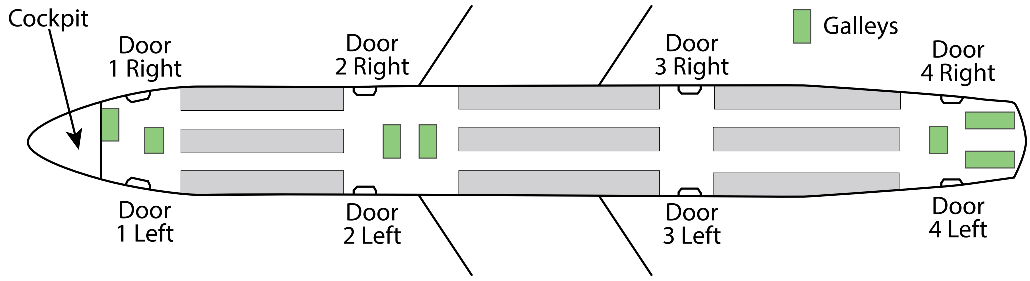


Figure 2

G-VSXY cabin layout

1.6.3 Arrangement of A330 cargo compartment

The A330 has two Lower Deck Cargo Compartments (LDCCs), known as the forward and aft cargo compartments, each accessed via a dedicated cargo door on the right side of the aircraft. Both compartments are ventilated and can accommodate cargo and baggage packed in cargo containers or pallets. An area at the rear of the aft cargo compartment, known as the bulk cargo compartment, is used for loose items of cargo or baggage. This area is accessible through a separate smaller bulk cargo door on the right side of the aircraft and is separated from the aft cargo compartment by a curtain or cargo netting.

1.6.4 Lower deck cargo compartment smoke detection system

1.6.4.1 General

The Smoke Detection System (SDS) in the LDCC detects smoke in the forward, aft and bulk cargo compartments and generates visual and aural warnings in the cockpit. Four smoke detectors are installed in the forward compartment and six in the aft compartment.

The SDS is controlled and monitored by the Smoke Detection Function (SDF) of the Cabin Intercommunication Data System (CIDS). The CIDS is a microprocessor-based system which operates, controls and monitors the main aircraft cabin systems. The CIDS-SDF is a hardware and software platform, housed within the CIDS director. Two CIDS directors (No 1 and No 2) are located in the forward avionics bay. In normal operation SDF 1 is active and SDF 2 is in 'hot standby'.

1.6.4.2 System layout

The smoke detectors are arranged in pairs and are installed in ceiling cavities in the cargo compartments. Smoke detectors 1WH & 2WH and 3WH & 4WH are located in the forward cargo compartment and detectors 5WH & 6WH and 7WH & 8WH are located in the main area of the aft cargo compartment. Detectors 9WH & 10WH are located in bulk cargo area of the aft cargo compartment; as the bulk cargo area is not sealed, the aft and bulk cargo compartments are considered as a single compartment at system level.

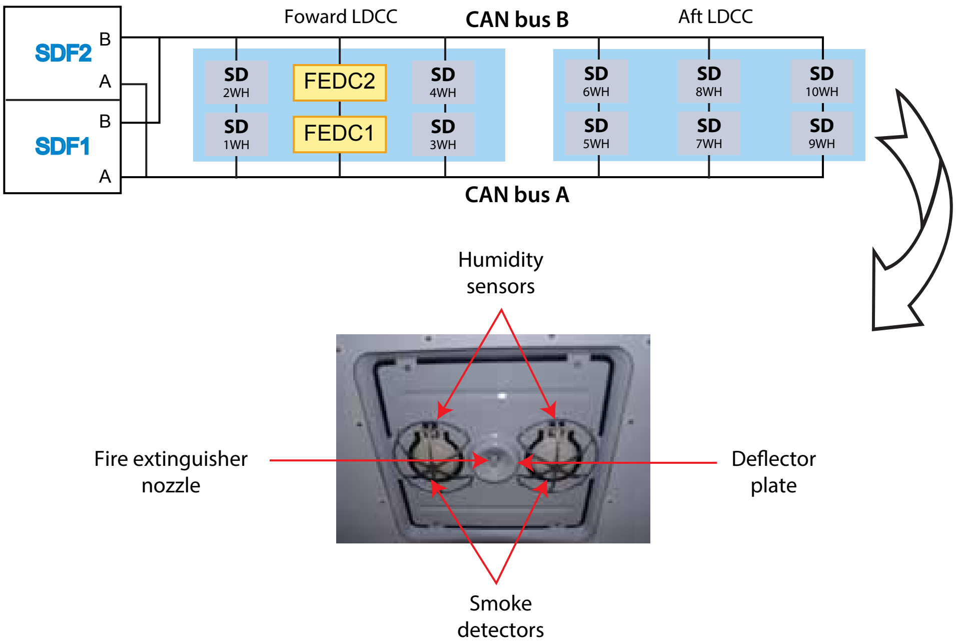


Figure 3

Smoke detection system schematic and typical smoke detector cavity

Two Controller Area Network (CAN[9]) busses supply the communication between both CIDS-SDF and the smoke detectors, and also the Fire Extinguishing Data Converters (FEDC) of the fire extinguishing system. Odd-numbered smoke detectors are connected to CAN Bus A and FEDC 1; even-numbered detectors and FEDC 2 to CAN Bus B (Figure 3). This arrangement provides system redundancy.

The CIDS-SDF polls the smoke detectors every two seconds, via the CAN busses.

9 A CAN bus is a single or dual wired networked data communication bus. CAN is a serial message-based bus protocol used to connect individual systems and devices without the need for conventional multi-wire looms.

1.6.4.3 LDCC Smoke warnings

Smoke or fire in either cargo compartment causes the smoke detectors to send an ALARM signal to the CIDS-SDF via the relevant CAN bus, which in turn sends an alarm signal to the Flight Warning Computer (FWC) and the Electronic Centralised Aircraft Monitor (ECAM). The following warnings will be generated in the cockpit:

- the forward or aft cargo SMOKE warning light will be illuminated on the overhead panel
- the red light in the master warning pushbutton switch will flash
- the repetitive master warning chime will sound
- a 'SMOKE FORWARD CRG SMOKE' or 'SMOKE AFT / BULK CRG SMOKE' warning will be shown on the upper ECAM display

Additionally, when a smoke warning occurs, the isolation valves of the cargo-compartment ventilation system close automatically.

1.6.4.4 Smoke detection system philosophy

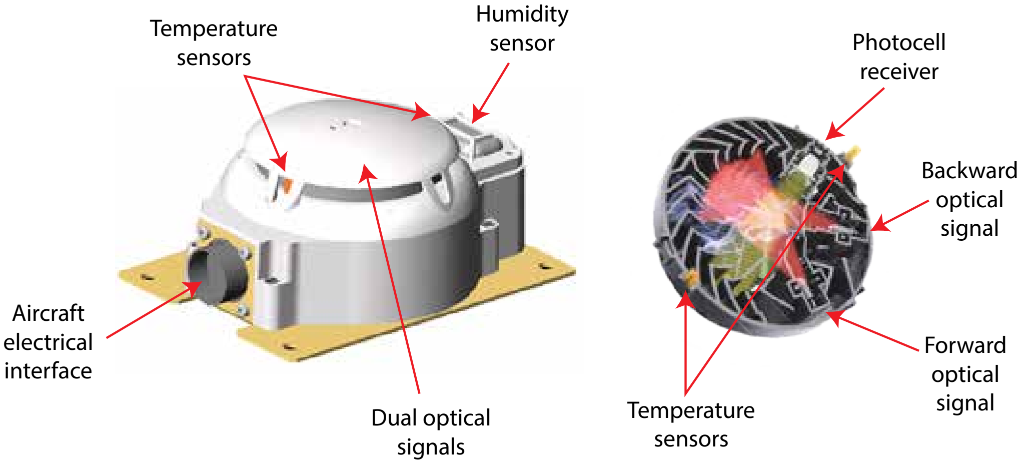
During normal operations, the smoke detectors operate in pairs to prevent spurious smoke warnings. A smoke warning will be generated in the cockpit when two smoke detectors installed in the same cavity, detect smoke, or when two smoke detectors installed in different cavities but in the same cargo compartment detect smoke. When a smoke detector detects smoke, it is said to be in ALARM status.

In normal operation, if only one detector of a pair detects smoke and sends an ALARM status signal, after 180 seconds the CIDS-SDF automatically checks the second detector in that cavity. If this test shows a normal function of the second detector, no smoke warning is generated in the cockpit. The alarm of the first detector is considered to be false and the first detector is declared in FAULT. If however this test shows an abnormal function of the second detector, the smoke warnings come on in the cockpit. The alarm of the first detector is considered to be valid.

1.6.4.5 Smoke detectors

1.6.4.5.1 'Multi-criteria' smoke detectors – general description

The smoke detectors fitted in each LDCC are 'multi-criteria' type detectors (P/N PMC1102-02) with two optical channels, two thermal channels and one humidity channel (Figure 4a). The smoke detectors have a processing unit comprised of a micro controller unit with software which manages the smoke detection, monitoring of the measurement circuitry and communication with the CIDS-SDF. The measurement circuitry resides on a printed circuit board (PCB) known as the measurement board. The detectors also have a Non-Volatile Memory (NVM) module for event storage and an aircraft electrical interface, which allows the smoke detector status to be communicated to the CIDS-SDF.



Figures 4a and 4b

PMC1102-02 Smoke detector and smoke detector optical chamber (cover removed)

The optical channels operate on the principle of reverse scattered light. Within the optical chamber, two LED light sources (infrared emitting diodes) and a single light receiver (photocell) are arranged within a labyrinth (Figure 4b), such that the photocell cannot receive light. One light beam is oriented towards the receiver (forward) and the other in the opposite direction (backward), and they are energised alternately. When smoke is present, the smoke particles reflect and scatter part of the light beam (Figure 5). The photocell receives this light and generates an analogue signal which triggers the ALARM status.

Two temperature sensors (T1 and T2) measure the ambient temperature within the cargo compartment and comprise the thermal channels. A single humidity (Hr) sensor measures the relative humidity within the cargo compartment.

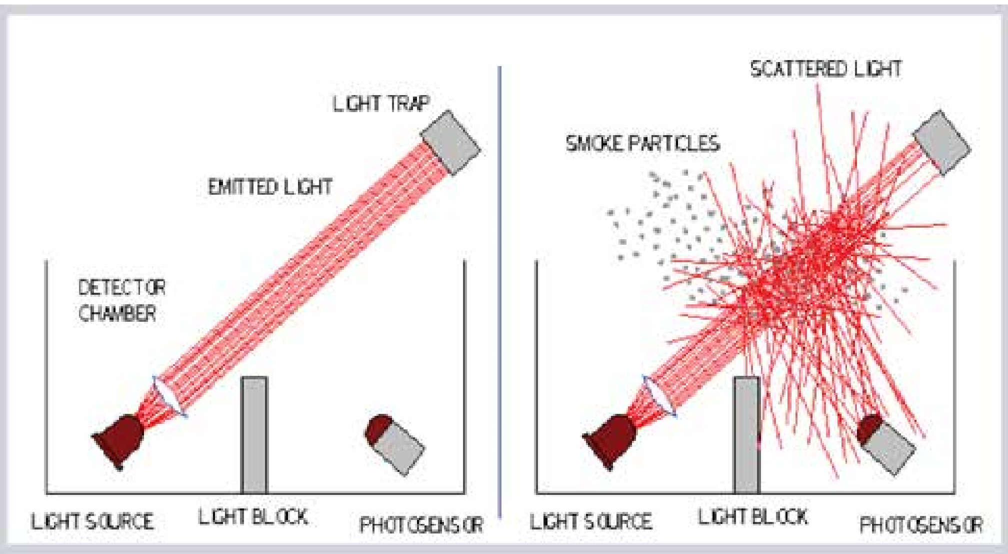


Figure 5

Scattered light principle for smoke detection

1.6.4.5.2 Temperature sensors

The two temperature sensors are thermistor-type sensors. A thermistor is a temperature-sensing element, made from a chip of semiconductor[10] material, which exhibits a large change in resistance proportional to a small change in temperature. An electronic circuit on the measurement board transforms the resistance value into a temperature output. The thermistors have a negative temperature coefficient, which means they have a high resistance at low temperature, but the resistance drops rapidly as they warm up. The semiconductor chip is soldered to a lead frame and the whole assembly is encapsulated between thin films of Kapton[11] tape and PET[12] tape (Figure 6).

[10] A semiconductor is a material which has electrical conductivity between that of a conductor, such as copper and an insulator such as glass. The conductivity of a semiconductor increases with increasing temperature, behaviour opposite to that of a metal.

[11] Kapton is a polyamide film with good electrical insulation and temperature properties.

[12] Polyethylene terephthalate.

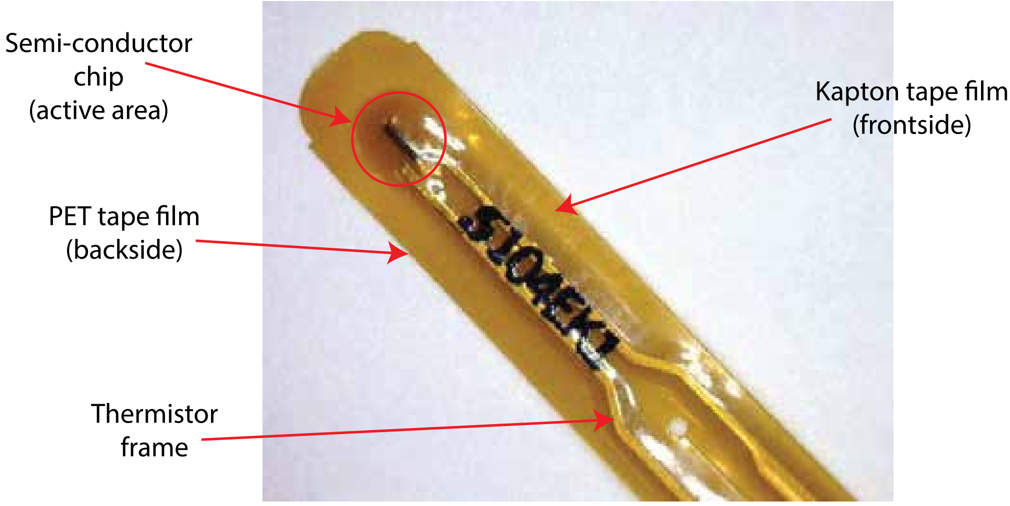


Figure 6

Thermistor-type temperature sensor

1.6.4.5.3 Humidity sensor

The humidity sensor (Figure 7) is a capacitive-type sensor with a frequency output. The dielectric[13] sensing element is a polymer which absorbs or releases water proportional to the relative humidity level, and thus changes the capacitance of the capacitor. An electronic circuit on the measurement board transforms the capacitance value into a frequency output.

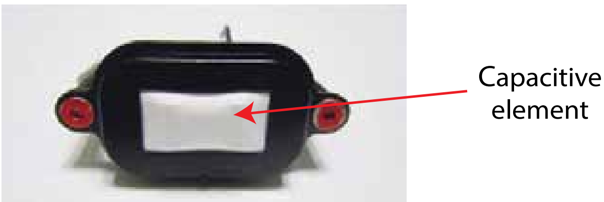


Figure 7

Humidity Sensor

1.6.4.5.4 Adaptive alarm threshold

The multi-criteria smoke detector acquires measured signals from the optical, thermal and humidity channels. These signals are corrected and processed to compute the ALARM condition.

The primary detection criteria of the multi-criteria detector, is based on the backward optical signal. Parameters derived from the optical signals and the

[13] A dielectric is an electrical insulator that can be polarized by an applied electric field.

temperature and humidity sensors constitute secondary detection parameters. These are used by a detection algorithm within the smoke detector software to compute the optical alarm threshold.

Obscuration of the optical signal (such as by smoke particles) is measured in percentage obscuration per metre (%/m). If light obscuration is detected above the threshold level, the smoke detector will register ALARM status. The threshold level will vary according to the algorithm computations.

The smoke detector may also register a thermal ALARM condition, based purely on temperature measurement, to take account of smokeless fires.

1.6.4.5.5 Internal monitoring and 'degraded' mode

As the multi-criteria functionality of the smoke detector depends on many directly-measured signals, the detector employs an internal monitoring logic to monitor the status of these parameters to ensure they are valid and within the expected range.

This includes monitoring of the electrical current at the backward and forward optical emitters (backward LED and forward LED); the voltage at the photocell (IR receiver); the measured values at the temperature sensors (T1 and T2); the temperature at the humidity sensor (Trh); the temperature at the measurement PCB (Tpcb); and the measured value at the humidity sensor (Hr).

If the Tpcb, backward LED or IR receiver signals are lost or are out of range, then the smoke detector registers a FAULT condition and is no longer able to detect or report a smoke condition.

In the case of (a) inconsistent or out of range humidity or thermal measurements, or (b) if the T1, T2, Trh or Hr or forward LED signals are lost, the detector enters a mode of reduced operability, known as the DEGRADED mode. In this mode, the detector is still operative as an optical smoke detector, but loses the multi-criteria functionality because the temperature and humidity measurements are no longer taken into account. The adaptive optical threshold reverts to a fixed threshold of 6 %/m. Where a detector becomes DEGRADED due to inconsistent or out of range temperature measurements, it will return to normal status once the temperature returns to a value within the permissible range. Where a detector becomes DEGRADED due to inconsistent or out of range humidity measurements, it will be latched in the DEGRADED mode. After 4,380 hours in the DEGRADED mode, the detector will go into the FAULT condition.

The acceptable range for the T1 and T2 temperature sensors is -50ºC to +125ºC. The acceptable range for the Hr sensor is -20% to +166% RH (corrected to 0% to 100% RH).

1.6.4.5.6 'Contaminated' condition

In the case of contamination of a smoke detector (eg by dust), the smoke detector will register as being in the CONTAMINATED condition, in order to provide an early indication of a future cleaning requirement.

For technical reasons, a DEGRADED smoke detector will also report being CONTAMINATED even if no contamination is present. Both faults require the smoke detector to be returned to the manufacturer or an approved overhaul facility, to be reset or cleaned.

1.6.5 Smoke detection system faults

1.6.5.1 The effects on the SDS, and indications, of a smoke detector fault

At an SDS system level, the DEGRADED mode and the CONTAMINATED condition are considered as Class 3 faults, which require no immediate maintenance intervention. There are no associated cockpit effects and as such, these conditions are not notified to the flight crew.

In the case of one smoke detector FAULT in a cargo compartment, redundancy is lost locally in that cavity. Where several smoke detectors in the same cargo compartment are in the FAULT condition, but only one per cavity, redundancy is lost locally within each smoke detector pair. In both cases the SDS remains operational and a Class 2 ECAM Maintenance Status Message is generated. Class 2 Maintenance Status messages are displayed on the lower ECAM screen, but only in flight phase 1 and 10, before engine start-up and after engine shutdown, respectively. The aircraft manufacture recommends that Class 2 faults should be fixed at the first opportunity, and not later than 800 flight hours.

In the case where both smoke detectors of a particular cavity are in the FAULT condition, the SDS is declared inoperative and a Class 1 Maintenance Message is generated, and an ECAM warning displayed on the upper ECAM screen. The aircraft can be dispatched in this condition if the conditions stipulated in the A330 MEL[14] are fulfilled. In this case the MEL requires that the affected cargo compartment must not contain any flammable or combustible materials.

1.6.5.2 The effects on the SDS, and indications, of a CAN Bus failure

A WRG CAN BUS A or WRG CAN BUS B Class 2 Maintenance Status Message is generated when all devices on the respective CAN Bus have declared themselves as failed or when all devices on the CAN Bus are not responding to interrogation by the CIDS director, despite power being detected on the CAN Bus. Communication between the CIDS director and the smoke detectors and

[14] Minimum Equipment List.

FEDC on the affected CAN-Bus is lost, and thus redundancy of the SDS in both cargo compartments is lost. The SDS is said to be in 'single detection mode'.

1.6.5.3 'Single detection mode'

In single detection mode the SDS remains operational due to the devices on the remaining CAN Bus, and no immediate maintenance intervention is required prior to dispatch of an aircraft. In this mode a smoke warning can be triggered by a single smoke detector detecting smoke in a cargo compartment. If the smoke detector is in the ALARM condition for two consecutive polling cycles (4 seconds) the smoke warnings will be generated in the cockpit.

In the case of double CAN Bus failure (CAN A + CAN B), the whole SDS is lost. This is a Class 1 failure and an ECAM warning is displayed on the upper ECAM screen. The aircraft cannot be dispatched in this condition and maintenance intervention is required.

1.6.6 Smoke detector non-volatile memory

The smoke detector NVM stores faults and warnings detected by the internal monitoring function and alarm states computed by the fire detection function. The memory is divided into four sections:

Event	Maximum events stored	SDS System effect	Description
Warning	10	None	The smoke detector can detect and report a smoke condition to the CIDS-SDF in a reliable manner, but has detected some abnormal occurrence. A warning may result from a data transmission error on the digital CAN Bus.
Failure	10	Maintenance Class 3	An error is detected by the secondary sensor monitoring but detector can still detect smoke via backward optical channel. Equivalent to DEGRADED mode.
Fault	20	Maintenance Class 2	The smoke detector is no longer able to detect or report a smoke condition to the CIDS-SDF. It must be removed for maintenance.
Alarm	10	Dependent on SDF logic	The smoke detector detects a smoke condition. If this is confirmed an alarm signal is transmitted to the CIDS-SDF.

Warnings, failures and faults may be accompanied by a Troubleshooting Data (TSD) code which identifies the specific reason for the event being recorded. Alarms are accompanied by a number of recorded parameters including the raw, corrected and processed signals from the optical, thermal and humidity channels, algorithm functions and the alarm thresholds.

1.6.7 Fire extinguishing system

1.6.7.1 General

Two fire extinguisher bottles, containing pressurised Halon 1301[15] gas, supply the fire extinguishing system. The fire extinguishing system is monitored and controlled by FEDC 1 and FEDC 2, which communicate with the CIDS-SDF via CAN Bus A and CAN Bus B.

1.6.7.2 System layout

Both fire bottles are located in the forward cargo compartment. Each bottle has two discharge outlets, which allow the extinguishing agent to be sprayed into either the forward or into the aft cargo compartment. One fire extinguisher nozzle is located in each smoke detector cavity, in between each pair of detectors (Figure 3). A deflector plate surrounds the nozzle and is intended to direct the flow of extinguishing agent downwards and away from the smoke detectors. An electrically-operated explosive cartridge initiates the activation of the fire bottles. Each cartridge has two squibs, squib A and squib B. When electrical power is supplied to the squibs, the cartridges fire and rupture metal diaphragms in the discharge outlets.

Both FEDCs are located adjacent to the fire extinguisher bottles in the forward cargo compartment.

1.6.7.3 System operation

When a smoke condition has been detected and the respective smoke warnings activate in the cockpit, the flight crew must manually activate the fire extinguishing system. This is done by pushing the FWD AGENT or AFT AGENT pushbutton switch for the appropriate cargo compartment. These pushbuttons are located directly below the SMOKE warning light for the applicable cargo compartment, on the cockpit overhead panel 212 VU (Figure 8).

The agent pushbutton switches control the 28 V DC power supply to the squibs in the cartridges. The FWD AGENT pushbutton switch fires the forward cartridge in each bottle, and the AFT AGENT pushbutton fires the aft cartridges.

[15] Halon 1301 is a liquefied, compressed gas that stops the spread of fire by chemically disrupting combustion.

The extinguishing agent from bottle 1 flows directly to the relevant cargo compartment, completely discharging within approximately one minute. The extinguishing agent from bottle 2 flows through a flow metering system which ensures that the agent is released slowly, over a period of approximately 240 minutes, to maintain a minimum halon concentration of at least 5% during the remainder of the flight.

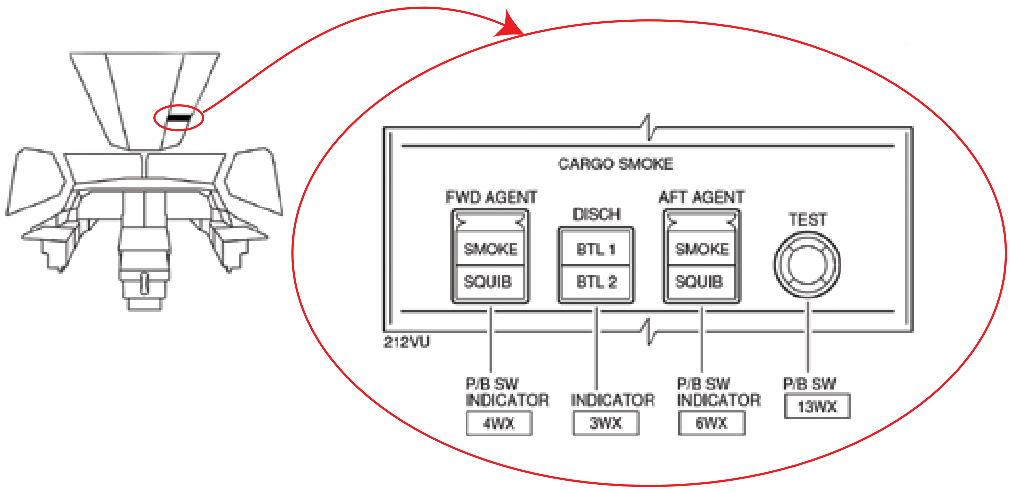


Figure 8

Cockpit overhead panel 212VU – Cargo smoke

When the extinguishing agent has been released a pressure switch on each bottle sends a signal via the FEDC to the CIDS director. The CIDS director sends the signal to the FWC, the Central Maintenance System (CMS) and the DISCH indicator on the cockpit overhead panel, which illuminates.

1.6.8 System test and fault monitoring

1.6.8.1 General

The CIDS-SDF and the FEDC incorporate Built-In Test Equipment (BITE), with operational monitoring, fault isolation and maintenance test functions, for the smoke detection and fire extinguishing systems.

The SDS components perform a self-test when initially powered up and then continuously monitor themselves during operation. Any faults detected are recorded in the CIDS director NVM and are also passed to the CMS.

The purpose of the CMS is to analyse aircraft system faults in order to identify the responsible components. It is primarily a troubleshooting aid for maintenance personnel and can be accessed from the flight deck via the Multifunction Control and Display Unit (MCDU). The CMS generates a Post-Flight Report (PFR) after every flight, which includes details of any Class 1 and Class 2 faults and their associated cockpit effects.

A number of status reports for the SDS and fire extinguishing system can be accessed via the CIDS-SDF menu on the CMS. These include a Smoke Warning Report, which identifies the smoke detectors responsible for triggering a smoke warning; a Fire Extinguishing Report, which contains the details of any fire extinguishing events; a Previous Legs Report; a Ground Report; and a Class 3 Faults Report, which details faults not included on the PFR. Additionally a 'snapshot' facility enables detailed information on relevant parameters to be recorded, known as Troubleshooting Data (TSD). For maintenance purposes, the SDS system can also be commanded to perform a self-test via the CMS.

1.6.9 Emergency escape slides

The aircraft was fitted with eight dual-lane escape slide-rafts, one at each cabin exit. These provide rapid egress of passengers and crew from the aircraft to the ground in an emergency evacuation on land. They also serve as life rafts in the event of ditching on water.

The slide-rafts are contained in a pack-assembly, installed on the door structure. Deployment is automatic when the door is opened with the emergency control-handle set in the ARMED / AUTOMATIC position.

1.6.9.1 Escape slide-raft description

Each slide-raft consists of an inflatable assembly, an inflation system and a packboard assembly. The inflatable assembly is comprised of two independent pneumatic tubes made from neoprene-coated nylon fabric. Inflation in adverse wind conditions is assisted by one primary, one secondary and two lateral restraints, which maintain slide-raft rigidity during the inflation sequence. The primary restraint is located towards the top (or head) end of the slide and requires a 310 lbf +/- 20 lbf breaking force. The secondary restraint is located towards the bottom (or toe) end of the slide and requires a 410 lbf +/- 20 lbf breaking force. The lateral restraints have a 70 lbf breaking force. The two halves of the mechanical restraints are held together by frangible wire, which shears when the breaking force is reached.

The inflation system has a reservoir to store a nitrogen and carbon dioxide gas mixture, a regulator valve to control the output of gas, and hoses to transfer the gas to two aspirators which inflate the slide-raft. Inflation typically takes six seconds.

The slide-raft unit is attached to the aircraft by a metal girt bar inserted through a fabric girt panel.

1.6.9.2 Escape slide-raft operation

When the door is armed, as it opens, the fabric girt panel is pulled taut. As the door travels outwards, the tension in the girt panel pulls the packboard assembly away from release rails on the door. As the packboard falls out of the aircraft, the packboard covers open and the slide-raft unit is released. A firing lanyard actuates the regulator valve upon reaching its travel limit, allowing gas from the reservoir to be supplied to the aspirators and the slide-raft inflation to be initiated. As pressure begins to build up in the slide-raft, the primary and lateral restraints are released. The momentum generated as the primary restraint releases, causes the secondary restraint to release.

Reliable operation of the slide-raft is dependent upon correct packing of the slide and achieving adequate inflation pressure. Slide packing is carried out manually in accordance with the slide manufacturer’s packing instructions. The dimensions of the folds on the inflatable assembly during packing are considered critical to correct operation of the slide raft.

1.7 Meteorological information

The weather at London Gatwick Airport at the time the aircraft landed was wind from 020ºM at 6 kt, varying between 320º and 080º, visibility 10 km or greater, scattered cloud at 4,800 ft, temperature 10ºC, dewpoint minus 4ºC and QNH of 1026 HPa.

1.8 Aids to navigation

Runway 08R is equipped with an Instrument Landing System (ILS) with a 3º glidepath and Distance Measuring Equipment (DME).

1.9 Communications

Not applicable.

1.10 Aerodrome information

London Gatwick Airport is an international airport that is operational 24 hrs a day. The main runway, 08R/26L, is 3,316 m long and 46 m wide and the Runway 08R landing threshold is displaced by 393 m. The declared distances for Runway 08R are:

Takeoff run available (TORA):	3,159 m
Takeoff distance available (TODA):	3,311 m
Accelerate stop distance available (ASDA):	3,233 m
Landing distance available (LDA):	2,766 m

1.11 Flight recorders

The aircraft was equipped with a 25-hour duration Flight Data Recorder (FDR), a 120-minute Cockpit Voice Recorder (CVR) and a Digital ACMS Recorder (DAR). A record of the entire incident flight was available from the recorders including the status of the aft cargo smoke warning, which was recorded once per second on the FDR.

The aircraft was airborne for a total of 38 minutes and 36 seconds. Activation of the aft cargo smoke warning was recorded on fifteen separate occasions, 12 of which occurred in flight and three after landing. The total duration of the warnings was 260 seconds. Figures 9 and 10 provide more information on the activation times and duration of the warnings.

The aircraft touched down at 1127:21 hrs, with a peak recorded normal load of 1.17 g and a recorded landing weight of 225,090 kg. Maximum reverse thrust was used and the aircraft came to a stop on the runway centre line approximately 30 m beyond Taxiway D (approximately 1,630 m from the Runway 08R threshold and 1,300 m from the end of the runway).

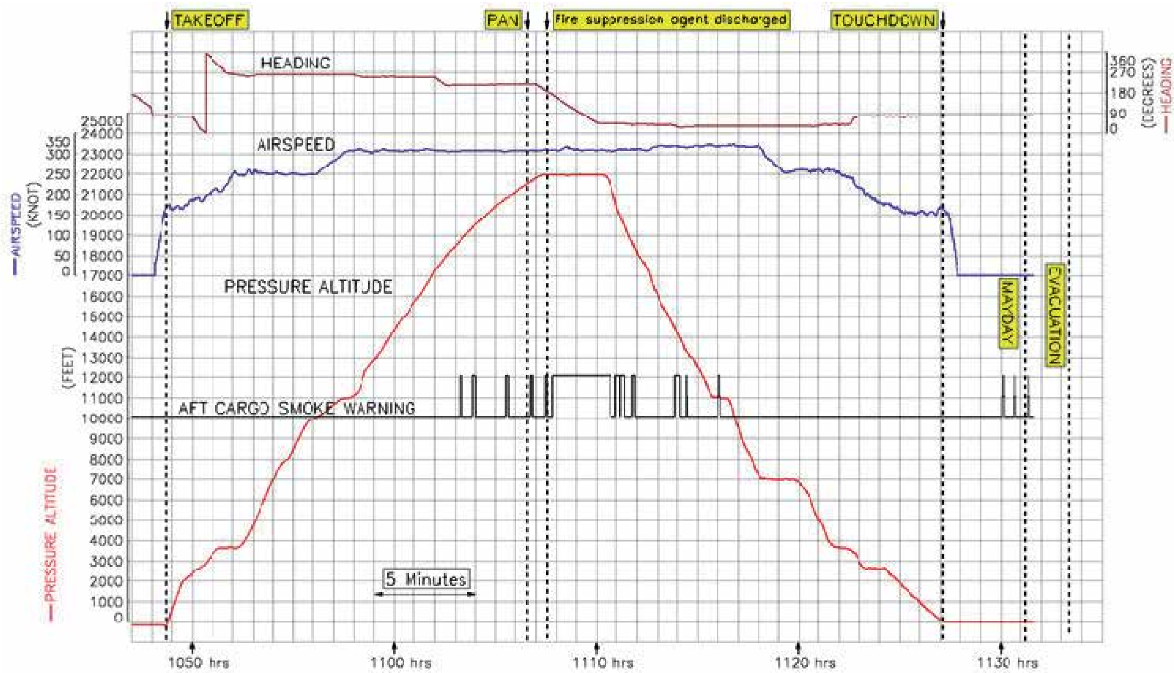


Figure 9

Flight profile - activation of aft cargo smoke warnings

As part of the evacuation checklist, the engine master switches and the aircraft batteries were selected off, which caused the FDR and CVR respectively to stop recording.

Occurrence	Activation time from – to (HHMM:SS)	Duration of warning	Airborne/ on ground
1	1103:14 - 1103:21	7 seconds	Airborne
2	1103:54 - 1104:03	9 seconds	Airborne
3	1105:30 - 1105:37	7 seconds	Airborne
4	1106:46 - 1106:51	5 seconds	Airborne
5	1107:28 - 1107:33	5 seconds	Airborne
6	1107:48 - 1110:41	173 seconds (2 minutes 53 seconds)	Airborne
7	1110:58 - 1111:09	11 seconds	Airborne
8	1111:12 - 1111:23	11 seconds	Airborne
9	1111:46 - 1111:53	7 seconds	Airborne
10	1113:54 - 1114:07	13 seconds	Airborne
11	1114:28 – 1114:30	2 seconds	Airborne
12	1116:03 – 1116:08	5 seconds	Airborne
13	1130:05 – 1130:08	3 seconds	On ground
14	1130:43 – 1130:44	1 second	On ground
15	1131:23 – 1131:24	1 second	On ground

Total duration of warnings = 260 seconds (4 minutes and 20 seconds)

Figure 10

Activation of aft cargo smoke warnings (illustrated in Figure 1)

1.12 Aircraft examination

1.12.1 Initial

An AAIB-supervised examination of the aircraft commenced on the day of the incident and a number of ground checks were carried out over the following two days, with the operator's assistance.

An inspection of the aircraft cargo holds, cabin and flightdeck revealed no evidence of fire, smoke or heat damage. The following cargo was being carried on the incident flight:

- Aft cargo compartment: 4 x pallets of sweet peppers
- Bulk cargo compartment: bags, baby buggies and manual wheelchairs
- Forward cargo compartment: 1.5 x pallets of sweet peppers, 10 x baggage bins, 2 x cargo bins

The emergency escape slide-rafts had been detached from the aircraft prior to the examination, to enable the aircraft to be removed from the runway. However photographs taken prior to detaching the slides showed the condition of the R4 slide-raft, which had not fully inflated.

Some minor denting was noted on fuselage skin panels below a number of the doors, coincident with the locations at which the emergency escape slides had been deployed.

1.12.2 Fault and troubleshooting data

1.12.2.1 Post-flight report

The CMS PFR obtained during the investigation showed the following fault messages relevant to the smoke detection and fire extinguishing systems on the day of the incident:

Time hrs	Phase of Operation	Fault Message	Fault Class	Cockpit Effect	Fault Message Meaning
1035	Engine Start	CRG BTL 1 SQUIB (4003WX) FWD A/ WRG: FEDC 1 / 2	Class 2 Hard	MAINTENANCE STATUS SMOKE	Wiring fault on Cargo Fire Bottle 1, forward hold
1035	Engine Start	WRG: CAN BUS A	Class 2 Hard	MAINTENANCE STATUS SMOKE	CAN Bus A Wiring Fault
1103	Cruise			SMOKE AFT / BULK CRG SMOKE	Aft Cargo Smoke Warning
1107	Cruise	CRG BTL 1 SQUIB (4001WX) AFT / WRG: FEDC 1/2	Class 1 Intermittent		Cargo Fire Bottle 1 squib fired

The items in parentheses are the aircraft manufacturer’s circuit component identifiers, known as Functional Item Numbers (FINs).

A 'WRG CAN BUS A' fault was recorded at 1035 hrs on the PFR at engine start; the Last Leg Report within the CMS indicated that this fault was already present at 0859 hrs, which most likely corresponds to when electrical power was applied to the aircraft prior to the flight. This fault indicates that the SDS was in single detection mode.

The 'CRG BTL 1 SQUIB (4003WX) FWD A/ WRG: FEDC 1/2' fault registered at engine start is a known issue associated with the power-up sequence of the FEDC and fire extinguishing system components, and is considered to be a spurious message not relevant to the incident.

The 'CRG BTL 1 SQUIB (4001WX) AFT/ WRG: FEDC 1/2' at 1107 hrs is consistent with the manual activation of the fire extinguishing bottles.

1.12.2.2 CIDS-SDF fire extinguishing report

The Fire Extinguishing Report confirmed that a fire extinguishing event had occurred at 1107 hrs in the aft LDCC during the incident flight.

1.12.2.3 CIDS-SDF smoke warning report

The Smoke Warning Report recorded 15 separate smoke events[16], as follows:

Time hrs	Smoke Detector	Location
1103	10WH	Aft LDCC
1105	10WH	Aft LDCC
1106	10WH	Aft LDCC
1107	10WH	Aft LDCC
1107	6WH	Aft LDCC
1107	8WH	Aft LDCC
1108	10WH	Aft LDCC
1110	10WH	Aft LDCC
1111	8WH	Aft LDCC
1111	10WH	Aft LDCC
1113	10WH	Aft LDCC
1114	10WH	Aft LDCC
1116	10WH	Aft LDCC
1130	10WH	Aft LDCC
1131	10WH	Aft LDCC

16 If the CMS detects more than one alarm from a smoke detector in the same one minute recording period, it will only record this once. This explains the minor timing discrepancies between the Smoke Warning Report, the FDR data presented in Figure 10 and the smoke detector NVM presented in 1.16.1.2.2.

Thus, the information indicated that the smoke event was initiated by smoke detector 10WH, in the bulk area of the aft LDCC. At 1107 hrs, coincident with the discharge of the cargo fire bottles, smoke detectors 6WH and 8WH also entered ALARM status. 8WH again entered ALARM status at 1111 hrs. All remaining smoke warnings were generated by 10WH. Smoke detectors 6WH, 8WH and 10WH were connected to the operative CAN Bus B; there were no smoke warnings generated by the smoke detectors connected to CAN Bus A.

1.12.2.4 CIDS-SDF Class 3 faults report

The CIDS-SDF Class 3 faults report indicated that smoke detectors 6WH and 8WH registered as being in the DEGRADED mode and CONTAMINATED, coincident with the discharge of the cargo fire bottles at 1107 hrs on the incident flight.

1.12.2.5 CIDS-SDF ground report

The CIDS-SDF Ground Report printed after the incident contained fault messages which indicated that smoke detectors 7WH and 8WH registered DEGRADED and CONTAMINATED at 1344 hrs on the day of the incident. This most likely corresponds to the time that the aircraft power was restored, in order to enable it to be towed from the runway.

1.12.2.6 CIDS-SDF system test

The CIDS-SDF System Test was performed a number of times during the post-incident aircraft examination and troubleshooting. The test indicated that smoke detectors 7WH and 8WH were DEGRADED and CONTAMINATED.

1.12.2.7 Aircraft checks

A number of troubleshooting tasks were performed on the CIDS-SDF system under the supervision of the AAIB. In addition the operator performed a wiring check of CAN Bus A and no anomalies were noted.

1.13 Medical and pathological information

One adult and one child passenger received bone fractures during the evacuation.

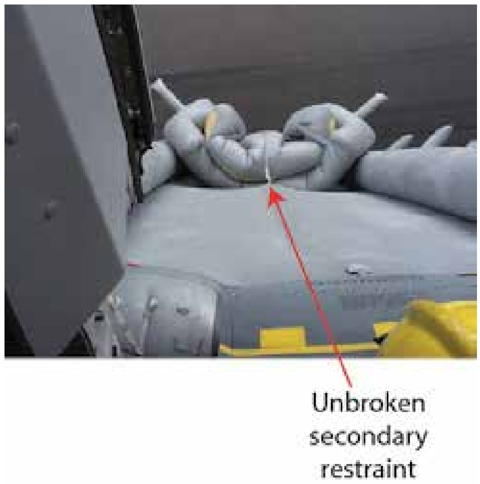
1.14 Fire

Not applicable.

1.15 Survival aspects

1.15.1 Inflation of the escape slide-rafts

A review of video evidence of the aircraft evacuation showed that the slide-raft inflation commenced normally after the R4 door had been opened. However the primary restraint appeared to release earlier than normal and the slide-raft did not fully inflate. The deployment sequence stopped at the secondary restraint. Figures 11a and 11b show the condition of the R4 slide following the evacuation.



Figures 11a and 11b

R4 slide partially inflated

1.15.2 Examination of the R4 slide-raft

The R4 slide-raft (P/N 7A1508-125, S/N AA5588) was examined at the manufacturer's facility. All subassembly parts were found correctly assembled and all mechanical restraints were installed at the correct locations. The secondary restraint was unbroken. Minor damage and abrasions were evident on some subassembly components and some small perforations on the inflatable assembly were noted. However these were considered to be consistent with the slide having been moved across the ground, after removal from the aircraft.

No anomalies which could have contributed to the partial inflation of the slide-raft were found with the inflation system components.

The unbroken secondary restraint from the R4 slide-raft was pull-tested, and it separated at 396 lbf, which was within the specification requirements of 410 lbf +/- 20lbf.

1.15.3 Previous incidents of slide-raft partial inflation

The slide-raft manufacturer had previously investigated four in-service reports of P/N 7A1508 series slide-raft partial inflations during scheduled maintenance tests, in which early release of the primary restraint was caused by non-release of the secondary restraint. It had been determined that a particular fold of the inflatable assembly, made during packing of the slides, had pre-loaded the primary restraint, such that it could release early during the deployment sequence. Early release of the primary restraint can alter the slide deployment sequence such that insufficient force develops to release the secondary restraint.

As a result of those investigations, the slide-raft manufacturer implemented a change to the packing instructions, to alter the dimensions of the subject fold, in order to alleviate any tendency for early release of the primary restraint.

1.15.4 Slide packing instructions

Revision B of the packing instructions document PI 501753 which contained the new dimensions of the fold, was published in October 2010 and communicated to all operators and slide service centres via Service News letter SNL 25-215, in November 2010. As all slide-rafts are required to be removed for a 3-yearly overhaul, the aircraft manufacturer determined that in-service slides would not be recalled for repacking, but would instead be re-packed on an attrition basis, as they were returned for overhaul.

A review of the manufacturing records for S/N AA5588 determined that it had been manufactured in October 2010 and had been packed in accordance with Revision A of the packing instructions, prior to implementation of the packing change. The slide had not been repacked since manufacture.

1.15.5 Risk assessment of slide-raft partial inflations

The certification standard relating to emergency evacuations on the A330 aircraft is EASA Certification Standard CS 25.8503. Compliance with this standard is demonstrated by achieving full emergency evacuation of the aircraft in 90 seconds, with not more than 50% of the emergency exits in use.

Following the G-VSXY emergency evacuation, the aircraft manufacturer performed a retrospective risk assessment of the P/N 7A1508 series slide-raft partial inflations due to early release of the primary restraint, in order to determine whether any additional action was required.

A slide-raft partial inflation renders the associated emergency exit unusable during an emergency evacuation, which represents a reduction in safety margin. The possibility of more than one slide-raft not correctly deploying at the same time could not be ruled out.

The aircraft manufacturer calculated the failure rate of P/N 7A1508 series slide-rafts based on the previous known occurrences and an estimation of the number of scheduled maintenance deployments to date. They determined that the probability of two or more slide-rafts failing in an emergency case, due to early release of the primary restraint, was within the safety objective stipulated by EASA for this situation. As this achieved the minimum safety objective and exceeded the minimum certification criteria, the EASA and the aircraft manufacturer considered that no additional safety action was necessary.

1.15.6 The evacuation

Two video recordings of the evacuation were available to the investigation. One, taken from a Police helicopter, showed the right side of the aircraft and the other, taken using a hand-held video camera, showed the left side of the aircraft. Both views were from behind the aircraft looking forwards. The unsteady nature of the videos, particularly from the hand-held camera, meant that it was only possible to estimate some of the details of the evacuation from the recordings.

All of the doors opened simultaneously and all of the escape slides deployed and inflated correctly apart from the slide at door R4. From the first sign of a door opening until the first passenger exited the aircraft took approximately 12 seconds. The bulk of passengers evacuated within one minute although there were a small number of people, possibly crew who had been checking that the cabin areas were clear, who left up to 109 seconds after the doors began to open.

It was not possible to establish accurately the number of people leaving from each exit. It was estimated from the view of the right side of the aircraft that 70 people evacuated using the doors on the right, approximately 15 from Door R1, 30 from Door R2 and 25 from Door R3. The remainder, approximately 244 people, evacuated using the doors on the left.

The videos showed that the flow of people from the left doors (Figure 12) was much quicker than from the right (Figure 13). On the right side a number of people sat down in the doorway before descending the slide; some people fell to the ground at the bottom of the slide and others slowed their own evacuation because they were carrying hand baggage (Figure 14). The video also showed members of the RFFS standing at the bottom of the slide at Door 3R directly in line with the escape path.

Figure 12

Still image from video showing left side approximately 30 seconds after evacuation commenced

Figure 13

Still image from video showing right side approximately 30 seconds after evacuation commenced

Figure 14

Door 3R showing passengers with hand baggage, sitting to use the slide and members of the RFFS waiting to assist

1.15.6.1 Passenger questionnaire

A passenger questionnaire asking about the flight was distributed to all passengers and approximately 100 replies were received by the AAIB. One passenger travelling with young children commented on the form that there was no one at the bottom of the slide to catch the children. A number of passengers stated they took their hand baggage with them whereas others commented that passengers retrieving hand baggage from overhead lockers delayed the evacuation. A number of passengers landed awkwardly at the bottom of the slides including an elderly lady who toppled forward and landed headfirst onto the concrete.

1.15.6.2 Evacuation injuries

According to members of the RFFS, a number of passengers coming off the slides appeared to be in pain. One passenger was carried to safety because she was unable to walk after hitting the ground. Another lady was found by the RFFS lying with blood in her eye and complaining of a sore back. One passenger was in considerable pain at the bottom of the slide having sustained an injury to his leg.

All cabin crew members received minor friction burns and/or scrapes during the evacuation either from the slide or during the transition from the slide to the tarmac. When she got to the bottom of the slide, the FSM was projected onto the tarmac and sustained ligament damage to her left arm.

1.15.7 Pre-flight safety briefing requirements

At the time of the event the requirement for passenger briefing was contained in EU OPS 1.285 which stated:

> *'An operator shall ensure that:*
>
> *a) General:*
>
> *1. Passengers are given a verbal briefing about safety matters. Parts or all of the briefing may be provided by an audio-visual presentation.*
>
> *2. Passengers are provided with a safety briefing card on which picture type instructions indicate the operation of emergency equipment and exits likely to be used by passengers'*

Before takeoff passengers were required to be briefed on the location of emergency exits and the location and contents of the safety briefing card.

The requirements of EU OPS 1.285 will be superseded by Commission Regulation (EU) 965/2012 which came into force on the 28 October 2012. EASA states, including the UK, have been granted a two-year derogation for its implementation, meaning it will come into force on 28 October 2014. Subpart B, *Operating Procedures*, requires at paragraph CAT.OP.MPA.170, *Passenger Briefing,* that:

> *'The operator shall ensure that passengers are:*
>
> *a) given briefings and demonstrations relating to safety in a form that facilitates the application of the procedures applicable in the event of an emergency; and*
>
> *b) provided with a safety briefing card on which picture-type instructions indicate the operation of emergency equipment and exits likely to be used by passengers'*

Further amplification is provided in AMC1 CAT.OP.MPA.170 which suggests that before takeoff the passenger briefing should include the location of emergency exits and the location and the contents of the safety briefing card.

Civil Aviation Publication (CAP) 393, *The Air Navigation Order* (ANO), Article 38 (4) (d), requires passengers to be informed of the location of escape slides and given instructions as to how they are to be used. CAP 789, *Requirements and Guidance Material for Operators,* states in paragraph 13.5 d) that the following information should be included on the safety briefing card:

> *'Evacuation slides – correct method of use, manual inflation handle and restrictions for high-heeled shoes.'*

Although the ANO remains in force, the EU regulation is overriding in this area.

1.15.8 The Operator's pre-flight safety briefing

The Operator provided each passenger with a safety briefing card which contained the information required. Door operation was described and two small pictograms indicated that passengers should not carry hand baggage and that they should jump into the slide with their arms folded across their chest.

A video presentation fulfilled the requirements of both the safety briefing and safety demonstration, and included emergency operation of the doors and manual inflation of the escape slide. It also directed viewers towards the safety briefing card. Cabin crew were present in the cabin during the presentation.

1.16 Tests and research

1.16.1 G-VSXY component checks

1.16.1.1 General

Components of possible relevance to the investigation were removed and bench tested at manufacturers' facilities and, where relevant, strip-examined. Fault and troubleshooting data were retrieved from the NVMs of CIDS director 1, FEDC 1 and all six aft cargo smoke detectors.

No faults were found with the CIDS director 1 or FEDC 1 when subjected to the manufacturer's Acceptance Test Procedures (ATP). Analysis of the NVM from both units did not add to the information already available from the aircraft BITE data in the CMS.

1.16.1.2 Smoke detectors

1.16.1.2.1 Acceptance Test Procedures

The six smoke detectors removed from the aft cargo compartment were subjected to the manufacturer's ATP.

No faults were found with smoke detectors 5WH, 6WH, 9WH and 10WH. Smoke detectors 7WH and 8WH were confirmed latched in the DEGRADED mode due to a failed humidity sensor (measured value out of range). During the test, the humidity sensors on 7WH and 8WH measured relative humidity of 183% and 159% respectively; the relative humidity in the test room was 49.9%.

1.16.1.2.2 Results of Smoke Detector NVM download[17]

Smoke Detector 10WH

The 10WH memory contained ten *failures*, six of which occurred on various dates in December 2011 and January 2012. The remaining four *failures* did not have valid dates associated with them[18]. All of the *failures* had error code 60, corresponding to 'temperature sensor 1 out of range.' There were ten thermal-channel *alarms* recorded, all of which occurred between 1342 and 1403 hrs on 18 April 2012, two days after the incident. Raw temperature values of between +59ºC and +84ºC were recorded. There were no *alarms* recorded for the incident sector on 16 April 2012, this element of the NVM having been overwritten by the *alarms* on 18 April 2012.

Smoke Detector 8WH

The 8WH memory contained ten *failures*, with error code 70, corresponding to 'humidity sensor out of range.' None of the failures had valid dates associated with them.

There were two optical-channel *alarms* stored in the 8WH memory, which occurred at 1106:55 and 1110:19 hrs on the incident sector. By the time of the second *alarm*, the optical threshold had dropped to 6%/m, indicating that the detector was in the DEGRADED mode. The lowest raw temperature value recorded was -40ºC.

Smoke Detector 6WH

The 6WH memory contained one *failure*, which occurred at 1107:05 on the incident sector. The failure had the error code 61, corresponding to 'temperature sensor 2 out of range.'

There were three optical-channel *alarms* stored in the 6WH memory, which occurred at 1106:55, 1108:06 and 1108:26 hrs on the incident sector. By the

17 The '*failures*' and '*alarms*' noted in this section refer to the events tabulated in 1.6.6.

18 Where smoke detector NVM contains an event without a valid date, it indicates that the smoke detector was not receiving time and date information from the CIDS-SDF. For the detectors on CAN Bus A these events could have occurred during the incident sector when the CIDS-SDF could not communicate with the detectors. Or they could have occurred prior to the smoke detectors being fitted on the aircraft. No conclusions can be drawn from these events.

time of the second alarm, the optical threshold had dropped to 6%/m, indicating that the detector was in the DEGRADED mode. The lowest raw temperature value recorded was -53ºC.

Smoke Detector 9WH

There were ten thermal-channel *alarms* stored in the 9WH memory, which occurred at various times on 19 and 20 March 2012, one month before the incident[19]. Raw temperature values of between +58ºC and +68ºC were recorded. There were no *alarms* logged for the incident sector.

Smoke Detector 7WH

The 7WH memory contained ten *failures*, none of which had valid dates associated with them. All of the failures had error code 70, corresponding to 'humidity sensor out of range.'

Smoke Detector 5WH

No relevant data.

1.16.1.2.2 Environmental Testing

Smoke detectors 9WH and 10WH were subjected to extended periods of operation in a climatic chamber during which the measured values on the temperature and humidity sensors, and the ALARM status, were recorded. The test profiles included a test conducted at constant temperature (25ºC), with relative humidity varied in steps, and a test performed at constant RH (25%) with temperature varying in steps.

Both smoke detectors exhibited erratic temperature measurement from the T1 temperature sensor across all test profiles, with recorded values considerably in excess of the actual temperature. This erratic temperature measurement was evident even in moderate conditions (eg 25ºC and 25% RH). Smoke detector 10WH also exhibited erratic temperature values during an 8-hour period at ambient temperature, prior to the test cycle being initiated in the climatic chamber. Multiple thermal-channel alarms were generated throughout the testing by both detectors.

[19] During 19-20 March 2012, the aircraft completed four sectors. The PFRs for all sectors were reviewed and no smoke events were noted. No perishable goods were carried on these flights.

1.16.1.2.3 Laboratory Testing

Testing of measurement boards for 9WH and 10WH

The measurement boards from smoke detectors 9WH and 10WH were subjected to a detailed examination at an independent laboratory in order to investigate the operation of the thermal channel circuit. No anomalies were noted with the solders or conformal coating on the measurement boards.

Optical inspections of the T1 and T2 temperature sensors from both measurement boards revealed the presence of bubbles in the insulating envelopes of the thermistors (Figure 15a). A crack in the Kapton tape was also evident very close to the active area of the T1 thermistor from 10WH. The crack was located close to a wrinkle in the tape (Figure 15b).

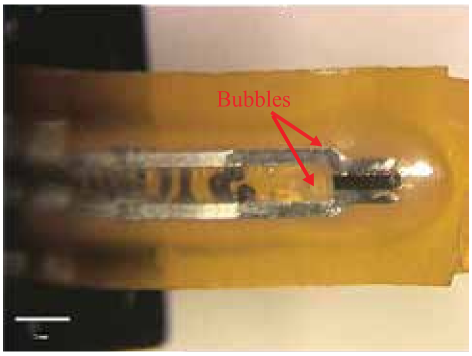


Figure 15a

Bubbles in T1 thermistor from 9WH

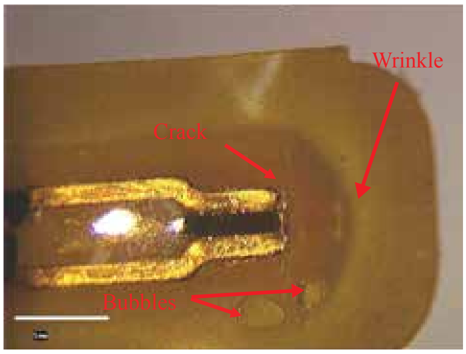


Figure 15b

Bubbles and crack in T1 thermistor from 10WH

The electrical characteristics of the thermistors were measured and observed to be in accordance with the specifications. However when the thermistors were immersed in water, to simulate high condensation conditions, the resistance of 9WH T1 was unstable, with large variations. The resistance of 10WH T1 was very low, indicating an erroneously high temperature.

A dye-penetrant[20] test was performed; the dye penetrated the Kapton tape of both T1 thermistors, thus indicating leakage on the thermistor envelopes which made them susceptible to the ingress of humidity. For the 10WH T1 thermistor, the crack in the Kapton was identified as the leak point; the leak point for the 9WH T1 thermistor could not be visually identified.

[20] A dye-penetrant test is a non destructive inspection technique in which a phosphorescent liquid dye is use to identify surface defects in non-porous components. The component is either immersed in or sprayed with the dye, which enters any surface defects via capillary action. Illumination under ultraviolet light reveals any defects.

Detailed examination of T1 thermistors from 9WH and 10WH

The four thermistors from 9WH and 10WH were sent to the thermistor supplier's facilities, for further detailed examination together with four new thermistors from stock, for comparative purposes. The supplier verified that the resistance value of all the thermistors was within the required specification when tested in ambient conditions and at up to 90% relative humidity. However the insulation resistance of the T1 thermistors from 9WH and 10WH was compromised when they were immersed in water.

The supplier advised that a defect in the thermistor's insulation resistance could cause a short circuit or reduced resistance value, if a conductive substance, for example water, contacted the electrodes of the thermistor chip and bridged the gap.

The metal frames of all four thermistors were observed to be bent, close to the active area, and the number of bubbles and size of bubbles in the four thermistors were greater than in those thermistors taken from stock. However all the thermistors conformed to the supplier's inspection criteria for bubbles (section 1.18.1.2).

Detailed examination of the thermistors in a Scanning Electron Microscope (SEM) also revealed minor damage, including a crack and some scratches, on the PET film of three of the thermistors. The damage was located close to the bend in the frame, leading the supplier to consider that the thermistors had been subject to an external bending force.

Humidity sensors from smoke detectors 7WH and 8WH

The humidity sensors removed from smoke detectors 7WH and 8WH were laboratory-tested by their manufacturer. A performance test was carried out to characterise the frequency response of the sensors over a full range of relative humidity values from 20% to 95%. The results are shown in Figure 16.

The performance test confirmed that while the sensors reacted to varying levels of humidity by altering the output signal, the frequency response curve was offset from the nominal values by approximately 2,000 Hz for 7WH and by approximately 3,000 Hz for 8WH. The profile of the response curve was also noticeably different at high humidity levels. Such high frequency outputs are indicative of lower than actual humidity readings by the sensors.

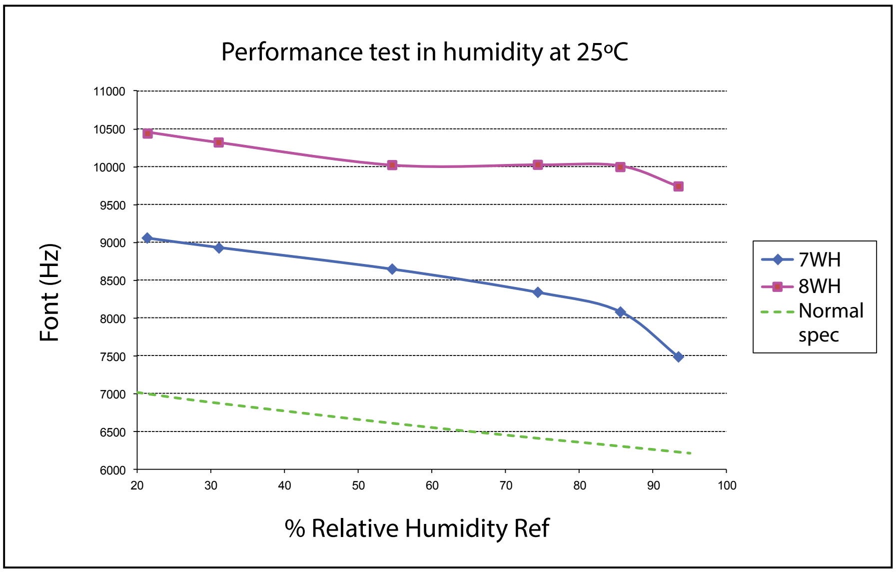


Figure 16

Frequency output for 7WH and 8WH vs Relative Humidity

The capacitive sensing elements of the humidity sensors were de-soldered from the electronic circuit on the measurement boards and tested separately. The electronic circuits were verified as exhibiting nominal function and characteristics when the sensing elements were replaced with known good units.

The capacitive response of the sensing elements was tested across a full range of relative humidity values. A downward shift in the response curves was observed, indicating a low capacitance value for a given relative humidity compared with expected values.

A detailed visual inspection under a microscope revealed discolouration of the sensing elements and traces of delamination of the sensing layers. It was determined that this damage was consistent with exposure to external aggression or stress, such as thermal shock, high pressure or chemical aggression. It was considered that direct exposure to the high pressure halon extinguishing agent dispensed by the fire extinguisher nozzles could account for such damage.

Humidity sensors from smoke detectors 9WH and 10WH

The humidity sensors from smoke detectors 9WH and 10WH were subjected to the same laboratory testing as those from 7WH and 8WH. No anomalies were noted with their performance.

1.17 Organisational and management information

1.17.1 The Operator's Cabin Safety Manual

The operator's Cabin Safety Manual contains information relating to SOPs and Safety Equipment Procedures (SEP). Paragraph 7.7.1 of the manual, *Notification of Abnormal/Emergency Incidents to Cabin Crew*, states:

> *'to indicate that an abnormal emergency situation has arisen, the captain will say twice over the PA "**will the Flight Service Manager (FSM) report to the flight deck immediately"** and switch the Fasten Seatbelts signs on.'*

On hearing this command in-flight:

> *'All cabin crew working on the left hand side of the aircraft will proceed to the first forward double galley to await a briefing from the FSM.'*

On the Airbus A340 aircraft, this instruction directs cabin crew to the galley between Doors L2 and R2; on the Airbus A330 and Boeing 747-400 aircraft, it directs them to the galley between Doors L1 and R1.

Paragraph 7.7.3 of the Cabin Safety Manual, *Content of Abnormal/Emergency Briefing,* contains information on the format and content of the commander's briefing to the FSM in the event of abnormal or emergency situations. An abnormal situation is one in which a diversion or precautionary landing has the potential to escalate but an evacuation is not intended; an emergency situation is where the intention is to evacuate the aircraft. The briefing, known as a NITES brief, is given in the following format:

Nature: What has happened; what information can be given to the passengers?

Intentions: What are the commander's intentions; will emergency services meet the aircraft on arrival; is the aircraft likely to ditch or land at an airport?

Time remaining: How long does the FSM have to prepare the cabin and brief the crew and passengers?

Escape routes: Are there any known factors affecting the escape routes?

Signal to brace: The signal that will indicate that touchdown is imminent.

The content under each heading varies slightly depending on whether it is a briefing for an abnormal or an emergency situation and the final two headings are only briefed for emergency situations.

Paragraph 7.6 of the manual, *Rejected Takeoff (RTO) and Unplanned Runway Incidents*, relates to situations where the aircraft needs to stop unexpectedly on the runway. If the commander believes that evacuation is a possibility, he or she should make the alert PA:

> *'Cabin crew standby.'*

A stand down PA should be made by the commander if he or she determines that an evacuation is not necessary, either immediately after coming to a halt or after having previously told the cabin crew to standby. The stand down PA is:

> *'Cabin crew and passengers please remain seated.'*

Paragraph 7.11.4, *Evacuation Speed,* states:

> *'Do not stop an evacuation for a pile up at the bottom of the slide. This will soon sort itself out.'*

1.17.2 Types of emergencies and associated procedures

Civil Aviation Publication (CAP) 168, *Licensing of Aerodromes,* states in section 10.2 of Chapter 9 that an Aircraft Ground Incident is:

> *'Where an aircraft on the ground is known to have an emergency situation, other than an accident, requiring the attendance of emergency services.'*

A Full Emergency is declared:

> *'When it is known that an aircraft in the air is, or is suspected to be, in such difficulties that there is a danger of an accident.'*

These definitions are the same as those contained within CAP 493, *Manual of Air Traffic Services Part 1*.

Section 5.4 of the Emergency Orders at London Gatwick Airport states that an AGI is:

> *'Where an aircraft on the ground is involved in an incident (whether or not another aircraft or vehicle is concerned) which could result in an aircraft accident developing.'*

There are no procedures within the orders to upgrade a Full Emergency to an Aircraft Ground Incident and, in this case, the Watch Manager did not include the nature of the problem when he made his upgrade call on the crash line and he did not make a follow-up call on the emergency line. However, in relation to a Full Emergency, Part 4 Section A paragraph 4.1 states that:

> *'Except in the event of an Aircraft Accident, re-grading of any emergency procedure must not be initiated until full consultation has taken place between the ATC Watch Manager and the RFFS Officer in Charge.'*

The *Manual of Air Traffic Services (MATS) Part 2* for London Gatwick Airport gives instructions in relation to aircraft evacuation in paragraph 1.7 of Section 7, *Mandatory Alerting Action*. It states that:

> *'Whenever ATC becomes aware that the aircraft is to be evacuated using emergency escape equipment an Aircraft Ground Incident is to be initiated (unless………. a Full Emergency has already been initiated for the aircraft concerned).'*

1.17.3 Comments from the aircraft and airport operators

1.17.3.1 Simulator training for evacuations

The aircraft operator agreed that when a crew 'lands' the simulator with an engine fire it is assumed that there will be a practice evacuation. However, the operator believed that the evacuation decision-making process is adequately covered in its training syllabus in which it is stressed that it is important to balance the possibility of people being injured during an evacuation against the risk of not evacuating. Simulator exercises, such as landing in non-normal configurations and Rejected Takeoffs (RTO), include evacuation as a consideration depending on the failure condition, speed of reject and subsequent wheel/brake condition etc. The operator stated that it emphasises to flight crew that a decision to evacuate should not be a 'knee-jerk reaction'.

1.17.3.2 Cabin crew procedures

The use of the phrase 'first forward double galley' as a briefing location originated when the operator used an aircraft type in which the galley between Doors 1L and 1R was too small to hold the briefing. The phrase had not been changed as new aircraft types were introduced even though it subsequently directed cabin crew to different door numbers depending on the aircraft type they were working in. The operator commented that there was only one double galley on the A330 (between Doors 1L and 1R) and so it was surprising that the crew had not gone there for the briefing. Following this incident, the operator considered changing the instruction to 'the first galley', which would have been suitable for all of its current aircraft types. On reflection, however, the operator decided not to make any changes to the instruction because the A330 was a new aircraft type which many of the crew were operating for the first time. They considered that the change might cause problems on its other aircraft types and variants because cabin crew were familiar with the current instruction.

1.17.4 Safety action

1.17.4.1 The airport operator

Following this incident, the airport operator reviewed its Emergency Orders in cooperation with other agencies including the police, NATS[21], the airport RFFS, the ambulance service, other airlines and ground handling agencies. The aim was to address the issues that had been identified during the multi-agency debrief following the incident. In particular, action was taken to improve communication between the agencies, enable greater numbers of police officers to be present to assist in a future evacuation, and to ensure there was a common understanding of different types of incident and the procedures in place for re-grading an incident.

1.17.4.2 Air Navigation Service Provider

Following an internal investigation, NATS took action to improve its procedures and interaction with other agencies at the airport, especially the RFFS. It reviewed MATS Part 2 and the Emergency Orders to ensure consistency in relation to procedures and communication requirements when re-grading from a full emergency to an AGI.

In order to improve communication between ATC and aircraft in an emergency or abnormal situation, NATS introduced a Temporary Operating Instruction (TOI) at Swanwick ATC Centre relating to the use of a 'NITS' notepad. The acronym NITS refers to a briefing format similar to the one used by the operator in this incident and the letters stand for:

Nature:	What is the nature of the emergency?
Intention:	What is the intention of the flight crew?
Time:	How much time will be required to deal with the problem or to return/divert to an airport?
Special instructions:	Are there any special instructions, for example emergency services to be put on standby?

[21] The UK national Air Navigation Service Provider.

In the event of a PAN or MAYDAY the controller would, if possible, obtain the NITS information from the flight crew and record it on the notepad. The completed briefing would then be passed to the relevant adjacent ATC sector or unit.

The TOI was incorporated into MATS Part 2 at Swanwick ATC Centre in December 2012 and, following the trial, it was extended to Prestwick ATC Centre and airports within the UK where NATS is the Air Navigation Service Provider (ANSP).

1.17.4.3 The aircraft operator

The aircraft operator, along with other UK airlines, was aware of the NATS initiative with regard to NITS notepads through participation in NATS Safety Partnership Agreement meetings. The operator made its crews aware that NATS controllers understood the NITS format and that using it would improve the flow of accurate information to emergency services at the intended landing point.

Following the incident, the operator reviewed its training to highlight the differences that would be encountered when evacuating down a real slide compared to the training slide. Cabin crew were to be encouraged to consider whether there was an immediate danger inside the aircraft before deciding whether or not it was appropriate to reduce the evacuation rate in response to a request to do so from the RFFS. Future Crew Resource Management (CRM) training would include discussion of the importance of using correctly phrased commands.

1.18 Additional information

1.18.1 Thermistors

1.18.1.1 Thermistor manufacturing process

Multiple thermistors are assembled in a strip. The thermistor chips are soldered to the lead frames and dipped in liquid solder. The frames are then sandwiched between the Kapton and PET insulating films, each of which has a layer of epoxy resin adhesive pre-applied, and placed in a vacuum press. The strips are then cut to form individual thermistors.

The thermistor supplier reported that no significant changes to the production process had been implemented since 2008, when the thermistors from 9WH and 10WH had been manufactured. Additionally the supplier advised that there were no steps during production, storage or packing which it considered could lead to bending of the thermistor frame.

1.18.1.2 Thermistor inspection criteria

Following manufacture, each thermistor is subject to inspections of visual appearance and the insulation resistance is tested by immersion in water. The presence of bubbles between the insulating films is a normal part of the thermistor assembly process and the supplier's inspection criteria define the permissible locations of such bubbles. The supplier defines a 'tentative line', which follows the profile of the thermistor chip and frame (Figure 17). Bubbles inside this line are permitted; bubbles on or outside this line may compromise the sealing of the edges of the insulating envelope and are not permitted. The supplier considers that the bubbles do not affect the performance of the thermistor and there is no limitation on bubble size, provided they are within the tentative line.

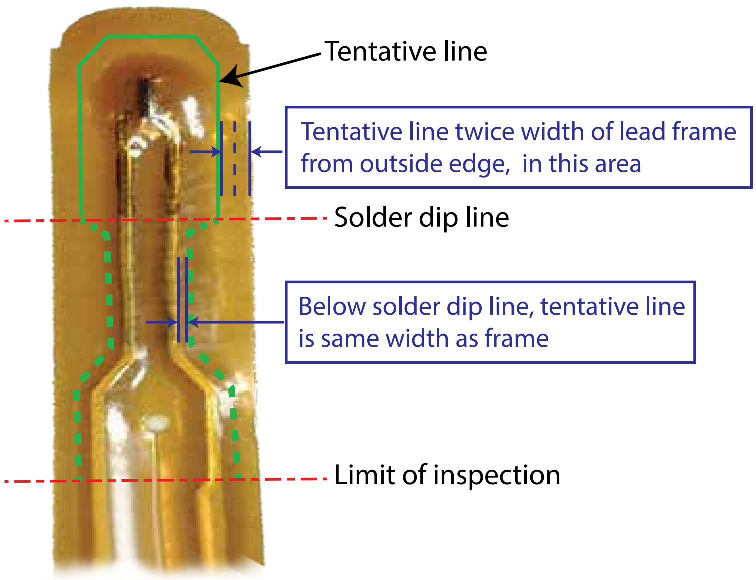


Figure 17

Thermistor tentative line

The thermistors are tested for robustness by placing them between two glass epoxy plates and a load of 30 N is applied, for a period of 60 seconds.

The thermistors are used in a variety of industrial applications and are not subject to any testing specific to their use in an aerospace application.

1.18.1.3 Additional thermistor examinations

A sample of 26 thermistors from seven different manufacturing batches, were tested at an independent laboratory. These included seven thermistors from in-service smoke detectors returned to the manufacturer for overhaul; two from smoke detectors used in qualification testing, which had been subject to chemical exposure (insecticide and cleaning agent) and 17 thermistors from stock, two of which were intentionally bent at 90º.

All of the thermistors examined had bubbles inside the Kapton tape, below the active area of the thermistor, ranging in size from 100 to 400 µm. However some bubbles of up 1 mm diameter were observed around the active area of the thermistors.

On three of the thermistors, including the two from chemical test and one from an in-service detector, some of the bubbles were outside the tentative line. The thermistors from stock did not have any bubbles outside the tentative line. The thermistors subjected to chemical test also had a higher number of bubbles than the others. It was considered that this could be due to degassing[22] and migration of the adhesive paste which assembles both plastic films. Two thermistors were observed to contain black fibres inside the envelope.

Electrical characterisation tests of all the thermistors were performed in air and water. One of the thermistors returned from service exhibited a short circuit both in air and when immersed in water; a subsequent dye penetrant test confirmed leakage of the insulating envelope. Examination of this thermistor in a SEM revealed the presence of some surface cracks and a small hole. But it was not possible to determine a link between number and size of bubbles in this thermistor, and the short circuit.

There was no evidence of a short circuit on the two bent thermistors, indicating that although bent, the integrity of the insulating envelope was not compromised.

1.18.1.4 Thermistor handling procedures – safety action

As a result of this investigation, the smoke detector manufacturer identified three manufacturing process improvements aimed at limiting manual handling of thermistors and protecting the thermistors during assembly, in order to minimise any risk of the thermistors being damaged during assembly. New tooling has been developed to better support the measurement board and thermistor during soldering, protect the thermistor during transportation and storage and to protect the thermistor when the smoke detector cover is being installed. The new tooling was scheduled to be implemented in November 2013.

[22] Degasification is the removal of dissolved gases from liquids.

1.18.1.5 Testing of stock thermistors by the smoke detector manufacturer

The smoke detector manufacturer undertook further temperature and humidity testing on 96 thermistors held in stock, from two separate batches manufactured in 2011. A number of the samples were pierced to introduce small holes into the active area in order to understand the failure mode better. Additionally some of the thermistors were intentionally bent. Temperature shock cycling was also carried out in order to simulate the ageing of the thermistors and to evaluate the effect on their performance. However, even on those thermistors with intentionally induced damage, it was not possible to replicate the failure of the electrical properties of the thermistors seen in 9WH and 10WH T1 thermistors. The testing therefore could not establish a link between thermistor age and damage to the insulating envelope.

The Kapton film of one thermistor was peeled back to expose the chip fully. The chip was sprayed with water, immersed in water, immersed in a water-and-dust solution and immersed in a salt solution. However, even when subjected to this level of external aggression it was not possible to create a short circuit or an appreciable reduction in performance of the thermistor, so no conclusion could be drawn.

Safety action

At the conclusion of the AAIB investigation, the extensive testing performed by the smoke detector manufacturer had not identified the cause of the damage observed on the thermistors from 9WH and 10WH, nor the root cause of the spurious thermal alarms. However they stated their intention to continue testing to identify a root cause. New information presented by the smoke detector manufacturer at the conclusion of the investigation suggests that they had made progress towards identifying a possible root cause. This is discussed in more detail in section 1.18.6.

1.18.2 Humidity sensors

During manufacture, the frequency response of all humidity sensors is tested at three points corresponding to 20%, 55% and 80% relative humidity at 25ºC.

1.18.3 Certification requirements

The certification standard relating to cargo compartment smoke detection systems on A330 aircraft is EASA Certification Standard CS 25.858 (previously Joint Aviation Requirement 25.858). CS 25.858 requires that the following must be met for each cargo compartment:

> a. *The detection system must provide a visual indication to the flight crew within one minute after the start of a fire.*
>
> b. *The system must be capable of detecting a fire at a temperature significantly below that at which the structural integrity of the aircraft is substantially decreased.*
>
> c. *There must be a means to allow the crew to check in flight the functioning of each smoke detector or fire circuit.*
>
> d. *The effectiveness of the system must be shown for all approved operating configurations and conditions.*

Although a desirable design objective for a cargo smoke detection system, CS 25.858 does not contain any specific requirements regarding the elimination of spurious smoke alarms.

Compliance with these requirements is demonstrated in a series of ground and flight tests, using a smoke generator. No additional tests were requested by the EASA when the multi-criteria smoke detectors were certified for installation on the A380, and subsequently on the A330.

EN 54[23], Part 7 *'Fire detection and fire alarm systems'*, requires that smoke detectors can detect all types of fire, from smouldering fire to flaming fire and defines a number of 'test fires', TF1 to TF7 which exhibit different fire characteristics. The smoke particles produced by the different types of fires vary in size.

1.18.4 Sources of false smoke alarms

Due to the environment in which they are installed, LDCC smoke detectors are subject to numerous sources of potential nuisance smoke alarms. These can include exhaust fumes from ground servicing equipment, condensation, fog or haze, dust, water vapour or fumes from perishable goods and insecticide sprays. In addition, cargo holds are subject to high rates of change of temperature, pressure and humidity. They may or may not be ventilated and there can be a large degree of variability in the cargo loading configuration. Aircraft equipped with conventional optical smoke detectors can therefore be subject to high rates of false alarms.

23 A mandatory industry standard developed by the European Committee for Standardisation, which defines the requirements and laboratory tests for every component of a fire detection and fire alarm system.

1.18.5 Smoke detection system design philosophy

In order to satisfy the certification requirements, in traditional single-channel optical smoke detectors, the optical threshold is limited to 3%/m, to enable early detection of fire types for which their sensitivity is the lowest. Airborne particles generated by many nuisance sources of smoke alarms can be of similar, or larger sizes, to smoke particles, and can therefore interrupt the light beam within the smoke detector optical chamber. Basic optical smoke detectors cannot discriminate between 'nuisance' particles and smoke particles and are thus sensitive to false smoke alarms as a result of environmental conditions.

Since development of the A380, Airbus required that LDCC smoke detectors must reject all the main types of false alarm events, such as haze, dust, insecticide, condensation. The CIDS-SDF system with the PMC1102 multi-criteria smoke detectors was developed for use on the A380 in order to eliminate the sensitivity to temperature and humidity exhibited by conventional smoke detectors. This system was subsequently qualified for use on the A330 and A350 aircraft.

By combining the temperature criteria with the optical signals, the algorithm adjusts the sensitivity of the smoke detector to flaming fires and fires that do not produce smoke (eg alcohol fires), by lowering the optical threshold. Combination of the humidity criteria with the optical signals prevents deceptive phenomena due to high humidity variations, from triggering an ALARM status. Algorithm logic validation and rejection logic enable rejection of the main sources of false alarms.

With the 60-second detection time requirement imposed by the certification requirements, smoke detection is a compromise between fast detection and signal reliability. Testing carried out during certification demonstrated a significant improvement in false alarm rejection, compared with basic optical smoke detectors.

The G-VSXY incident is the first known incident of multiple spurious smoke warnings on an aircraft equipped with a CIDS-SDF smoke detection system and PMC1102 multi-criteria smoke detectors.

1.18.6 Previous in-service problems with PMC1102 smoke detectors

Since their introduction on the A380, two in-service issues had been identified on PMC1102-02 smoke detectors, and the smoke detector manufacturer had developed two modifications to address these issues. At the time of the incident to G-VSXY the modifications had been approved by the aircraft manufacturer, but had not yet been introduced on production smoke detectors.

Nor had details of the modifications been promulgated to operators of aircraft equipped with PMC1102-02 smoke detectors. As such the smoke detectors on G-VSXY did not have these modifications embodied.

The first modification, a software update, provided an enhancement of the internal humidity monitoring cycle of the smoke detector, which had been determined to be too restrictive.

The second, a hardware upgrade, was developed to address problems identified with temperature measurement on the T1 and T2 thermal channels. These were traced to an insulation problem at the junction where the thermistors are soldered to the measurement board. Silicon coating had been applied at the thermistor junction on the back face of the measurement board during assembly, but not on the front face. The silicon insulation on the measurement boards from 9WH and 10WH was not examined in the course of this investigation, because the thermistors had already been removed from the measurement board for examination when this information became available to the investigation. It was therefore not possible to determine whether the absence of silicon insulation may have contributed in any way to the inaccurate temperature measurement observed on the T1 thermistors.

However, testing carried out by the smoke detector manufacturer, after the conclusion of the AAIB investigation, suggested that the absence of silicon insulation at the thermistor junction could allow contamination to build up on the thermistor pins. In particular, the tests showed that if a smoke detector were to be exposed to very salty or polluted humid air, residual salt or other pollution could remain between the pins of the thermistor after evaporation of the humidity. If the smoke detector was then exposed to further humidity, the deposit could create a short circuit between the thermistor pins and could lead to spurious thermal alarms.

1.18.7 Other smoke events

Following the event on G-VSXY, a number of other incidents involving aircraft equipped with CIDS-SDF and multi-criteria smoke detectors were reported to the aircraft manufacturer.

In November 2012, an A330 experienced a spurious forward cargo compartment smoke warning. The warning disappeared before the flight crew activated the fire extinguishing system. Smoke detectors 1WH and 4WH were identified as having initiated the smoke event. Further investigation revealed inconsistent temperature measurement on one of the thermal channels. The NVM for the event on both detectors had been overwritten by subsequent thermal alarms. One detector had measured temperatures of around -113ºC, while the other had measured temperatures of around +105°C. In both cases the relative humidity levels were very high. The humidity sensor on smoke detector 3WH was also found to be out of range. At the time of the event, the repair shop at the smoke detector manufacturer's facility was not aware of the ongoing G-VSXY investigation. As a result the smoke detectors were repaired without further investigation.

In February 2013, an A330 experienced a spurious aft cargo compartment smoke warning. The fire extinguishing system was activated by the flight crew, however no additional smoke warnings were experienced after discharge of the fire extinguishing agent. It was determined that this was most probably because the cargo compartment was not full, nor were there any cargo bins loaded immediately under the smoke detectors. Investigation by the aircraft manufacturer revealed that the SDS was in single detection mode during the incident, however no CAN Bus fault was logged. The reason for the SDS being in single detection mode is not yet known, and is under investigation by the aircraft manufacturer. Of possible relevance is that the aircraft had experienced a single CAN Bus fault on a previous sector. Smoke detector 8WH was identified as the detector which initiated the event and has been sent to the smoke detector manufacturer for examination. Additionally both CIDS directors were removed and sent to the aircraft manufacture for extensive testing.

As of June 2013, the aircraft manufacturer was aware of six occurrences of spurious smoke warnings on A330 aircraft equipped with CIDS-SDF and multi-criteria smoke detectors, based on 600,000 flight cycles operating experience.

Safety action

Although the occurrence rate is low compared to aircraft equipped with traditional optical detectors, the aircraft manufacturer is not satisfied with this rate and has committed to address the issue with a technical fix.

1.18.8 CAN Bus wiring faults

The aircraft manufacturer conducted a review of available A330 fleet fault history data for CAN Bus wiring faults on aircraft equipped with CIDS-SDF, for the period between 1 January 2012 and 22 March 2013. There were a total of 63 CAN Bus faults recorded on A330 passenger aircraft; these included 56 CAN Bus A faults (including the G-VSXY event) and three CAN Bus A and B faults. There were also four CAN Bus faults related to the avionics bay smoke detection system.

During the same period there were 94 single CAN Bus faults recorded on A330F freighter aircraft.

None of the events analysed, apart from the G-VSXY event, had any operational consequence as there were no smoke warnings generated by the detectors on the remaining CAN Bus. No events were recorded for A380 aircraft.

The fault review confirmed an unexpectedly high rate of single CAN Bus faults on A330 aircraft. There were no associated reports of any actual problems with the CAN Bus wiring from the operators of the aircraft involved. In the absence of any hard wiring defects, the aircraft manufacturer suspected that these faults could potentially be attributed to an internal problem with the CIDS-SDF's ability to monitor the devices on the affected CAN Bus. This may have caused the CIDS-SDF to detect a condition at the detectors or the wiring, which did not actually exist. The manufacturer has therefore launched an internal investigation to understand the root cause of these CAN Bus faults. The results from the testing of the CIDS directors, from the aircraft involved in the February 2013 spurious smoke warning event, will form part of that investigation.

Safety action

Subject to the findings of their investigation, the aircraft manufacturer has committed to develop a technical fix for the CAN Bus faults, which will culminate in a modification to the SDF.

1.18.9 Fire extinguishing system qualification testing

During qualification of the A380 LDCC fire extinguishing system, a flight test was carried out to demonstrate the effectiveness of the fire extinguishing system to suppress a fire inside the LDCC for a minimum period of 240 minutes, as required by the applicable certification criteria. The test objectives were to demonstrate that a minimum level of halon concentration was maintained in the LDCC for the duration of the flight. No anomalies were noted with the LDCC smoke detectors following exposure to the halon extinguishing agent. The test was conducted without any cargo loaded in the LDCC, as an empty cargo compartment represents the worst case scenario for halon concentration.

Had cargo containers been loaded in the LDCC, the small volume between the top of the cargo containers and the smoke detectors, is likely to have resulted in a more significant localised temperature drop and higher concentration of halon in the immediate vicinity of the smoke detectors.

1.18.10 Operational documentation

The A330 Flight Crew Operations Manual (FCOM) procedure for smoke warnings in the forward and aft / bulk cargo compartments, contains the following note:

> *'Expect the smoke warning to remain after agent discharge, even if the smoke source is extinguished. Gases from smoke source are not evacuated, and smoke detectors are also sensitive to the extinguishing agent.'*

1.19 Useful or effective investigation techniques

Not applicable.

2 Analysis

2.1 Operational analysis

2.1.1 The flight

G-VSXY was 15 minutes into its flight, climbing through FL187 when the pilots were presented with the first SMOKE AFT/BULK CRG SMOKE Master Warning. The crew began to try and diagnose the problem through a visual inspection of the cabin and discussion on the radio with the operator's engineering department. Despite thinking the warning was probably spurious, when it returned for the third time the commander decided that the prudent course of action would be to return to London Gatwick Airport.

Air traffic control of the flight was being undertaken by Brest ATC and the co-pilot informed the controller that there was a technical problem with the aircraft and that the flight would need to return to London Gatwick Airport. The message was misunderstood initially and the commander declared a PAN to highlight the urgency of the situation and to inform the controller that the aircraft was beginning its turn towards London. Although the controller realised that the aircraft was returning to London, and passed the crew a frequency for London Control, subsequent events[1] suggested that she did not fully understand the nature of the problem at the time the crew left her frequency.

When the commander decided to call the FSM to the flight deck to brief her on the nature of the problem with the aircraft and tell her his intentions, he used the phrase "FSM TO THE FLIGHT DECK". He did not repeat the phrase as was required by the cabin safety manual and the message was poorly understood. Once the message had been understood by the cabin crew, they went to the wrong location for their briefing, probably because the galley they reported to would have been the correct galley on the Airbus A340 aircraft on which they were more used to working. The operator considered changing the briefing location to one that would be consistent across all types within the airline. However, because the outcome had not been affected adversely by the crew going to the wrong location, and because the act of changing procedures can itself promote errors in their implementation, the operator decided that, on balance, it would leave its current procedures in place. In order to try and improve the flow of accurate information between the flight crew and cabin crew during aircraft incidents, the operator decided to reinforce during training the importance of making clear and correctly phrased commands.

[1] See section 2.1.4.

2.1.2 The decision to evacuate

The decision to evacuate an aircraft on the runway requires a commander to balance the risk to passengers of remaining on the aircraft against the risk of injury to passengers inherent in any evacuation. A commander will assess whether the cabin environment is safe and stable and whether it is likely to remain so before making a judgement as to the best course of action. In making the judgement, a commander needs information and, in this case, the commander had a number of different sources of information to aid his decision: his knowledge of the FCOM; the nature of the problem while airborne; the continuing intermittent smoke warning; the fire service, ATC and his crew.

The FCOM noted that smoke warnings should be expected to remain after fire extinguishing agent is discharged but the warning was intermittent throughout this incident and information in the FCOM did not relate to the actual circumstances the crew encountered. Further information available to the pilot came from ATC, which told him there might be smoke coming from the area of the engine, and from the fire service, which was unable to tell whether there was a fire. Finally, throughout the decision-making process, there was a continuing intermittent Master Warning relating to smoke within the aircraft.

It is difficult for a commander to come to the conclusion that a smoke or fire warning is spurious and make the decision not to evacuate given the life-threatening implications of being wrong. In this case, the commander decided that the safest course of action was to evacuate the passengers.

The commander later commented that simulator training might predispose pilots to make decisions to evacuate when faced with actual circumstances similar to those of a training scenario. When landing after an "airborne" exercise in the simulator, crews often find that a fire or smoke problem that they have been dealing with has not been contained. Information passed to the crew from "ATC" or from the "cabin crew" (the simulator instructor) normally leads to a situation where there is a clear requirement to evacuate. It is possible that this training predisposes a commander to make a decision to evacuate even when the information available to him is equivocal. Although the operator agreed there might be this predisposition, it also believed that its training, in relation to decision making for evacuation, takes this into consideration by emphasising the need to balance the risk of injury during an evacuation against the risk of not evacuating.

2.1.3 The evacuation

The commander said to the co-pilot during the approach that he would instruct the cabin crew to standby once the aircraft came to a halt. He actually said "CABIN CREW REMAIN SEATED" which was the stand down PA and which made the cabin crew believe that an evacuation would not be necessary. Even though the evacuation came as a surprise, it did not affect the performance of the cabin crew in their duties.

The evacuation commenced as soon as it was ordered by the commander and all doors were opened simultaneously. The escape slide at Door 4R did not fully inflate, which rendered the exit unusable, and the cabin crew redirected passengers to other exits. A number of passengers and crew received minor injuries during the evacuation most of which appeared to have been sustained when using the escape slides, in particular during the transition from the slide to the ground. The majority of cabin crew members expressed surprise about the high speed at which they came down the slide. The operator notes that the slide used for training is somewhat slower, due to health and safety considerations, and this difference is now highlighted during cabin crew evacuation training.

The evacuation from the left side of the aircraft was more rapid than from the right. A number of passengers sat down in exits before descending the slides and others struggled with large items of hand baggage which considerably slowed the flow of passengers.

The safety briefing card and pre-flight safety video used by the operator were compliant with the relevant requirements. The briefing card included information relating to the use of the escape slide in the form of two small pictures. There is no guidance provided on how to use the escape slides when travelling with young children and none is required by the regulations. The pre-flight safety demonstration provides an opportunity to brief passengers on the use of escape slides especially and is particularly effective when it is delivered in a video format. A demonstration including information on how to enter, descend and exit slides might, in this case, have increased the flow of passengers from the exits on the right side of the aircraft and generally minimised injuries. Further reinforcement of the need to leave hand baggage behind could also be included. The following Safety Recommendation is therefore made to the European Aviation Safety Agency:

Safety Recommendation 2014-005

It is recommended that the European Aviation Safety Agency amend AMC1 CAT.OP.MPA.170, 'Passenger briefing', to ensure briefings emphasise the importance of leaving hand baggage behind in an evacuation.

Safety Recommendation 2014-006

It is recommended that the European Aviation Safety Agency develops recommendations on the content of visual aids such as safety briefing cards or safety videos to include information on how passengers, including those with young children, should use the escape devices.

2.1.4 Communication with ATC

The message that there was smoke in the aft cargo bay, passed accurately to Brest ATC by the co-pilot, had been corrupted by the time it reached the fire crew at London Gatwick Airport such that they thought there was smoke in the cockpit and positioned their vehicles at the wrong end of the aircraft. Although this had no bearing on events in this incident, it highlighted that it is important for accurate information about the nature of a problem to be relayed between agencies.

The Brest ATC controller told London Control that the aircraft had "smoke on board" and this was passed on subsequently as "smoke in the cockpit" which was the message finally received by the London Gatwick Airport RFFS. It is possible that differences in native tongue contributed to the message being corrupted but, to improve the situation, NATS introduced the NITS format notepad for use by its controllers when eliciting information from crews experiencing a problem in flight. Not all airlines flying within UK airspace will currently be using the briefing format, although many UK airlines will. However, the formal structure is likely to improve the flow of information to ATC from an aircraft with a problem even when there is a difference in native language. Once information has been received and recorded in this format, it should be less likely for the message to be corrupted during onward transmission to different agencies.

2.2 Engineering aspects

2.2.1 Smoke event

Examination of the aircraft revealed no evidence of fire or smoke in the cargo compartments. Neither were any potential sources of fire or smoke identified in the cargo and baggage items loaded in the LDCC. This led the investigation to conclude that the smoke warnings were spurious.

2.2.1.1 Initial smoke warnings

A review of the available aircraft BITE data and smoke detector NVM indicates that the smoke warning event was initiated by smoke detector 10WH, in the bulk area of the aft cargo compartment, registering ALARM status on up to five separate occasions between 1103 and 1107 hrs and lasting from five to nine seconds each.

2.2.1.2 Smoke warnings following activation of the fire extinguishing system

Coincident with the activation of the fire extinguishing system at 1107 hrs, all of the smoke detectors on the operative CAN Bus B, 10WH, 8WH and 6WH, registered ALARM status. NVM from 6WH and 8WH confirmed that these were optical channel alarms. It can therefore be concluded that the discharge of the halon extinguishing agent caused sufficient light obscuration within these detectors to exceed the optical threshold.

Two further optical alarms were generated on 6WH at 1108 hrs and one further optical alarm by 8WH at 1110 hrs, by which time both of these detectors were in the DEGRADED mode with a reduced optical threshold, making them more sensitive to optical alarms. FDR data shows that the combined effect of these ALARMS was a continuous cockpit smoke warning lasting 2 minutes and 53 seconds.

Smoke detector 10WH then continued to generate a further eight smoke warnings throughout the remainder of the flight, ranging in duration from one to thirteen seconds each, three of which occurred after the aircraft had landed back at London Gatwick.

2.2.1.3 CAN Bus A fault

A CAN Bus A fault, which occurred at electrical power-up, led to the SDS operating in single detection mode. In this configuration, the odd-numbered smoke detectors were no longer polled by the CIDS-SDF. Only smoke detectors on CAN Bus B were capable of detecting and reporting a smoke condition to the SDS. Consequently, the SDS system logic which requires two smoke detectors to trigger a smoke warning was inhibited and 10WH, in isolation, was able to activate the cockpit smoke warnings.

The fact that 7WH registered as DEGRADED mode at the subsequent electrical power-up, following the aircraft evacuation, indicates that CAN Bus A had become available again by this time. Wiring checks did not reveal any physical anomalies with the CAN Bus A wiring. A review of the aircraft fault history before and since the incident did not reveal any other occurrences of this fault. The investigation was therefore unable to determine the reason for the CAN Bus A failure.

An unexpectedly high rate of single CAN Bus faults, similar to that experienced by G-VSXY, have been identified across the A330 fleet. In the absence of any associated hard wiring faults, the manufacturer considers that these faults could be attributed to the CIDS-SDF erroneously detecting a problem at either the CAN Bus wiring or the detectors. However the ATP testing performed on CIDS director 1 did not reveal any such faults with SDF 1. The aircraft manufacturer has therefore launched an internal investigation to determine the root cause of the CAN Bus faults.

As the SDS is equipped with two smoke detection loops there is no limitation on aircraft dispatch with a single inoperative CAN Bus. Although not attributable to genuine wiring anomalies, the erroneous CAN Bus faults nonetheless reduce the operability of the SDS to single detection mode. While the capability to detect a real fire is not compromised in single detection mode, inhibition of the dual detection logic increases the susceptibility to sources of false alarms. The associated Class 2 Maintenance Status Message is only visible to the flight crew when the engines are not running, thus might go unnoticed or its relevance may not be understood.

In this event to G-VSXY, the SDS configuration, in combination with a latent hardware failure in smoke detector 10WH, led to multiple spurious aft cargo smoke warnings and the flight crew had no means to determine that these warnings were spurious. The following Safety Recommendations are therefore made:

Safety Recommendation 2014-007

It is recommended that Airbus determine the causes of erroneous Controller Area Network (CAN) Bus faults and implement solutions to eliminate such faults.

Safety Recommendation 2014-008

It is recommended that Airbus amend the dispatch criteria for aircraft with single Controller Area Network (CAN) Bus faults, until such time as the causes of erroneous CAN Bus faults have been identified and addressed.

2.2.2 Inconsistent temperature measurement by smoke detector 9WH and 10WH

2.2.2.1 Smoke detector 9WH and 10WH anomalies

Despite NVM evidence of inconsistent and inaccurate temperature measurements by 9WH and 10WH prior to the incident flight, the smoke detector's internal temperature monitoring logic did not detect the anomalous temperature readings. This is most likely because, although high enough to trigger an ALARM, the temperatures sensed were within the operating range of the sensors. Previous thermal ALARMS did not result in aft cargo smoke warnings, most likely because both CAN Buses were available at the time and the ALARM would have been rejected by the CIDS-SDF as invalid. The faults therefore remained undetected until the incident flight, when the CAN Bus A failure combined with possible high levels of humidity due to the carriage of perishable goods, provided the combination of conditions necessary for the fault to manifest in a series of spurious smoke warnings.

In the absence of NVM for the incident flight, it was not possible to determine whether the smoke warnings triggered by 10WH were due to thermal or optical ALARMS. However based on the other available evidence it is highly likely that these were thermal-channel ALARMS triggered by erroneous measured temperature values in excess of the thermal alarm threshold.

Smoke detectors 9WH and 10WH passed the manufacturer's ATP testing with no faults found, despite confirmation by other test means, of inaccurate and inconsistent temperature measurement on the T1 temperature sensor of each detector. The following Safety Recommendation is therefore made:

Safety Recommendation 2014-009

It is recommended that Siemens amend the Component Maintenance Manual procedures for multi-criteria smoke detectors returned for overhaul, or issue a service letter, to improve fault detection of thermal channel hardware failures which can lead to inaccurate temperature measurement.

2.2.2.2 Other spurious smoke warnings – safety action

Of the six known spurious smoke warning events on A330 aircraft equipped with CIDS-SDF and multi-criteria detectors, at least two other events exhibited inaccurate or inconsistent temperature measurement from the temperature sensors, indicating that the G-VSXY event was not an isolated case. The aircraft manufacturer has committed to address this issue with a technical solution.

2.2.3 Thermistors

2.2.3.1 Damage to thermistors from 9WH and 10WH

Cracks and holes in the insulating envelope

Laboratory examination of the thermistors from 9WH and 10WH revealed damage to the Kapton tape film. The cracks and holes, located close to the active area, are likely to have affected the insulation resistance of the thermistors and exposed the thermistor chip to the external environment. Tests showed that when the thermistor chips came into contact with a conductive substance, such as water, they were unable to detect the correct resistance values for a given temperature, and the resulting temperature measurements were inaccurate. Infiltration of water through the holes or cracks effectively cancelled the insulation provided by the Kapton and PET.

The investigation was not able to determine how the integrity of the insulating envelope on the 9WH and 10WH thermistors, had become compromised. However, a number of thermistors examined, including those from 9WH and 10WH, exhibited bending on the thermistor frame near the active area.

The thermistors are delicate components and their location on the periphery of the smoke detector housing leaves them susceptible to being bent or trapped during assembly or maintenance, when the smoke detector cover is removed or replaced.

It was considered possible that holes or cracks could initiate in the Kapton or PET at the location of the bend. However it was not possible to reproduce this condition during simulated ageing tests where some thermistors had been intentionally bent.

Bubbles in the insulating envelope

The air bubbles observed in the insulating envelope of the 9WH and 10WH T1, and other thermistors examined in the course of the investigation, were determined to have no adverse effect on the insulation resistance of the thermistors. However, on a thermistor with a damaged envelope, water or other foreign conductive substances could potentially collect in the voids, which could affect the electrical characteristics of the thermistor.

Some thermistors examined in the course of the investigation exhibited larger bubbles than new thermistors from stock and some contained bubbles which were outside the tentative line. As all thermistors are visually inspected at manufacture, this raised the possibility that the bubbles had expanded and migrated outside the tentative line over time. The exact mechanism by which this could occur is not well understood, and could not be replicated by testing, but it was considered that the expansion and migration of bubbles could occur as a result of ageing, or degassing of the adhesive paste used to assemble both insulating films.

If the bubbles migrated to the edge of the thermistor, the envelope would no longer be sealed from the external environment. However it was not possible from test data to make any link between the presence of bubbles and damage to the envelope.

Summary

In summary, while the origins of the damage could not be confirmed, it is highly likely that the compromised insulating envelope on 10WH, when exposed to the possible high humidity environment in the aft cargo hold due to the carriage of perishable goods, was the root cause of the alarms which triggered the spurious smoke warnings.

2.2.3.2 Safety action by smoke detector manufacturer

The smoke detector manufacturer identified a number of process improvements, supported by new tooling, in order to reduce the likelihood of any mechanical stresses or unexpected shocks being applied to thermistors during assembly, storage or transportation.

2.2.4 Silicone coating on measurement board

Previous in-service problems with temperature measurement on PMC1102 smoke detectors had been investigated by the manufacturer and attributed to a lack of adequate silicon insulation at the location where the thermistors were soldered to the measurement board. The silicon insulation on the measurement boards from 9WH and 10WH were not examined, so it was not possible to determine whether this may have influenced the inaccurate temperature measurement at the T1 thermistors.

Recent laboratory testing conducted by the smoke detector manufacturer suggested that the absence of silicon insulation at the thermistor junction, in combination with salt pollution residue and high humidity conditions, could create a short circuit between the thermistor pins and lead to spurious thermal alarms. However it was not possible to draw any correlation between these laboratory findings and the possibility of pre-incident salt contamination of the smoke detectors on G-VSXY.

2.2.5 Effect of halon discharge on smoke detector operation

Smoke detectors 7WH and 8WH were confirmed by the ATP to be latched in the DEGRADED mode due to a failed humidity sensor. Both detectors were fitted in the same cavity in the centre of the aft cargo compartment, and the damage observed on the capacitive sensors was considered consistent with exposure to the halon extinguishing agent.

Smoke Detector 6WH was reported DEGRADED immediately after the halon discharge due to the T2 temperature value being out of range. It is likely that the localised thermal shock (-55ºC recorded) led to failure of the temperature sensor monitoring. 6WH did not latch in the DEGRADED mode, which indicates that the T2 temperature sensor monitoring was cleared at the next power-up, when normal ambient temperature was restored.

The DEGRADED mode status of smoke detectors 6WH, 7WH and 8WH was determined from CMS data, NVM and laboratory analysis, to be a direct consequence of the halon discharge and did not play any role in the initiation of the smoke event. Once DEGRADED the multifunction detectors were reduced to a pure optical smoke detectors, with a reduced fixed threshold for optical alarms, making them more sensitive to the light obscuration caused by the halon gas particles. It is likely that these alarms ceased as the halon dissipated from the immediate vicinity of the smoke detectors.

The smoke detectors removed from G-VSXY aft cargo compartment were the first examples of multi-criteria smoke detectors known to have been exposed to halon during an in-service fire extinguishing event, in a fully-loaded cargo compartment. Qualification tests for the fire extinguishing system were carried out in an empty cargo compartment and did not therefore result in damage to the smoke detectors.

The fire extinguisher nozzles are centrally mounted between pairs of smoke detectors in each cavity on the A330 and other aircraft have a similar configuration. A330 operational guidance advises flight crews that a smoke warning may persist following activation of the fire extinguishers, as the cargo compartments cease to be ventilated. A deflector plate aims to deflect the halon gas away from the smoke detectors, however the discharge of the extinguishing agent occurs in very close proximity to the detectors and results in a significant localised temperature drop. In particular, Bottle 1 is a rapid release bottle and is therefore discharged at high pressure. The G-VSXY incident indicates that the deflector plate is not sufficiently effective in diverting the halon away from the smoke detectors when the cargo compartment is loaded. Humidity sensors are tested at various temperatures following manufacture, but there was no requirement for them to be subjected to a sudden thermal shock. Their behaviour, therefore, when exposed to halon during a fire extinguishing event, was not anticipated prior to this event.

The humidity sensors from 9WH and 10WH did not exhibit any degradation as a result of exposure to the halon gas. It is likely that their location in the bulk cargo compartment, which was less densely loaded than the rest of the aft cargo compartment, allowed the halon to dissipate more rapidly from the immediate vicinity of the smoke detectors.

The precise impact of the halon exposure on the sensitive elements of the multi-criteria smoke detector appears to be determined by a number of variables, including the cargo loading configuration and thus the available volume of air for dissipation of the halon gas. As the precise effect cannot be predicted, the following Safety Recommendations are made:

Safety Recommendation 2014-010

It is recommended that Airbus introduce a maintenance requirement so that, following an activation of the Lower Deck Cargo Compartment (LDCC) fire extinguishing system in an aircraft equipped with multi-criteria smoke detectors, all smoke detectors in the affected cargo compartment are removed for examination and overhaul.

Safety Recommendation 2014-011

It is recommended that the European Aviation Safety Agency review the certification requirements for the location of fire extinguisher nozzles in relation to the smoke detectors, on aircraft equipped with multi-criteria smoke detectors, in order to minimise the adverse effects associated with activation of the fire extinguishing system.

2.2.5.1 Safety action by aircraft manufacturer

The aircraft manufacturer has advised the AAIB that the degraded mode ECAM message will be changed to a Class 2 Maintenance Message, in order that it is reflected on the ECAM status page.

2.2.6 Partial inflation of the R4 slide-raft

Video evidence of the aircraft evacuation showed that inflation of the R4 slide-raft commenced normally when the R4 door was opened. However the primary restraint was observed to release early and consequently the secondary restraint failed to release, leaving the slide-raft only partially deployed.

Previous similar partial inflations have been attributed to an anomaly in the slide-raft packing instructions, leading to an early release of the primary restraint and subsequent non-release of the secondary restraint. Given the similarities between the S/N AA5588 partial inflation and the previous events, the most likely explanation for the failure of the R4 slide-raft to fully deploy was pre-loading of the primary restraint, caused by a packing fold.

Although the manufacturer introduced a change to the packing instructions to address this known issue, by altering the dimensions of a particular fold, S/N AA5588 had been manufactured prior to the effective date of the new packing instructions. As this issue has already been addressed by the slide manufacturer, no further Safety Recommendation is considered necessary.

3 Conclusions

a) Findings

Operational aspects

1. The crew experienced a SMOKE AFT/BULK CARGO SMOKE Master Warning 15 minutes into the flight which repeated intermittently until just before the evacuation.

2. The crew carried out the appropriate ECAM actions in relation to the Master Warning which included discharging fire extinguishing agent into the aft cargo hold.

3. The message that there was smoke in the cargo hold was misunderstood by Brest ATC and corrupted during onward transmission leading to the RFFS at London Gatwick airport positioning fire vehicles at the wrong end of the aircraft.

4. Cabin crew reported to the incorrect location on the aircraft for their brief by the FSM.

5. Once the aircraft had come to a halt on the runway, the commander instructed the cabin crew to stand down rather than stand by.

6. The escape slide at Door 4R did not fully inflate which rendered the exit unusable.

7. The evacuation was completed in 109 seconds, with most passengers out within one minute.

8. There was confusion between the incident commander on the ground and the ATC Watch Manager, as to the correct status of the incident. Consequently, there was a delay in passing a message to relevant emergency and support agencies that there had been an evacuation on the runway.

9. The RFFS found no evidence of smoke or heat spots in the aircraft.

Technical aspects - general

10. The aircraft was certified, equipped and maintained in accordance with the applicable regulations.

11. There was no evidence of fire, smoke or heat damage in the aft cargo compartment.

12. The aircraft was carrying a cargo largely comprised of perishable goods.

13. Fifteen separate aft cargo smoke warnings were generated during the flight. They were determined to be spurious warnings.

Technical aspects - smoke detection system

14. Redundancy in the SDS was lost at electrical power-up during the incident sector due to a CAN Bus A wiring fault, resulting in the SDS operating in single detection mode.

15. Redundancy in the SDS was restored at the subsequent electrical power-up.

16. Inspection of the CAN Bus A wiring did not reveal any wiring anomalies.

17. The root cause for the CAN Bus A fault has not been determined.

18. The aircraft manufacturer identified an unexpectedly high rate of similar CAN Bus faults across the A330 global fleet. These faults are under investigation.

Technical aspects - smoke detectors

19. The initial smoke warnings were initiated by smoke detector 10WH.

20. Smoke detector 10WH generated 12 of the smoke warnings. 10WH NVM was not available for the incident sector, however it is likely that these were all thermal alarms.

21. Three additional optical alarms were generated by smoke detectors 6WH and 8WH, as a result of the fire extinguishing agent discharge.

22. Release of the halon fire extinguishing agent resulted in damage to the humidity sensors of the 7WH and 8WH smoke detectors and resulted in them becoming DEGRADED.

23. Release of the halon fire extinguishing agent resulted in smoke detector 6WH temporarily becoming DEGRADED, due to a localised temperature drop below the operating range of the temperature sensors.

24. The insulation resistance of the 9WH and 10WH T1 thermistors was compromised by damage to the insulating envelope, which exposed the active area of the thermistor to the external environment.

25. The damage to the insulating envelope degraded the electrical characteristics of the 9WH and 10WH T1 thermistors, such that the resistance response, and consequently the measured temperature value for a given temperature, was inaccurate.

26. The investigation was not able to determine the cause of the damage to the Kapton film of the 9WH and 10WH T1 thermistors.

27. The investigation was not able to reproduce a reduction in thermistor electrical performance, even on thermistors with intentionally induced damage.

28. Acceptance Test Procedures did not detect the faults on the 9WH and 10WH T1 thermistors.

29. The smoke detector internal temperature monitoring did not detect the faults on the 9WH and 10WH T1 thermistors.

30. The T1 thermistors from 9WH and 10WH were part of a batch manufactured in 2008.

31. One other thermistor examined in the course of the investigation exhibited similar damage to that on the 9WH and 10WH T1 thermistors, and a similar deterioration of the thermistor's electrical performance. It had been subject to chemical spray during smoke detector qualification testing.

32. Bubbles were present in the insulating envelope of the T1 thermistors from 9WH and 10WH, and other thermistors examined in the course of the investigation.

33. Thermistors removed from in-service smoke detectors contained a greater number and larger size bubbles than new thermistors from stock.

34. The presence of the bubbles did not, in isolation, have any impact on the electrical characteristics of the thermistors, when tested.

35. A previously identified issue with silicon coating at the junction of the thermistors and the measurement board could not be ruled out as a contributory factor.

Technical aspects - escape slide-raft findings

36. The R4 slide-raft did not fully inflate and consequently the R4 exit was not available during the emergency evacuation.

37. The secondary restraint on the R4 slide-raft was unbroken.

38. The partial inflation of the R4 slide-raft most likely resulted from a packing fold, which caused early release of the primary restraint and non-release of the secondary restraint.

39. The R4 slide-raft was manufactured and packed before a change to packing instructions was implemented, to address previous similar partial inflations.

b) Causal factors

The investigation identified that injuries were sustained during the evacuation of the aircraft. The evacuation was initiated based on the commander's assessment of the available sources of information, including the repetitive and intermittent nature of the aft cargo smoke warnings.

The investigation identified the following causal factor for the intermittent cargo smoke warnings:

(i) A latent fault on the T1 thermistor of smoke detector 10WH, in combination with a CAN Bus fault and possible high levels of humidity in the cargo compartment due to the carriage of perishable goods, provided circumstances sufficient to generate multiple spurious aft cargo compartment smoke warnings.

c) Contributory factors

The investigation identified the following contributory factors for the intermittent cargo smoke warnings:

(i) The thermal channel fault in 10WH was not detected prior to the event by the internal smoke detector temperature monitoring.

(ii) The proximity of the fire extinguisher nozzles to the smoke detectors.

4 Safety Recommendations

The following Safety Recommendations are made:

4.1 **Safety Recommendation 2014-005:** It is recommended that the European Aviation Safety Agency amend AMC1 CAT.OP.MPA.170, 'Passenger briefing', to ensure briefings emphasise the importance of leaving hand baggage behind in an evacuation.

4.2 **Safety Recommendation 2014-006:** It is recommended that the European Aviation Safety Agency develops recommendations on the content of visual aids such as safety briefing cards or safety videos to include information on how passengers, including those with young children, should use the escape devices.

4.3 **Safety Recommendation 2014-007:** It is recommended that Airbus determine the causes of erroneous Controller Area Network (CAN) Bus faults and implement solutions to eliminate such faults.

4.4 **Safety Recommendation 2014-008:** It is recommended that Airbus amend the dispatch criteria for aircraft with single Controller Area Network (CAN) Bus faults, until such time as the causes of erroneous CAN Bus faults have been identified and addressed.

4.5 **Safety Recommendation 2014-009:** It is recommended that Siemens amend the Component Maintenance Manual procedures for multi-criteria smoke detectors returned for overhaul, or issue a service letter, to improve fault detection of thermal channel hardware failures which can lead to inaccurate temperature measurement.

4.6 **Safety Recommendation 2014-010:** It is recommended that Airbus introduce a maintenance requirement so that, following an activation of the Lower Deck Cargo Compartment (LDCC) fire extinguishing system in an aircraft equipped with multi-criteria smoke detectors, all smoke detectors in the affected cargo compartment are removed for examination and overhaul.

4.7 **Safety Recommendation 2014-011:** It is recommended that the European Aviation Safety Agency review the certification requirements for the location of fire extinguisher nozzles in relation to the smoke detectors, on aircraft equipped with multi-criteria smoke detectors, in order to minimise the adverse effects associated with activation of the fire extinguishing system.

Unless otherwise indicated, recommendations in this report are addressed to the appropriate regulatory authorities having responsibility for the matters with which the recommendation is concerned. It is for those authorities to decide what action is taken. In the United Kingdom the responsible authority is the Civil Aviation Authority, CAA House, 45-49 Kingsway, London WC2B 6TE or the European Aviation Safety Agency, Postfach 10 12 53, D-50452 Koeln, Germany.