FINAL REPORT

AIRBUS A380-800, REGISTRATION 9V-SKD

SMOKE IN LAVATORY

SINGAPORE CHANGI AIRPORT

31 JANUARY 2011

AIB/AAI/CAS.072

Air Accident Investigation Bureau of Singapore
Ministry of Transport
Singapore

3 October 2012

The Air Accident Investigation Bureau of Singapore

The Air Accident Investigation Bureau (AAIB) is the air accidents and incidents investigation authority in Singapore responsible to the Ministry of Transport. Its mission is to promote aviation safety through the conduct of independent and objective investigations into air accidents and incidents.

The AAIB conducts the investigations in accordance with the Singapore Air Navigation (Investigation of Accidents and Incidents) Order 2003 and Annex 13 to the Convention on International Civil Aviation, which governs how member States of the International Civil Aviation Organization (ICAO) conduct aircraft accident investigations internationally.

In carrying out the investigations, the AAIB will adhere to ICAO's stated objective, which is as follows:

> *"The sole objective of the investigation of an accident or incident shall be the prevention of accidents and incidents. It is not the purpose of this activity to apportion blame or liability."*

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SYNOPSIS

At 10.45 p.m. on 31 January 2011, a cabin crew member on an Airbus A380 flight from Hong Kong to Singapore heard a loud bang when he was in a lavatory. He later noticed an electrical burning smell and smoke. He discharged a fire extinguisher into the area from where the smoke was coming out. The smoke subsequently cleared and the aircraft landed without further incident. No passenger or crew was injured.

An inspection after the aircraft had landed in Singapore found signs of burning at the feeder terminal block and feeder cables that were situated below the lavatory, behind the left side wall of the forward cargo compartment. Some feeder cable lugs were found melted and there was soot on the components around the feeder terminal block. Some insulation blankets adjacent to the feeder terminal block were also burnt.

A degraded Main Excitation Cable had probably caused an over-voltage across the Lightning Protection Units (LPUs) attached to the feeder terminal block, resulting in a short circuit between the three phase feeder cables and structural grounding. The short circuit caused excessive current to flow through the feeder cables attached to the feeder terminal block. The operation of the Over-Current protection limited the damage due to overheating.

The Air Accident Investigation Bureau of Singapore (AAIB) has classified this occurrence as a serious incident.

AIRCRAFT DETAILS

Aircraft type	: Airbus A380-800
Operator	: Singapore Airlines
Aircraft registration	: 9V-SKD
Numbers and type of engines	: 4 x Rolls Royce Trent 900
Type of flight	: Scheduled passenger flight
Date/time of incident	: 31 January 2011, 10.45 p.m.

GLOSSARY OF ABBREVIATION

APU	:	Auxiliary Power Unit
CIC	:	Cabin Crew-In-Charge
FOV	:	Fast Over-Voltage
GGPCU	:	Generator and Ground Power Control Unit
LPUs	:	Lightning Protection Units
VFG	:	Variable Frequency Generator

1 FACTUAL INFORMATION

All times used in this report are Singapore times. Singapore time is eight hours ahead of UTC (Coordinated Universal Time).

1.1 History of the Flight

1.1.1 On 31 January 2011, an Airbus A380 was flying the Singapore-Hong Kong-Singapore sectors. When the No.1 engine was started prior to departure at Singapore, the Electronic Centralised Aircraft Monitoring (ECAM) system displayed the alert message "ELEC GEN 1 FAULT[1]". The No.1 Variable Frequency Generator (VFG) installed on the No.1 engine was reset and the alert message was cleared. The aircraft took off from Singapore and arrived uneventfully in Hong Kong.

1.1.2 When the No.1 engine was started prior to departure at Hong Kong, the ECAM alert message "ELEC GEN 1 FAULT" appeared again. The flight crew attempted to clear the message by resetting the No.1 VFG but was unsuccessful. The deferred defect status of the aircraft was such that the aircraft could not depart with this fault. So the flight crew arranged for the aircraft to be towed back to the gate to let the engineering staff address the problem.

1.1.3 Based on the fault code observed, the engineering staff referred to the aircraft manufacturer's procedure for troubleshooting. They interchanged the No.1 Generator and Ground Power Control Unit (GGPCU[2]), which controlled the VFG fitted to the No.1 engine, with the serviceable No.6 GGPCU, which controlled the Generator B fitted to the Auxiliary Power Unit (APU)[3]. A test was carried out on both GGPCUs and the result was satisfactory[4]. The subsequent engine start was normal and the ECAM alert message "ELEC GEN 1 FAULT" did not appear. The aircraft then took off from Hong Kong. The First Officer was the pilot flying. The Pilot-in-Command was the pilot monitoring. On the flight deck, there was an Instructor Pilot who was performing a line check on the flight crew.

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[1] "ELEC GEN 1 FAULT[1]" indicates a fault of Electrical Generator No.1.

[2] No.1 to 4 GGPCUs control the VFGs fitted on No.1 to No.4 engines respectively. No.5 and No.6 GGPCU control the Generator A and Generator B fitted on the Auxiliary Power Unit respectively.

[3] The troubleshooting procedures indicated that the No.1 GGPCU should be replaced with a serviceable one. As there was no spare GGPCU available, the engineering staff interchanged No. 1 GGPCU with the serviceable No. 6 GGPCU.

[4] The pins used by the GGPCU when connected to No.1 to No.4 VFGs and when connected to the APU generators are different, so it is possible that a GGPCU found faulty when connected to the No.1 VFG can still be serviceable when connected to an APU generator.

1.1.4 About 45 minutes before arriving Singapore (the aircraft was then about three hours into the flight), an ECAM message indicating smoke in lavatory LM35 on the main deck of the aircraft (see **Figure 1**) appeared.

1.1.5 At this time, the Cabin Crew-In-Charge (CIC) was in lavatory LM35 and he heard a loud bang. The lights in the lavatory went out and the CIC noticed an electrical burning smell.

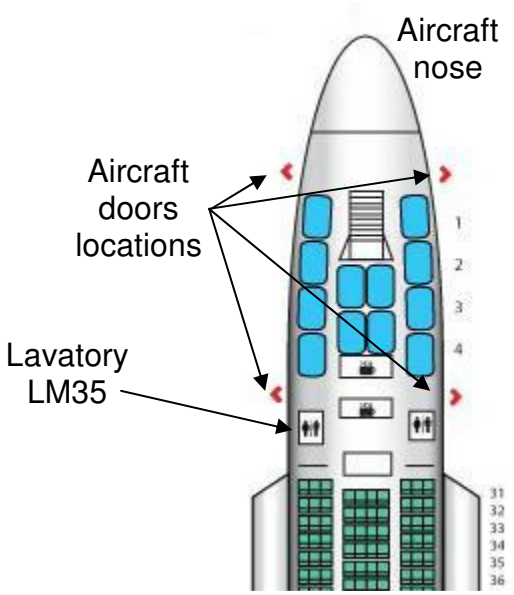


Figure 1: Location of lavatory LM35 on A380 main deck (Top view)

1.1.6 The CIC asked two flight attendants to check the lavatory while he reported the occurrence to the flight crew. One of the attendants ran his hand over the wall panels in the lavatory to feel for heat but he did not detect any.

1.1.7 When the CIC returned to lavatory LM35, he saw smoke emitting from the base of the wall panel under the sink[5], but he could not locate the source of the smoke. He positioned a fire extinguisher under the sink towards the smoke (as illustrated in **Figure 2**) and discharged the fire extinguisher. The smoke and burnt smell cleared about 10 minutes later.

1.1.8 The door of lavatory LM35 was left open for the rest of the flight for monitoring. No subsequent smoke or burnt smell was observed. The aircraft continued its flight to Singapore without further incident.

1.1.9 There were 381 persons on board. There were no injuries.

[5] According to the CIC, the smoke was light, white, and visibility was not obscured.

Figure 2: CIC discharging fire extinguisher (illustration only)

1.2 Damage to Aircraft

1.2.1 The aircraft was inspected after landing in Singapore. Signs of burning were found on the feeder terminal block for the No.1 VFG located in the forward cargo compartment below lavatory LM35 (see **Figure 3**), on the feeder cables connected to the feeder terminal block and on the insulation blankets around the feeder block (see **Figure 4**). The inner surface of the cover of the feeder terminal block was partially covered with soot but did not show any sign of heat damage.

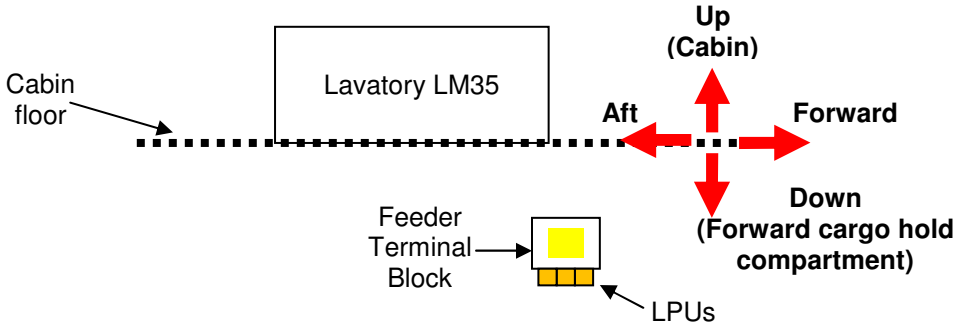


Figure 3: Location of feeder terminal block

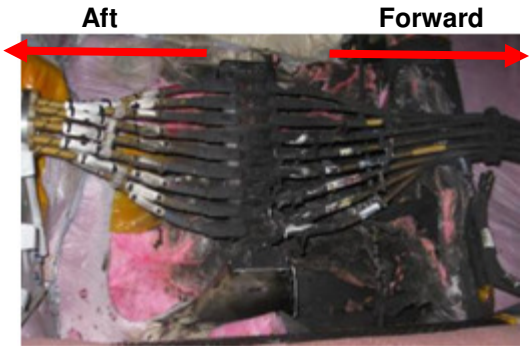
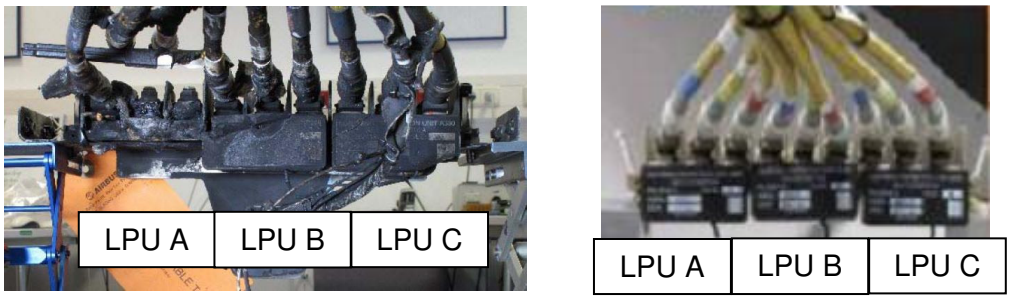


Figure 4: No.1 VFG feeder terminal block

1.2.2 The Lightning Protection Units (LPUs) connected to the feeder terminal block showed signs of melting (see **Figure 5**).



Damaged LPUs Intact LPUs

Figure 5: Damaged LPUs as compared with intact ones[6]

1.2.3 The engineering crew replaced the burnt components[7] and performed a test of the aircraft electrical system which required the affected No.1 engine to be run at idle power. The result of the ground test was satisfactory and the aircraft was released for a flight on 20 February 2011.

1.2.4 During take-off on this flight, the ECAM alert message "ELEC GEN 1 FAULT" appeared when the engines were set to take-off power. The crew abandoned the take-off and taxied the aircraft back to its bay.

1.2.5 During the subsequent troubleshooting[8], the Main Excitation Cable[9] was found to be degraded. The sheath and shielding of the Main Excitation Cable and the insulation of the negative (blue) Main Excitation Wire were damaged (see **Figure 6**).

1.2.6 There was no heat or stress damage found in the proximity of the Main Excitation Cable damage. There was no maintenance work performed on the Main Excitation Cable since the aircraft was delivered to the operator. Figure 7 illustrates the locations of the various components.

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[6] For ease of understanding of this report, the affected LPUs are labeled as A, B and C.

[7] The operator sent pictures of the damage to the aircraft manufacturer and received repair procedures (i.e. to replace affected components) from the manufacturer.

[8] Full wiring continuity and insulation check was carried out with the assistance of aircraft manufacturer personnel.

[9] Main Excitation Cable consisted of two wires, a red positive Main Excitation Wire, and a blue negative Main Excitation Wire. GGPCU controls the VFG output voltage by varying the voltages of the Main Excitation Cable.

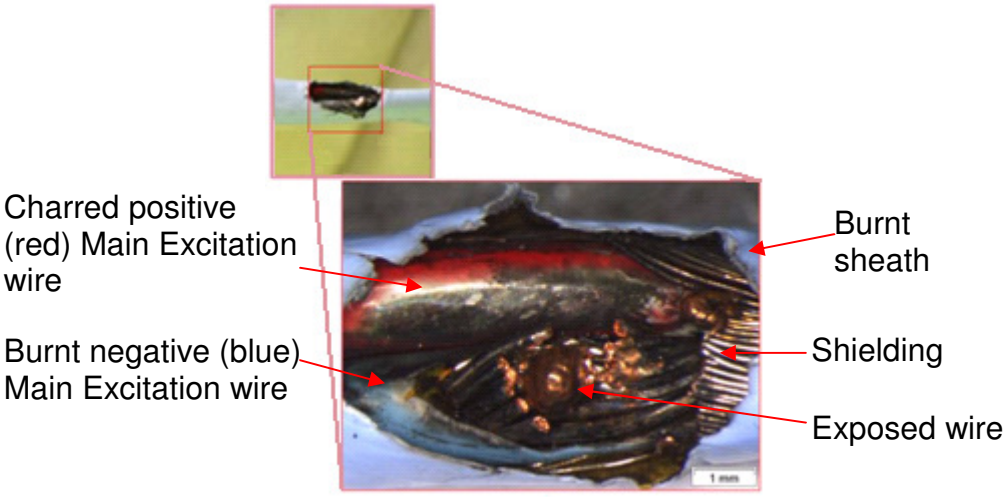

Figure 6: Main Excitation Cable damage

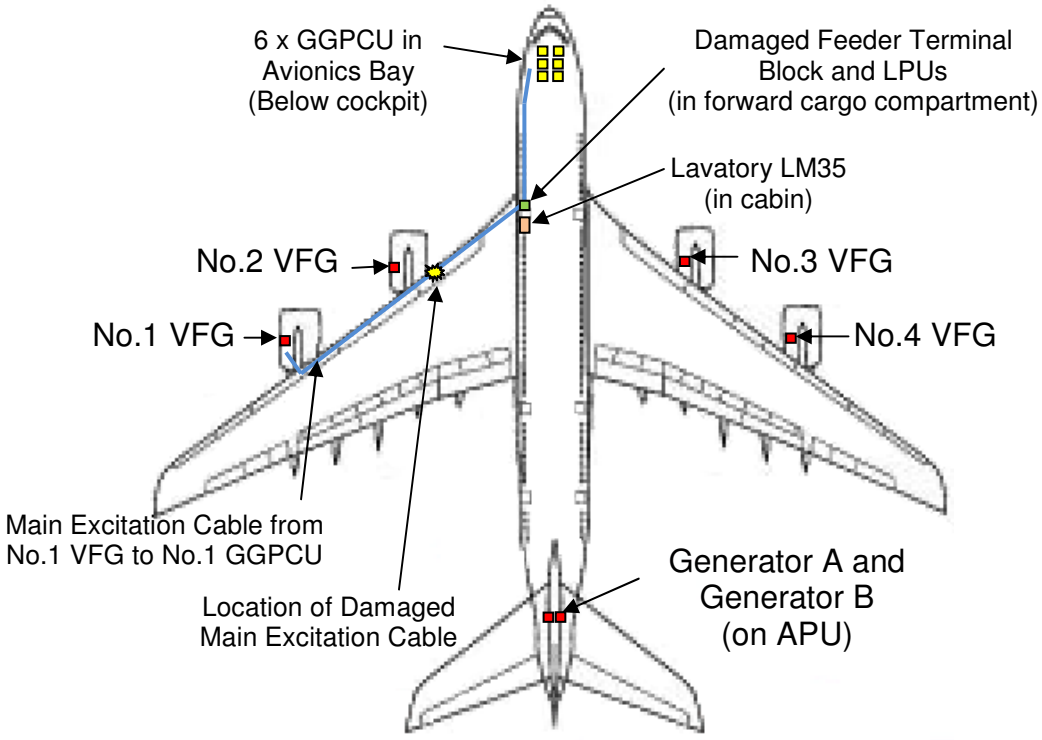

Figure 7: Locations of affected components

1.3 Flight Recorders

1.3.1 There were no DFDR data that were relevant to the incident.

1.3.2 The cockpit voice recording during the incident had been over-written.

1.4 Test and Research

1.4.1 No.1 electrical system

1.4.1.1 **Figure 8** shows a schematic diagram of the No.1 electrical system. The No.1 GGPCU controls the output voltage of the No.1 VFG by varying the current flowing in the Main Excitation Cable which comprises a positive (red) excitation wire and a negative (blue) excitation wire. The output voltage and current of the VFG are monitored by the GGPCU through the Primary Electrical Power Distribution Centre.

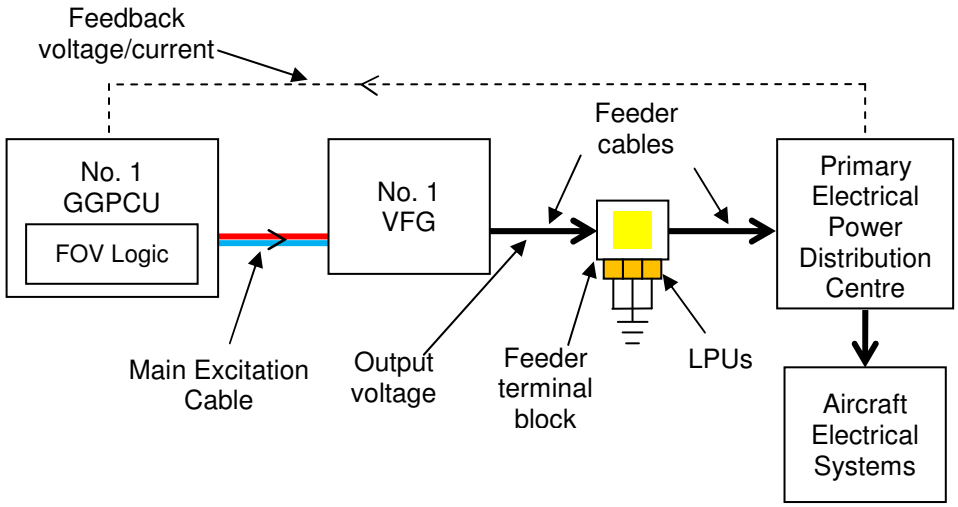

Figure 8: No. 1 electrical system

1.4.1.2 Each GGPCU has a Fast Over-Voltage (FOV) protection logic and an Over-Current protection logic. The FOV protection logic would inhibit the output of the VFG (i.e. zero VFG output) if the VFG output voltage is greater than 143Vac and the negative Main Excitation Wire voltage is less than 19Vdc. The Over-Current protection logic would inhibit the VFG output when any phase current of the VFG output is greater than 435A.

1.4.1.3 According to the data of the non-volatile memories of the GGPCUs in respect of the incident flight on 31 January 2011, the FOV protection logic did not trigger when the No.1 VFG output voltage reached 181Vac (as the negative Main Excitation Wire voltage was higher than 19Vdc, as shown by the GGPCU memory data). The data also showed that an Over-Current event was subsequently detected[10], and the Over-Current protection logic triggered, when the highest phase current reached 1511A.

[10] A VFG output current above 435A (highest phase) detected by GGPCU is considered to be an Over-Current event.

1.4.1.4 Failure analysis of the Main Excitation Cable revealed that the negative Main Excitation Wire was damaged by electrical arcing between the negative Main Excitation Wire and the cable shielding that enveloped the positive and negative Main Excitation Wires.

1.4.2 Lightning Protection Units (LPUs)

1.4.2.1 The LPUs are made up of Zener diodes[11]. The LPUs protect the electrical system against voltage surges during lightning strikes. They are electrically connected between the feeder cables and the electrical ground, i.e. the aircraft structure. Under normal operating condition, they block the feeder cable voltages from one another and from the electrical ground. When the feeder voltage is above 270V peak (such as in a lightning strike), the LPUs will conduct and allow any transient electrical charge to flow through them to the electrical ground, thus preventing damage to the electrical system.

1.4.2.2 An examination of the damage on the LPUs suggested that the damage was caused by excessive current flowing through the LPUs.

1.4.3 Flow of Fire Extinguishing Agent

1.4.3.1 When the CIC demonstrated to the investigation team how he had discharged the fire extinguisher, it was observed that the fire extinguishing agent did not reach the feeder terminal block (see diagram (not to scale) in **Figure 9**).

1.4.4 Variable Frequency Generator (VFG)

1.4.4.1 The No.1 VFG was sent to the VFG manufacturer in the UK for testing. Visual inspection did not reveal any abnormality. The No.1 VFG was subjected to a standard Production Acceptance Test (PAT) and the results were satisfactory.

1.4.4.2 The teardown examination of the No.1 VFG did not reveal any anomality that could have caused functional or performance degradation.

[11] A Zener diode is a diode which allows current to flow in the forward direction, and also in the reverse direction when the reverse voltage is above a specific rated voltage (i.e. breakdown voltage).

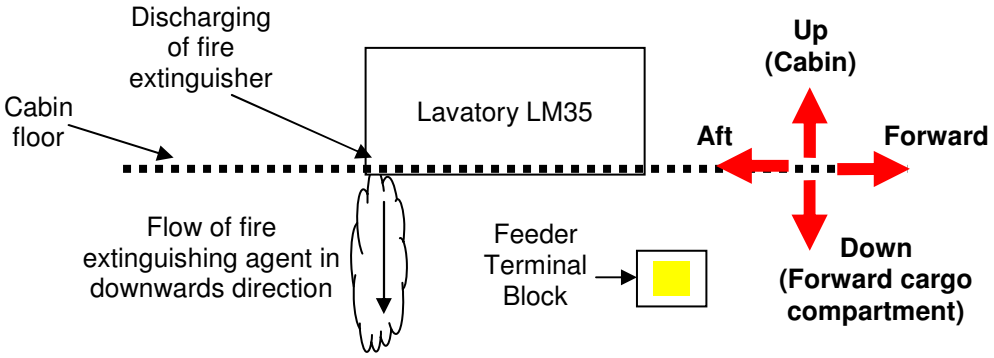

Figure 9: Flow of Fire Extinguishing Agent

1.4.5 Generator and Ground Power Control Unit (GGPCU)

1.4.5.1 The No.1 and No.6 GGPCUs were sent to the GGPCU manufacturer in the UK for testing. Visual inspection of these GGPCUs did not reveal any abnormality.

1.4.5.2 The GGPCUs were subjected to a standard PAT and an Environment Stress Screening test. They were also tested with a functional VFG (not the VFG involved in the occurrence). All results were satisfactory.

2 DISCUSSION

2.1 Main Excitation Cable

2.1.1 Following the occurrence on 31 January 2011, the feeder terminal block for the No.1 VFG and the LPUs connected to the feeder terminal block were found to be damaged and were replaced. The aircraft was eventually released for service on 20 February 2011. An occurrence at the first flight after the release for service led to the discovery of the damage to the Main Excitation Cable (see paragraph 1.2.5). This damage to the Main Excitation Cable probably existed prior to or during the occurrence on 31 January 2011 and is suspected to be the cause of the 31 January 2011 occurrence.

2.1.2 Failure analysis of the Main Excitation Cable revealed that the negative Main Excitation Wire was damaged by electrical arcing (see paragraph 1.4.1.4). The electrical arcing could explain the damage to the feeder terminal block for the No.1 VFG and the LPUs connected to the feeder terminal block:

(a) The electrical arcing means there was a short circuit of the negative Main Excitation Wire to the cable shielding. This could cause the VFG output to increase beyond 143Vac. However, the GGPCU FOV protection did not trigger because the negative Main Excitation Wire voltage was higher than 19Vdc.
(b) The VFG output voltage continued to increase beyond the breakdown voltage of the LPUs, causing the LPUs to conduct. The LPUs, designed for lightning strike (high transient voltage of short duration), conducted for a duration longer than they were designed for. This resulted in a short circuit between the feeder cables attached to the feeder terminal block and the electrical ground, causing excessive currents to flow through the feeder cables. The design of the lightning protection system was such that it did not prevent the feeder cables from being shorted to the electrical ground when excessive voltage is output by the VFG.
(c) The excessive current flowing through the feeder cables overheated and damaged the feeder terminal block and the LPUs. The Over-Current protection was eventually triggered and limited the damage due to overheating.

2.1.3 The electrical arcing also suggests that there might be prior damage to or imperfection of the insulation of the negative Main Excitation Wire. However, this cannot be ascertained. According to the operator, there had been no maintenance work performed on the Main Excitation Cable since the aircraft was delivered to the operator. Therefore it seems unlikely that the insulation damage, if there really was, occurred after aircraft delivery. The insulation damage or imperfection could also have arisen during the aircraft manufacturing process, but there is no evidence in this regard.

2.2 GGPCU protection logics

2.2.1 According to the data of the non-volatile memories of the GGPCUs in respect of the incident flight on 31 January 2011, the FOV protection logic did not trigger when the No.1 VFG output voltage reached 181Vac as the negative Main Excitation Wire voltage was still higher than 19Vdc. According to the GGPCU manufacturer, the FOV protection logic was not designed to be triggered in a scenario where the VFG output voltage is above 143Vac and the negative Main Excitation Wire voltage is above 19Vdc.

2.3 Electrical System Troubleshooting and Test Procedures

2.3.1 Following the occurrence on 31 January 2011, the engineering crew replaced the damaged terminal block, LPUs and feeder cables and tested the affected electrical system. The troubleshooting and test procedures did not require the engineering crew to perform a full wiring continuity and insulation check. Had a full wiring continuity and insulation check been performed during troubleshooting or test of the affected electrical system, the damaged Main Excitation Wire, if it existed, could have been detected.

2.4 Resetting of Electrical Generators

2.4.1 When the ECAM alert message “ELEC GEN 1 FAULT” appeared, the troubleshooting procedure required the flight crew to reset the affected VFG (in this case, No.1 VFG). If the ECAM alert message did not reappear, no further action was required and the aircraft could continue with the flight.

2.4.2 The occurrence on 31 January 2011 indicated that this procedure was unable to address the root cause of the ECAM alert message. If the flight crew reported the electrical fault to the engineering crew, a thorough troubleshooting could have been performed and the damaged Main Excitation Wire, if it existed, could have been detected.

2.5 Fire Detection and Suppression

2.5.1 There was no fire detection or suppression system installed on the aircraft to detect fire in the vicinity of the feeder terminal block nor was there a means for the cabin crew to access the damaged feeder terminal block to fight any fire there. The flow of the fire extinguishing agent discharged from lavatory LM35 (see **Figure 2** and **Figure 9**) could not reach a fire at the feeder terminal block.

2.5.2 The fire that damaged the feeder terminal block had probably extinguished by itself but it remains a concern that there is no sure way of detecting and extinguishing a fire in that area.

3 SAFETY ACTIONS

3.1 Fleet Inspection

3.1.1 Following the occurrence on 20 February 2011, the operator completed an inspection of its A380 aircraft fleet for degradation of the Main Excitation Cable. No similar wire degradation was found.

3.2 Updating of Operating Procedure

3.2.1 The aircraft manufacturer issued a notice on 4 April 2011 to all A380 operators to disallow flight crew to reset the generator in the case of ELEC GEN 1(2)(3)(4) FAULT or ELEC APU GEN A(B) FAULT.

3.3 Fast Over-Voltage

3.3.1 The GGPCU manufacturer has redesigned the GGPCU FOV protection logic to enable it to trigger when the negative Main Excitation Wire voltage is higher than 95% of the positive Main Excitation Wire voltage. This logic has been tested to work for a range of short circuit impedances.

3.3.2 The GGPCU manufacturer will be implementing the modification to all GGPCUs.

3.4 Troubleshooting Procedure

3.4.1 The aircraft manufacturer revised the troubleshooting procedure on 1 October 2011. The revised procedure requires an insulation check of the excitation line circuit (which includes the Main Excitation Cable) to be performed.

4 SAFETY RECOMMENDATIONS

It is recommended that:

4.1 The aircraft manufacturer, as holder of the type certificate, review the design of the lightning protection system to prevent short circuiting of the feeder cables when excessive voltage is output by the Variable Frequency Generator. [AAIB Recommendation R-2012-002]

4.2 The aircraft manufacturer, as holder of the type certificate, review the need for fire detection and suppression in the vicinity of the feeder terminal block. [AAIB Recommendation R-2012-003]

4.3 The European Aviation Safety Agency require the aircraft manufacturer, as holder of the type certificate, to review the design of the lightning protection system to prevent short circuiting of the feeder cables when excessive voltage is output by the Variable Frequency Generator. [AAIB Recommendation R-2012-004]

4.4 The European Aviation Safety Agency require the aircraft manufacturer, as holder of the type certificate, to review the need for fire detection and suppression in the vicinity of the feeder terminal block. [AAIB Recommendation R-2012-005]