

AIRCRAFT ACCIDENT REPORT 1/2015



**Report on the accident to
Airbus A319-131, G-EUOE
London Heathrow Airport
24 May 2013**

Air Accidents Investigation Branch

**Report on the accident to
Airbus A319-131, G-EUOE
London Heathrow Airport
on 24 May 2013**

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EU Regulation No 996/2010 and
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Air Accidents Investigation Branch
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June 2015

***The Right Honourable Patrick McLoughlin
Secretary of State for Transport***

Dear Secretary of State

I have the honour to submit the report on the circumstances of the accident to Airbus A319-131, registration G-EUOE, at London Heathrow Airport on 24 May 2013.

Yours sincerely

Keith Conradi
Chief Inspector of Air Accidents

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GLOSSARY OF ABBREVIATIONS USED IN THIS REPORT

AC	Alternating Current	FMGS	Flight Management Guidance System
ADD	Aircraft Deferred Defect	FMU	Fuel Metering Unit
AFRS	Airport Fire and Rescue Service	GPWS	Ground Proximity Warning System
agl	above ground level	Hz	Hertz
AMC	Acceptable Means of Compliance	ICAO	International Civil Aviation Organisation
AMM	Aircraft Maintenance Manual	IDG	Integrated Drive Generator
ATC	Air Traffic Control	ILS	Instrument Landing System
ATCO	Air Traffic Control Officer	JAA	Joint Airworthiness Authority
BEA	Bureau d'Enquêtes et d'Analyses pour la Sécurité de l'Aviation Civile	JAR	Joint Airworthiness Requirements
BSCU	Brake and Steering Control Unit	LAE	Licensed Aircraft Engineer
CAM	Cockpit Area Microphone	LFB	London Fire Brigade
CCM	Cabin Crew Member	LMA	Limited Maintenance Authority
CFDIU	Centralised Fault Display Interface Unit	LOE	Line Operation Evaluation
CFDS	Centralised Fault Display System	LPC	Line Proficiency Check
CMM	Component Maintenance Manual	LPSOV	Low Pressure Shutoff Valve
CRM	Crew Resource Management	LVDT	Linear Variable Differential Transformer
CS	Certification Specification	MCDU	Multipurpose Control and Display Unit
CVR	Cockpit Voice Recorder	MSN	Manufacturer's Serial Number (of the aircraft)
DU	Display Unit	ND	Navigation Display
EAA	Eastern Ancillary Area	NTSB	National Transportation Safety Board
EASA	European Aviation Safety Agency	PF	Pilot Flying
ECAM	Electronic Centralised Aircraft Monitor	PFD	Primary Flight Display
EEC	Engine Electronic Control	PFR	Post Flight Report
EIS	Electronic Instrument System	PM	Pilot Monitoring
EPR	Engine Pressure Ratio	PTU	Power Transfer Unit
ETSO	European Technical Standard Order	QAR	Quick Access Recorder
E/WD	Engine/Warning Display	QRH	Quick Reference Handbook
FAA	Federal Aviation Administration	SCCM	Senior Cabin Crew Member
FCOC	Fuel Cooled Oil Cooler	SD	Systems Display
FCOM	Flight Crew Operating Manual	SID	Standard Instrument Departure
FCTM	Flight Crew Technical Manual	SOP	Standard Operating Procedure(s)
FDR	Flight Data Recorder	SRM	Structural Repair Manual
FDU	Fire Detection Unit	SSA	System Safety Assessment
FL	Flight Level	VHF	Very High Frequency
FMA	Full Maintenance Authorisation		

Aircraft Accident Report No: 1/2015 (EW/C2013/05/02)

Registered Owner and Operator	British Airways Plc
Aircraft Type	Airbus A319-131
Nationality	British
Registration	G-EUOE
Manufacturer's Serial Number	1574
Place of Accident	London Heathrow Airport
Date and Time	24 May 2013 at 0716 hrs (times in this report are UTC, unless stated otherwise)

Introduction

The event was reported to the Air Accidents Investigation Branch (AAIB) at approximately 0736 hrs on 24 May 2013 by Heathrow Airport Operations and an AAIB investigation was commenced immediately. In accordance with the provisions of ICAO Annex 13, France (the state of aircraft design and manufacture) and the United States of America (the state of engine design and manufacture) appointed Accredited Representatives from the BEA¹ and the NTSB², respectively. Technical assistance was also provided by the operator, the aircraft manufacturer (Airbus), the European Aviation Safety Agency (EASA), International Aero Engines (IAE) and UTC Aerospace Systems (UTAS).

Summary

During takeoff from Runway 27L at London Heathrow Airport, the fan cowl doors from both engines detached from the aircraft, damaging the airframe and a number of aircraft systems. The flight crew elected to return to Heathrow and on the approach to land on Runway 27R, leaking fuel from a damaged fuel pipe on the right engine ignited and an external fire developed. The left engine continued to operate satisfactorily throughout the flight. The right engine was shut down promptly, reducing the intensity of the fire, and the aircraft landed safely. It was brought to a stop on the runway and the emergency services were quickly in attendance. The fire in the right engine was extinguished and the passengers and crew evacuated via the emergency escape slides on the left side of the aircraft.

¹ Bureau d'Enquêtes et d'Analyses pour la Sécurité de l'Aviation Civile.

² National Transportation Safety Board.

The investigation determined that a maintenance error had led to the fan cowl doors on both engines being left unlatched following scheduled overnight maintenance on the aircraft. The unlatched condition of the fan cowl doors was not identified prior to the aircraft's departure the next morning. A number of organisational factors were contributory to the maintenance error. The operator has since taken action to address these issues.

This, and numerous other similar events, shows that Airbus A320-family aircraft have a history of departing with the fan cowl doors unlatched. It is also evident that, in practice, the flight crew walk-around inspection is not entirely effective in detecting unlatched fan cowl doors and therefore a design solution is necessary. Enhanced methods of detection through design solutions are being considered by the aircraft manufacturer.

As a result of this investigation, five Safety Recommendations were made concerning: fatigue risk management; fan cowl door position warnings; fan cowl door certification requirements; in-flight damage assessments by cabin crew and aircraft evacuation procedures.

Factual Information

1.1 History of the flight

1.1.1 Pre-departure

This was the aircraft's first flight of the day following scheduled overnight maintenance (carried out by Technician A and Technician B) which required opening of the fan cowl doors on both engines.

The crew, comprising two pilots and three cabin crew, reported for duty at 0545 hrs at the operator's Crew Report Centre at Heathrow Airport for the scheduled flight to Oslo. The pilots and cabin crew briefed separately before proceeding to the aircraft which was parked on Stand 513 at Heathrow Terminal 5. They met on the aircraft about 45 minutes before the scheduled departure time.

The pilots reviewed the aircraft technical log together; the commander then began preparing the flight deck, whilst the co-pilot carried out the aircraft external walk-around checks. The co-pilot observed nothing unusual during his external checks. The aircraft was refuelled, giving a total fuel on board of 7,600 kg.

While the aircraft was being prepared for flight, a member of the operator's staff happened to take a sequence of photographs of the ground handling activities for the purpose of a ground handling training video. The photographs had inadvertently captured evidence that the fan cowl doors on both engines were in the unlatched condition. On the right engine this is indicated by the gap between the outboard fan cowl door and the nose cowl (Figure 1) and on the left engine by two latches protruding visibly below the cowl doors (Figure 2).



Figure 1
G-EUOE right engine, outboard fan cowl door,
showing gap with nose cowl (circled)



Figure 2

G-EUOE left engine fan cowl door latches visible in unlatched condition (circled)

The pushback tug arrived at the aircraft 15 minutes before the scheduled departure time. The tug driver conducted his pre-departure inspection, walking round the aircraft in an anti-clockwise direction, and found nothing unusual. The aircraft was pushed back from Stand 513 at 0657 hrs, with the fan cowl doors unsecured.

1.1.2 Takeoff

The aircraft took off at 0716 hrs from Heathrow Runway 27L, on a BPK 7G Standard Instrument Departure (SID), with the co-pilot acting as Pilot Flying (PF) and the commander as Pilot Monitoring (PM). FLEX (reduced) power was used, with flap CONFIG 1+F set.

During the takeoff roll a number of passengers observed the engine inboard fan cowl doors “flapping”. As the aircraft rotated, some passengers witnessed the fan cowl doors opening and then being forcefully detached from the engines by the airflow.

Pilots of an aircraft lining up on Runway 27L after G-EUOE’s departure observed a significant amount of debris on the runway, prompting them to transmit a PAN call to air traffic control (ATC).

1.1.3 After takeoff

A number of passengers on both sides of the aircraft pressed their cabin call buttons and shouted to attract the cabin crew’s attention. One passenger

seated on the right side, seeing what she believed to be smoke from the engine, shouted “fire”, but later informed the AAIB that she did not recall seeing an actual fire at this point.

The Senior Cabin Crew Member (SCCM) considered the passenger behaviour highly unusual and attempted to call the flight deck on the interphone. The commander noted the interphone call signal, which occurred as the landing gear was being selected up. As the aircraft was below 1,000 ft agl, he disregarded the call and concentrated on monitoring the aircraft’s flightpath. Cabin crew member No 2 (CCM2) observed that an internal trim panel on the right overwing emergency exit appeared damaged and reported this to the SCCM via the interphone.

As the aircraft climbed through the acceleration altitude of 1,100 ft, Autopilot 2 was engaged and the co-pilot moved the thrust levers to the CLIMB detent. One second later the autothrust disengaged and the master caution activated. The flaps were retracted as the aircraft accelerated to the target climb speed of 250 kt. After confirming that both engines appeared to be operating satisfactorily, the crew continued climbing the aircraft on the SID track to the first cleared altitude of 6,000 ft.

1.1.4 Interim events

On checking the Electronic Centralised Aircraft Monitor (ECAM), the commander saw that the ENG 2 EPR MODE FAULT message was displayed. He noted that the No 2 (right) Engine Pressure Ratio (EPR) gauge was blank. He followed the ECAM actions, selecting the N1 MODE ‘ON’ for engine No 2 and then engine No 1 (left engine). Four seconds later the master caution sounded again, with the ECAM indicating a Yellow hydraulic system loss. The commander turned off the Power Transfer Unit (PTU), in accordance with procedures, and the flight crew began reviewing the situation.

When the aircraft levelled at 6,000 ft, the co-pilot reported to the commander that he believed something had hit the right wing, as he could see damage to the wing leading edge. At 0720:20 hrs, after being transferred to the Departure radar frequency, the commander declared a PAN (urgency) to ATC, reporting that the aircraft had an engine problem and had lost a hydraulic system. He requested radar vectors and informed ATC that the aircraft would be returning to Heathrow. ATC acknowledged and confirmed that radar vectors would be provided to keep the aircraft in the vicinity of Heathrow.

The commander then returned to the ECAM actions for loss of the Yellow hydraulic system, during which he identified an ECAM indication associated with the right overwing emergency exit. The ECAM drill for this item required the pilots to monitor the cabin pressure and the aircraft to remain below flight level (FL) 100.

Once in the climb, the SCCM went down the cabin to assess the status of the right overwing emergency exit. Several agitated passengers near the exit immediately drew her attention to the damaged right engine as she approached. From her position, standing in the aisle, she had a limited view of the engine and she did not see that fuel was leaking from the engine.

After looking at the damage to the right engine, at 0722:53 hrs, some six minutes after her initial attempt to contact the pilots, the SCCM called the flight deck via the interphone to report what she had seen. When the commander answered, the SCCM informed him that the top of the right engine looked as if it was “blown open”. The commander did not request further details and responded that the aircraft was returning to Heathrow. Following a discussion, it was agreed that the SCCM would make an initial Public Address (PA) announcement to the passengers. The commander planned to make a further announcement once he had completed the checks.

The aircraft was vectored by ATC towards the Lambourne holding area and the co-pilot reduced speed to 220 kt. The commander informed the co-pilot that the SCCM had reported that part of the right engine cowling had detached, before commencing a review of the ECAM status display.

ATC informed the pilots “YOU’VE LEFT MULTIPLE ENGINE PARTS AND THERE WAS SMOKE AS YOU LEFT THE RUNWAY AT HEATHROW”. ATC then transferred the aircraft to a discrete frequency.

At 0726:30 hrs, the SCCM contacted the commander again by interphone, this time informing him that the left engine cowling was also missing. She added that when the cowling detached from the right engine, it had struck the right overwing emergency exit. The commander confirmed that the SCCM meant both engines had cowling damage, but did not enquire further.

After reviewing the situation, the pilots briefed for a landing on Runway 27R at Heathrow. The aircraft was 27 nm east of the airport at this time.

As the pilots started to apply the operator’s decision-making aid T-DODAR,¹ the ECAM fuel imbalance alert activated². The co-pilot immediately identified this as a probable fuel leak; ten seconds later the commander requested vectors to the ILS for 27R. ATC instructed the aircraft to turn left onto a heading to close with the localiser. Once the aircraft commenced the turn, the commander informed ATC that the aircraft had a fuel leak and that there were about five tonnes of fuel remaining on board.

¹ This is a mnemonic for: T-Time, D-Diagnose O-Options D-Decide A-Assign R-Review.

² This alert is triggered when there is a difference of 1,500 kg in the fuel quantity between the left and right wing tanks.

1.1.5 Cabin crew briefing

With the aircraft on a radar track to be fed into the approach, the commander made a PA announcement to the passengers. He informed them that one of the engine “covers” had come off and struck one of the doors, but both engines were operating normally and the flight would return to London. He then made an alert call instructing the SCCM to come to the flight deck for an emergency brief.

The SCCM entered the flight deck with CCM2, in accordance with the operator’s standard procedures. The commander briefed that the aircraft would be landing in about six minutes and that the cabin should be prepared for a normal landing. He explained they would be stopping on the runway for the aircraft to be inspected. The SCCM asked about the possibility of a fire occurring and what actions should be taken if this were to happen. Finally, the SCCM informed the commander that the cabin was already secure for landing. With the emergency brief completed, the cabin crew left the flight deck at 0734:00 hrs.

1.1.6 Fuel leak

As soon as the cabin crew left the flight deck, the co-pilot pointed out to the commander that he had calculated the fuel leak rate to be 100 kg in the previous 2 minutes and 20 seconds. They discussed the possibility that the fuel leak on the right side might result in the right engine running down, due to fuel exhaustion.

The aircraft was approximately 26 nm from touchdown with a total fuel remaining of about 4,200 kg, of which about 1,000 kg was in the right tanks. They revised the brief for a CONFIG 3 landing and informed ATC that the right engine might shut down due to a fuel leak. The commander reviewed the fuel imbalance checklist; both pilots confirmed there was no apparent fuel leak on the left side. The co-pilot re-calculated the fuel leak rate which he thought was about 100 kg/min on the right side and estimated that the fuel would be exhausted on that side at about the time they landed. He made repeated interventions to the commander about the fuel leak rate and the probable need to shut down the engine; but the commander did not agree that the engine should be shut down.

A number of passengers saw fuel leaking from the right engine. One passenger highlighted the leaking fluid to a member of the cabin crew, stating that it appeared to be fuel, but was told that it was not. Photographs taken by passengers show a significant fluid leak from the right engine (Figure 3).



Figure 3

Photograph taken by a passenger showing right engine fuel leak

1.1.7 Approach to land

The aircraft established on the ILS localiser at 14.7 nm from touchdown, at an altitude of 4,000 ft, with flap CONFIG 2 selected. At 12 nm, the aircraft was cleared to land by ATC, with the surface wind reported as 290° at 10 kt.

At 0739:30 hrs, approximately 9.5 nm from the runway, the commander declared that he would shut down the right engine. In his later recollection of events, he stated that he had been prompted to do this because there was a loud “bang”, a marked swing of the aircraft, followed shortly thereafter by the engine instrument parameters rapidly reducing. The engine fire alarm activated a few seconds later.

At 9.4 nm from touchdown, the right engine fire warning activated. The commander, without confirmation from the co-pilot, quickly shut down the right engine and discharged the first fire extinguisher bottle. The autopilot disconnected and the co-pilot continued to fly the approach manually, whilst the commander transmitted a MAYDAY to ATC notifying them that he was intending to land, but might have to go around. He then lowered the landing gear, before discharging the second fire extinguisher bottle in accordance with the ECAM timer. The fire warning remained active and the commander told the co-pilot that they would need to land from this approach. Flap CONFIG 3 was selected for the landing, without modifying the Flight Management Guidance

System (FMGS) or Ground Proximity Warning System (GPWS) settings. Although he was not Pilot Flying, the commander took control of the thrust lever, instructing the co-pilot to concentrate on flying the approach.

The commander provided the co-pilot with speed information, and took control of the aircraft at about 500 ft agl and 1.4 nm from touchdown. He instructed the co-pilot to manage the aircraft's speed using the thrust levers.

1.1.8 Landing

As the GPWS settings had not been changed for the flap CONFIG 3 landing, a GPWS 'TOO LOW FLAPS' warning sounded at a height of 240 ft; this was cancelled with the GPWS override switch. After touchdown the co-pilot selected full reverse thrust³ on the left engine, when requested by the commander.

During the landing roll, ATC informed the crew that flames were visible from the right engine and passed the surface wind of 290° at 13 kt. Autobrake was not selected and the commander used manual braking. The right main landing gear outer tyre burst during the landing roll.

Before bringing the aircraft to a halt, the commander turned it to the right, to place the right engine on the downwind side of the fuselage. He applied the parking brake and radioed ATC to ask what they could see. The time was 0744:20 hrs. The air traffic controller responded "STILL SEE FLAMES CONTACT 121.6 PLEASE AND THEY WILL GIVE YOU MORE DETAILS."

1.1.9 After landing

The flight crew set the fire service frequency of 121.6 MHz on the No 2 VHF radio. However the commander inadvertently transmitted on the ATC frequency which was still set on the No 1 VHF radio. ATC replied "FLAMES COMING STILL BUT THEY ARE PUTTING IT OUT." The commander immediately realised his error and re-transmitted on the No 2 VHF, asking for an assessment of the situation outside the aircraft. The fire chief informed the crew that there was a fire in the right engine and that it was being dealt with by the AFRS. The commander asked if he should evacuate the aircraft, but was told to hold by the fire chief, who was aware that the left engine was still running. The commander made a PA to the passengers instructing them to remain seated; at the same time the fire chief asked the crew to shut down the left engine. The co-pilot did so, but this resulted in the loss of No 2 VHF radio, requiring 121.6 MHz to be set on No 1 VHF, which was still electrically powered.

³ The use of thrust reversers is not recommended by the aircraft manufacturer in the case of a fuel leak (FCOM PRO-ABN-28 refers). The asymmetric use of thrust reversers is also not recommended (FCTMAO_020 refers).

With communications re-established, the fire chief instructed the commander to evacuate the aircraft on the left side, away from the fire. The commander ordered an evacuation, informing the cabin crew that there was a hazard on the right side of the aircraft. The aircraft was then evacuated without serious injury.

1.2 Injuries to persons

Injuries	Crew	Passengers	Others
Fatal	0	0	0
Serious	0	0	0
Minor/None	5	75	

1.3 Damage to aircraft

1.3.1 General

The inboard and outboard fan cowl doors from both engines had detached, close to the pylon attachment hinges. Whilst three of the four fan cowl doors had separated by delamination of the fan cowl's composite structure, the forward section of the right inboard door, together with the inboard nacelle aerodynamic strake, had remained attached to the aircraft (Figure 4). The majority of the detached remnants of the doors were recovered from Runway 27L.



Figure 4

Attached remnants of right engine inboard fan cowl door

Aerodynamic loads imparted to the engine pylons by the departing fan cowl doors had caused a severe buckle in the primary structure of the right pylon and damage to the forward fairing of the left pylon. The detached fan cowl doors had struck and damaged the inboard leading edge slats, the fuselage skin close to the overwing emergency exits, the overwing fairings, the right inboard flap and the left belly fairing. The impact to the right overwing emergency exit had dislodged the cabin trim cover on its interior handle, causing a DOOR R EMER EXIT ECAM message to be generated. In addition, the right engine's outboard fan cowl had struck the right wing leading edge at the outboard end of Slat 3, damaging this slat and the inboard end of Slat 4. The outboard flap track fairing on the right wing was punctured and the left horizontal stabiliser leading edge and lower skin were damaged.

The fixed leading edge structure behind the right inboard slat was damaged and a wing stringer was cracked. The right wing lower skin behind Slat 2 was gouged.

Debris had also struck the left main landing gear, damaging the leading edge of the fixed landing gear door, a wiring loom and a hydraulic brake pipe.

The right main landing gear outer tyre was damaged during the landing roll and had fully deflated.

1.3.2 Damage to engines

The left engine fan cowl doors had failed cleanly along the hinge line. There was no other damage to this engine.

The right engine and its attached cowlings were extensively heat damaged. The most significant damage was concentrated in the left and right thrust reverser C-ducts. These consist of two large half-annulus shaped doors extending from the rear of the engine fan case to the common nozzle assembly at the rear of the core engine. The outer 'barrel' of the front section of each C-duct consists of a carbon fibre grid structure called cascade vanes. These are normally covered by an outer sleeve. When thrust reverse is selected, the sleeve slides backwards and blocker doors extend into the duct, directing engine bypass air forward through the cascade vanes.

The translating sleeve and cascade vanes on the right engine were heavily fire damaged, particularly on the inboard side of the engine. The resin bonding the layers of carbon cloth together to form the sleeve had been consumed across a significant section, allowing the carbon cloth plies to separate and peel backwards. The underlying carbon fibre cascade vane grid structure had also been burnt away in large sections in the lower inboard quadrant. On

the outboard side the damage was less severe, but there was nevertheless extensive delamination and charring of the translating sleeve. The wiring located on the front edge of the thrust reverser C-duct, associated with position sensing of the translating sleeve, was significantly heat damaged. The common nozzle assembly showed extensive rippling of the outer skin and tempering colour change. There was also heat damage and extensive sooting on the engine pylon.

The nose cowl is attached to the front of the engine fan case. The gap between the back of the cowl and the thrust reverser C-duct is normally sealed by the fan cowl doors. With the fan cowl doors missing, the rear face of the nose cowl was exposed and exhibited extensive sooting around its circumference, with severe blistering of the paint around the top half of the cowl. The fan case itself was heavily sooted, particularly around the top inboard and outboard quadrants of the engine. There was extensive heat damage to most of the wiring looms located on the fan case although most of this wiring damage was superficial and limited to the outer plastic insulation sheath of the wiring. There was also mechanical damage to the heat shield insulation around the flexible hydraulic supply pipes along the top of the engine, although this had not extended through to the braided pipes themselves.

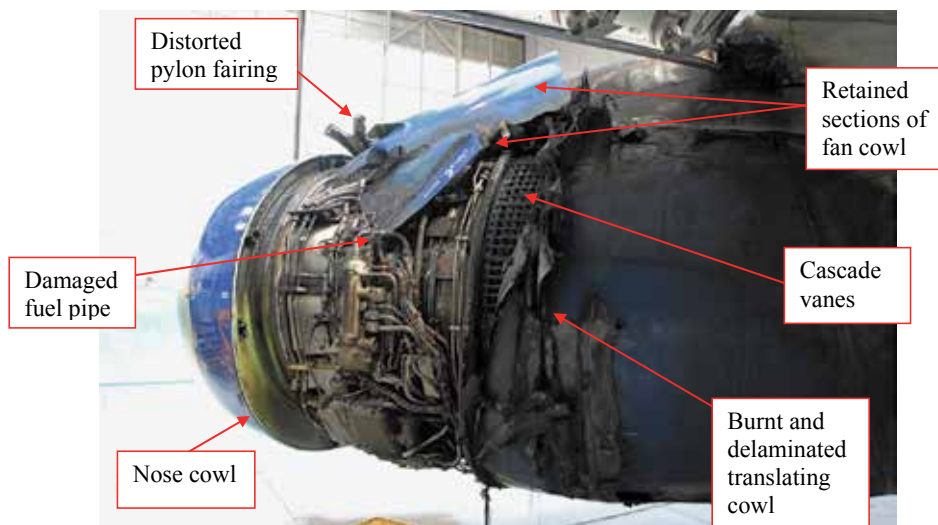


Figure 5

View of inboard side of the right (No 2) engine

Two large sections of the inboard fan cowl door remained attached to the right engine (Figure 5). The large section was attached to the hinge line along the top of the engine; the smaller section, incorporating the aerodynamic strake, was trapped behind a large diameter fuel pipe mounted on the fan case. Both attached sections showed extensive burning along their leading and lower edges. The fuel cooled oil cooler (FCOC) supply and return fuel pipes, behind

which the smaller section of fan cowl door was trapped, were also distorted. When the section of fan cowl was removed, puncture damage from the cowl was visible on the rear of the fuel metering unit (FMU) spill return pipe (Figure 6).



Figure 6

Damaged FMU spill return pipe after removal from the engine

A number of aircraft services (hydraulic, fuel, electrical and pneumatic), which run between the engine and the aircraft, are located within the engine pylon. The pylon forward fairing extends beyond the front of the primary load bearing structural section to cover the hydraulic manifold and pipes which supply fluid to the thrust reverser hydraulic system. The forward fairing is manufactured from stainless steel. The fan cowl doors are also attached to this structure. The fairing at the front of the pylon had been significantly distorted as the fan cowl doors broke away, causing it to come into contact with the P2/T2 probe wiring looms which exit the nose cowl at the top rear face of the cowl. This had resulted in mechanical damage to the wiring.

The thrust reverser hydraulic pipes were also damaged as the pylon fairing twisted, resulting in two pipes becoming detached from the manifold.

1.4 Other damage

None.

1.5 Personnel information

1.5.1 Commander

Age:	50 years
Licence:	Airline Transport Pilot's Licence
Aircraft Ratings:	B737, B757, A320
Last Licence Proficiency Check:	20 October 2012
Last Instrument Rating Renewal:	20 October 2012
Last Line Check:	31 May 2012
Last Medical:	28 February 2013
Flying Experience:	Total all types: 12,500 hours
	On Type: 6,600 hours
	Last 90 days: 131 hours
	Last 28 days: 41 hours
	Last 24 hours: 3 hours
Previous rest period:	18 hours

The commander had initially joined the operator as an engineering apprentice, before becoming a flight engineer on the Lockheed L-1011 TriStar for about five years. He then undertook pilot training and operated the Boeing 737 and 757 as a co-pilot, before completing the operator's A320-series type rating training and command upgrade approximately 11 years before the accident. The commander's most recent Line Operation Evaluation (LOE) was completed on 25 April 2013.

The commander informed the AAIB that, excluding simulator training, he had last flown the A320-series aircraft using manual thrust seven years before the accident.

1.5.2 Co-pilot

Age:	33 years
Licence:	Airline Transport Pilot's Licence
Aircraft Ratings:	B737, A320
Last Licence Proficiency Check:	12 August 2012
Last Instrument Rating Renewal:	12 August 2012
Last Line Check:	5 October 2012
Last Medical:	4 April 2013
Flying Experience:	Total all types: 5,400 hours
	On Type: 4,100 hours
	Last 90 days: 87 hours
	Last 28 days: 49 hours
	Last 24 hours: 4 hours
Previous rest period:	18 hours

The co-pilot joined the operator in 2006, having previously flown the Boeing 737 with another operator. He completed the operator's A320-series ground school on 5 September 2006. He last completed the operator's LOE in February 2013.

The co-pilot informed the AAIB that, apart from simulator training, he had never flown the A320-series aircraft using manual thrust.

As part of his A320-series type conversion training, the co-pilot had watched the operator's training video on the conduct of the external walk-around. This included information on checking the security of the fan cowl doors.

1.5.3 Senior Cabin Crew Member

The SCCM joined the operator in 1997 and operated on a variety of long and short haul aircraft. She completed SCCM training in 2006 and thereafter operated mainly on the Airbus. Her last recurrent training including Crew Resource Management (CRM) was on 8 September 2012. The day of the accident was her third consecutive operating day and her previous rest period was 16 hours.

1.5.4 Cabin Crew Member 2 (CCM2)

The CCM2 joined the operator in 1995 and operated on a variety of long and short haul aircraft. She last completed recurrent training, including CRM, on 25 February 2013. The day of the accident was her seventh consecutive operating day and her previous rest period was 18 hours.

1.5.5 Cabin Crew Member 3 (CCM3)

CCM3 joined the operator in 2012. She had completed her operator and type conversion training between 30 June and 18 July 2012, including CRM on 3 July 2012. The day of the accident was her third consecutive operating day and her previous rest period was 18 hours.

1.5.6 Line maintenance Technician A

Age:	41
Location/shift:	Terminal 5A, Short Haul
Licence:	EASA Part 66 Category B1 Aircraft Maintenance Licence
Licence expiry:	19 February 2018
Relevant approvals:	Full Maintenance Authority (FMA) on Airbus A319/20/21 Limited Maintenance Authority (LMA) on Boeing 767 (RB211)
Experience:	23 years with the company, including 16 years line maintenance experience
Recent duty pattern:	Four 12-hour day shifts and eight 12-hour nightshifts in last 14 days

Technician A had completed an A319/320/321 LMA training course on 16 January 2002 and qualified as an A3-rated LMA technician on 16 April 2003. He also completed an A318/319/320/321 B1 and B2 training course on 2 November 2012 and achieved B1 LAE status with Full Maintenance Authorisation on 18 April 2013, although he was not exercising the privileges of his B1 licence on the shift in question. The training materials for the B1 training course included the following modules relating to fan cowl doors:

- Location and identification of the fan cowl doors
- Opening and closing of the fan cowl doors in accordance with the Aircraft Maintenance Manual (AMM), including viewing of an Airbus training video
- Opening and closing fan cowl doors tutorial

He had last received bi-annual human factors continuation training on 15 November 2012.

1.5.7 Line maintenance Technician B

Age:	53
Location/shift:	Terminal 5A, Short Haul
Licence:	EASA Part 66 Category A3 Aircraft Maintenance Licence
Licence expiry:	9 May 2015
Relevant approvals:	Limited Maintenance Authority (LMA) on Airbus A319/20/21 Limited Maintenance Authority (LMA) on Boeing 767 (RB211)
Experience:	27 years with company, including 16 years line maintenance experience
Recent duty pattern:	Four 12-hour day shifts and six 12-hour nightshifts in last 14 days

Technician B had completed an A319/320/321 LMA training course on 23 March 2001; this training course presented information relating to safety considerations, access, location and operation of the fan cowl doors. He qualified as an A3-rated LMA technician on 31 May 2001 and had last received bi-annual human factors continuation training on 10 January 2013.

1.5.8 Tug driver

The tug driver had been employed by the operator since 1984, mainly in aircraft ground handling. The accident day was his first day on shift after three days off.

The operator's internal investigation identified that the tug driver had completed the relevant 'Aircraft Departure Qualification Training' in 2003 and a revalidation course in 2010.

The 2010 course syllabus included a non-aircraft specific section on 'engine checks' stating: '*Check engine clips are closed*'. The training material handout included a generic statement to: '*check cowling clips are closed*', but no photographs or further information was provided. The training section on engines included checking for damage, leaks, and ensuring the oil filler access panel was closed, but did not have a specific requirement to check the fan cowl door latches.

1.6 Aircraft information

1.6.1 Leading particulars

Registration:	G-EUOE
Type:	Airbus A319-131
Serial number:	1574
Year of manufacture:	2001
Airframe hours at time of accident:	28,362
Engines:	2 x IAE V2522-A5 turbofan engines

1.6.2 Recent maintenance

The accident occurred on the aircraft's first flight following scheduled line maintenance the previous night. A Weekly Check was performed on G-EUOE whilst it was parked overnight on Stand 513 at Heathrow Terminal 5. The maintenance work, performed by Technicians A and B, included a check of the integrated drive generator (IDG) oil levels on both engines and required the fan cowl doors to be opened to access the IDGs. As a result of a maintenance error, the fan cowl doors on both engines were left unlatched. A detailed description of the maintenance activity is provided in Section 1.6.16 of this report.

1.6.3 Fan cowl description

The engine fan cowl is composed of two semi-circular fan cowl doors that are installed between the inlet nose cowl and the translating thrust-reverser cowl. Each door is approximately 1.4 m in length and 3.1 m in height, measured circumferentially. The doors are of a bonded composite construction, consisting of an aluminium honeycomb core with carbon fibre skins. The left door has a mass of 42 kg and the right door 47 kg. One of the design specification requirements for the fan cowl door installation was that operation of the fan cowl doors must be achievable by one person.

The doors are attached to the engine pylon by four hinges at their upper edge and are fastened together by four latches attached to the lower edge of the right door. Each latch operates a hook that engages with a clevis bolt on the lower edge of the left door. The hook is operated by an over-centre linkage in the latch, driven by a pivoted stainless steel handle, which is locked with a spring-loaded 'press to release' catch.

Each latch assembly is mounted on a pivot pin attached to the right door. When fully locked, the latch assembly fits flush with the outside of the doors. When not engaged, rotation of the latch assembly is limited by an anti-swivel plate, also carried on the pivot pin, and itself able to rotate by approximately 30°. A latch can be in one of five possible configurations (Figure 7):

- (a) Latch fully locked and flush with the cowling; cowling locked.
- (b) Latch unlocked following press of release catch, latch handle projecting beneath cowling under gravity. As the hook linkage has not been extended past the over-centre position, the cowling is still locked due to hook pre-load.
- (c) Latch unlocked and rotated past the over-centre position, hook free to rotate from the latch handle; cowling not locked.
- (d) Cowl door open, resting on the hold-open device. Hook free to rotate from the latch handle, cowling not locked.

In this condition, the latch handles will protrude, under gravity, about 95 mm beneath the cowling. This is the condition which the AMM requires the latches to be left in when the fan cowls are open.

- (e) Cowl door open, resting on the hold-open device. Hook re-engaged with the latch handle, cowling not locked.

In this condition, the forward pair of latch handles will protrude, under gravity, about 40 mm beneath the cowling and the aft pair of latch handles will protrude about 60 mm. The AMM fan cowl door opening task 71-13-00-010-010-A does not permit the latches to be left in this condition, and contains the following caution:

'CAUTION: Do not engage the latch handle hooks when the fan cowl doors are open.'

From discussions with maintenance personnel during the course of the investigation it was determined that it was common practice to leave the latches in this condition when the fan cowls were open, as the fully free condition (depicted in Figure 7(d)), in their opinion, presented a personal injury risk. Seven of the eight latches from G-EUOE, which were recovered with the fan cowl debris from the departure runway, were found in this condition.



Figure 7

Possible configurations of the fan cowl door latches

Due to the low ground clearance of the nacelle, fastening the fan cowl door latches usually requires maintenance personnel to lie on the ground to access the latches. The fan cowl door latches are difficult to see unless crouched down so that the bottom of the engine is clearly visible.

To make it more obvious that fan cowl doors are unlatched, the nacelle is equipped with a hold-open device that is bolted to the fixed nose cowl. The device consists of a spring-loaded blocker bar assembly which, when depressed upwards against a spring by maintenance personnel using a screwdriver, allows the fan cowls to be raised from their closed position. Once the fan cowls are raised, the screwdriver is withdrawn from the device and the blocker bar lowers into the 'hold open' position by spring force. In this condition the device prevents the fan cowls from closing flush with the nacelle, due to gravity, and the fan cowl doors stand about 25 mm proud of the nacelle to provide a visual cue that the doors are not latched (Figure 8).

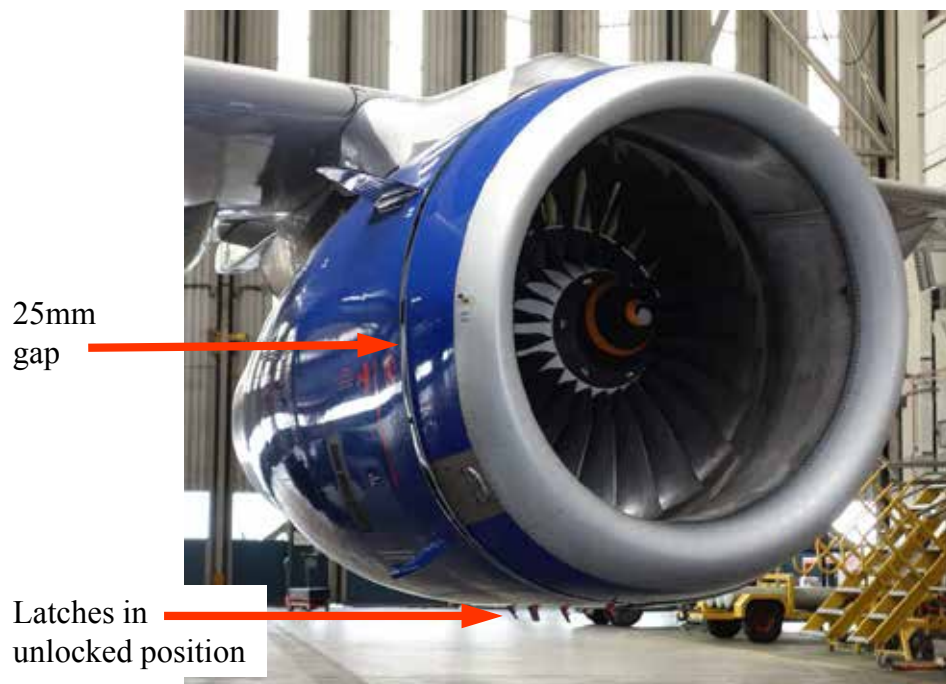


Figure 8

Fan cowl doors on the hold-open device; latches in unlocked position as shown in Figure 7(e)

The fan cowl doors can be propped open by two telescopic struts mounted on the inside of each door, to allow access for servicing.

A review of the repair and overhaul history for G-EUOE's fan cowl doors did not reveal any significant repairs that could have affected the way in which the cowls subsequently broke up when they detached from the aircraft.

1.6.4 AMM procedure for fan cowl door opening

Section 71-13-00-010-010-A of the AMM contains the instructions for opening the fan cowl doors. The approved procedure is summarised below:

- (1) *Place a warning notice on the ENG panel 115VU, on the centre pedestal, to tell persons not to start the engine.*
- (2) *Ensure that the ENG/FADEC GND PWR/1(2) pushbutton switch, located on the 50VU overhead maintenance panel, is off.*
- (3) *Place a warning notice on the 50VU panel to tell persons not to energise the FADEC 1(2).*

- (4) *Release the four latches and open the fan cowl doors approximately 6 inches, making sure that both doors are fully engaged on the hold-open device.*
- (5) *Open one of the fan cowl doors fully and extend one of the telescopic struts, before attaching the free end of the strut into the attach point bracket on the nacelle.*
- (6) *Repeat step (5) for the second telescopic strut.*
- (7) *Repeat steps (5) and (6) for the other fan cowl door.*
- (8) *Check the latch handles to make sure that all latch handle hooks are not engaged.'*

The AMM contains the following caution in relation to this step:

'CAUTION: Do not engage the latch handle hooks when the fan cowl doors are open.'

1.6.5 AMM procedure for fan cowl door closing

Section 71-13-00-410-010-A of the AMM contains the instructions for closing the fan cowl doors. The instructions are preceded by the following caution, added by the aircraft manufacturer in a revision to the AMM in August 2012:

'CAUTION: Do not leave this job after just closing the fan cowl doors, continue on to secure the latches. If you are called away prior to latching, then either re-open one cowl door or latch the latches before walking away from this engine.'

The approved procedure is summarised below:

- (1) *Hold the door open and disengage one of the telescopic struts. Collapse the strut and stow it.*
- (2) *Repeat step (1) for the other strut.*
- (3) *Lower the door slowly.*
- (4) *Repeat steps (1) – (3) for the other door.*
- (5) *Release the doors from the hold open device.*
- (6) *Hold the doors together and close the four latches, ensuring that all the latches stay in their respective slots in the fan cowl and are aligned with the bottom of the fan cowl surface.'*

1.6.6 Electronic Instrument System (EIS)

The EIS includes six Display Units (DU): the Commander and Co-pilot's Primary Flight Displays (PFD) and Navigation Displays (ND), the Engine/Warning Display (E/WD) and the Systems Display (SD).

1.6.7 Electronic Centralised Aircraft Monitor (ECAM)

The ECAM system incorporates the E/WD and SD. The E/WD presents primary engine and fuel quantity indications, flight control information and warning and/or caution messages (Figure 9). The SD presents aircraft status messages and system synoptic pages. In the event of an aircraft system fault, warning or caution messages will appear on the lower left of the E/WD screen, together with a list of Abnormal or Emergency actions to be performed by the crew. Some warnings and cautions (eg engine fire messages) have a higher priority than other messages and these will appear at the top of the ECAM actions list. The E/WD can display a maximum of seven messages at any one time. If more messages are present, they only appear once the flight crew has cleared the messages at the top of the E/WD.



Figure 9

Engine/Warning Display

1.6.8 Centralised Fault Display System (CFDS)

The CFDS provides an interface to maintenance information, along with methods to initiate system and subsystem Built-In Test (BITE) from the cockpit. It comprises a Centralised Fault Display Interface Unit (CFDIU), which receives data from other aircraft computers. The CFDIU is accessed from two

Multipurpose Control and Display Units (MCDUs) located in the cockpit, which can be used to initiate tests and to call up other reports such as the Post-Flight Report (PFR). This is a maintenance report, automatically produced at the end of each flight, showing the ECAM warnings and fault messages recorded during the flight.

1.6.9 Braking system

Each main landing gear is equipped with two braked wheels, numbered from one to four, from the outboard left wheel through to the outboard right wheel. Each of the four mainwheels is equipped with a brake which can be actuated by one of two independent systems. The Normal braking system uses the aircraft's Green hydraulic supply and can be operated using the brake pedals, or via an automatic braking system. In the event of a failure in the Normal braking system, the Alternate system can operate using an independent control system and the Yellow hydraulic supply. The Alternate system incorporates a hydraulic accumulator to provide pressure in the event of loss of the Yellow hydraulic supply.

An antiskid system prevents the wheels locking up during braking. This system operates only when the Green or Yellow hydraulic supplies are present. When braking using hydraulic accumulator pressure only, no antiskid is available and a minimum of seven full brake applications is available until the accumulator is depleted. When braking without antiskid, pilots are required to limit the brake pressure to a maximum of 1,000 psi, using the brake pedals and a gauge in the cockpit, to help prevent the wheels from locking.

In the event of loss of antiskid, a BRAKES A/SKID N/WS FAULT message is displayed on the ECAM. On this standard of A319, this is the only ECAM message covering faults with the antiskid system and the nosewheel steering system. As a result, nosewheel steering may be available with an antiskid fault and vice versa.

The braking system is controlled and monitored by the Braking and Steering Control Unit (BSCU). After each landing gear extension, the BSCU performs a functional test of the Normal and Alternate braking systems and the nosewheel steering system. Part of this test involves commanding each brake to a predetermined brake pressure and then measuring this pressure, to ensure it has been delivered. In Normal braking, if the pressure on one of the brakes is not as expected, the BSCU will switch to the Alternate system.

1.6.10 Autopilot

The aircraft autopilot system can be disengaged by the pilots using the autopilot disconnect pushbutton. The autopilot can also disengage by other actions, including flight control inputs by either pilot on their sidestick or rudder pedals. Movement of the rudder pedals by more than 10° will cause the autopilot to disengage.

The autopilot remains engaged in the event of a single engine failure and provides automatic yaw compensation.

1.6.11 Engine control

1.6.11.1 Normal engine control

Each engine is controlled by an Electronic Engine Control (EEC) unit located on the outside of the engine fan case. It utilises a closed-loop control logic based on the Engine Pressure Ratio (EPR). In order to calculate EPR the EEC requires data provided by various sensors, one of which is the P2/T2 sensor, located in the engine nose cowl. This senses the engine air inlet pressure and temperature.

The EEC calculates an EPR target based on the power setting demanded by the pilot with the thrust lever and compares this to the actual EPR, to determine the EPR error. This is then converted to a rate-controlled fuel flow command, which is summed with the current measured fuel flow from the engine, to produce a fuel flow error. This is converted to an electrical signal which the Fuel Metering Unit (FMU) uses to reposition the Fuel Metering Valve (FMV) for the engine. The change in fuel flow causes the engine to accelerate or decelerate, changing the actual EPR until it matches the commanded demand.

1.6.11.2 Alternate engine control

If the EPR cannot be calculated by the EEC, the engine control system reverts to an alternative mode based on N1, rather than EPR. N1 refers to the rotational speed of the low pressure rotor. There are two types of N1 control:

Rated N1 Mode

If the EEC cannot calculate EPR due to a loss of the P2 or P4.9 signal, the engine will revert to rated N1 mode. The pilot is then required to select this mode manually for both engines. Although functionality is reduced, the control system still provides protection for the engine from exceeding its maximum operating limits.

Unrated N1 Mode

If T2 or altitude data is lost, or the data entry modifier is failed at the time of control initialisation, the EEC automatically reverts to unrated N1 thrust mode. An overboost situation can occur in this mode if the pilot selects too high a thrust lever setting, as thrust is now directly proportional to thrust lever position. The thrust lever position indicator (a cyan circle) on the primary engine indications is unavailable in unrated N1 mode. In the event of loss of P2/T2 probe heating (which will eventually cause T2 to be declared invalid), the engine reverts directly to unrated N1 mode.

Autothrust is not available in either of the N1 modes and the pilot is required to control the engine thrust manually using the thrust levers.

1.6.11.3 P2/T2 Probe power supply

The P2/T2 probe is continuously heated to prevent ice build-up and the signals are temperature-corrected. The heater element is powered by the aircraft 115 V AC electrical supply via a relay controlled by the EEC. The recorded data for the accident flight shows that this relay was selected to the ON position for the right engine until the engine was shut down in flight. The power supply also has a dedicated thermal circuit breaker which, when inspected after the accident flight, was found to have tripped.

For the circuit breaker to isolate the power supply, an increase in electrical current above the circuit breaker's rated current is required. This causes the circuit breaker to heat up to a threshold temperature at which point it will trip and break the circuit, isolating the power supply. In order to reach the threshold temperature, the overcurrent can be low for a sustained period or high for a short duration. However, such thermal circuit breakers are of limited use in detecting interrupted arcing events as although the current within an electrical arc can be very high, the duration of the arc can be so short that insufficient heat is generated in the circuit breaker to reach the threshold temperature.

Arc Fault Circuit Breakers (AFCB) have been developed which use logic to analyse fluctuations in the current associated with an arc event, in combination with thermal thresholds, to trigger the circuit breaker. The EASA issued European Technical Standard Order (ETSO) C137 in July 2013, to standardise these new circuit breakers.

1.6.12 Fuel system

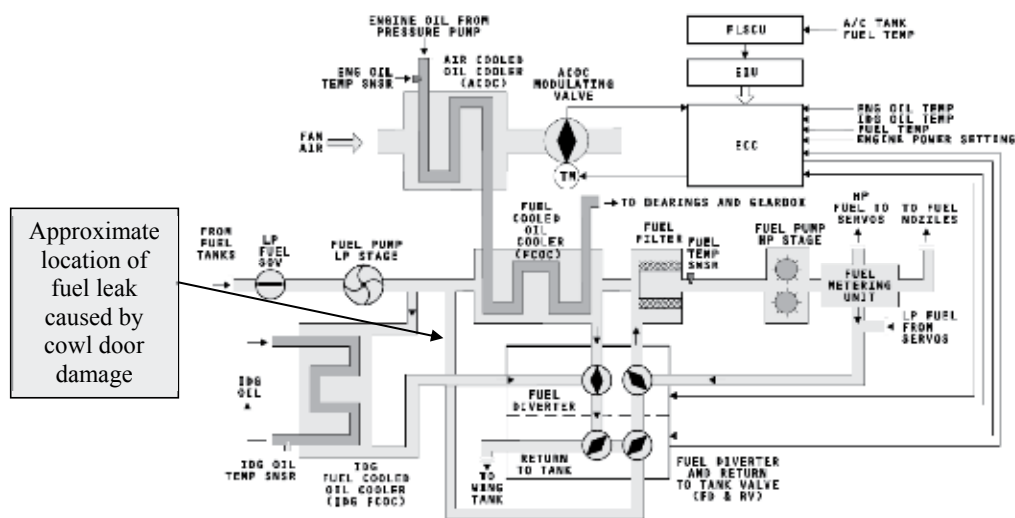


Figure 10
Fuel System

Fuel is supplied to the engine from its respective wing tank. From the Low Pressure Shutoff Valve (LPSOV), the fuel passes through the Low Pressure (LP) fuel pump, which supplies a constant fuel flow, regardless of engine demand. Some of the fuel is then used to cool the engine and IDG oil by passing through the FCOC and IDG FCOC (Figure 10), before continuing through a filter and High Pressure (HP) pump to the FMU. Metered fuel from the FMU then passes through a fuel flowmeter and on to the spray nozzles within the engine combustion chamber. The flowmeter provides feedback to the EEC and the ECAM display on the amount of fuel consumed by the engine.

At the time of the accident, the aircraft did not have automatic fuel leak detection but did have a fuel imbalance monitor. This is triggered once a difference of more than 1,500 kg is detected between the left and right wing tank quantities. There is no ECAM warning message for this condition but a flashing white advisory (ADV) symbol appears on the E/WD and the Fuel System Data page is displayed on the lower ECAM page (Figure 11). The FUEL title on the screen flashes and the fuel quantity in the fullest wing tank will flash.



Figure 11

E/WD with ADV indication and Fuel Page

1.6.13 IDG description and oil servicing requirements

Each engine has an integrated drive generator (IDG) mounted on the lower right side of the engine (Figure 12). The IDG converts variable-speed shaft power from the engine's high pressure shaft into constant frequency 400 Hz AC electrical power. Each IDG has a self-contained oil system in which oil is used to cool and lubricate internal components of the IDG. A vertical sight glass is provided on the IDG to allow the oil level within the IDG to be determined. Servicing is performed according to the oil level position in zones demarked by red, green and yellow coloured bands adjacent to the sight glass.

Oil must be added to the IDG when the oil level reaches the lower red band on the sight glass, as specified by AMM task 24-21-51-200-010. In order to replenish the IDG with oil, additional oil must be pumped into the IDG using a dedicated hand pump, also referred to as an 'IDG gun', which is specific to this task and IDG.

Due to its location on the engine, the IDG cannot be viewed or accessed unless the fan cowl doors are opened and AMM task 24-21-51-200-010 requires, as an initial step, the fan cowls to be opened.

As part of the investigation, the operator reviewed the frequency at which IDGs actually required servicing with oil during Weekly Checks on its A320-family aircraft; any oil uplift must be recorded in the aircraft technical log as part of the check. From a sample of 500 IDG oil level inspections, records revealed that 15 IDGs required oil replenishment, equating to a rate of 3%.

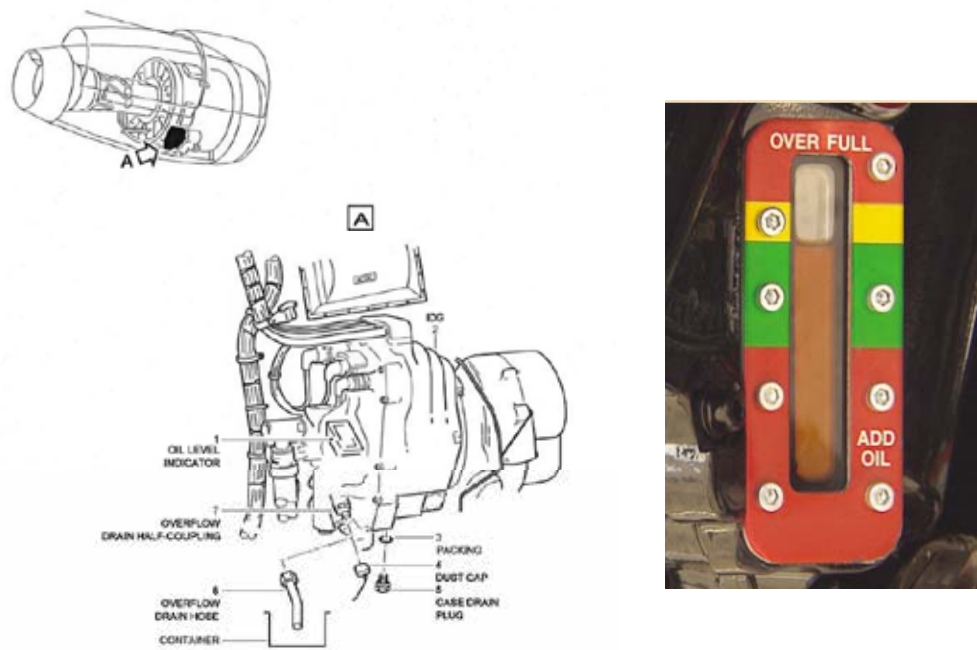


Figure 12

Location of the IDG on the V2500 engine

1.6.14 Aircraft fire detection system

The aircraft was equipped with an engine fire detection system comprising two separate detector loops of three sensor tubes connected in parallel. The three sensor tubes are distributed around key areas of the engine and pylon: around the forward engine mount, the accessory gearbox on the fan case, and the aft section of the core engine compartment.

The system is controlled by a Fire Detection Unit (FDU). In a fully serviceable system, both detection loops must sense a fire to trigger a flight deck warning. This warning consists of a red light illuminating in the fire pushbutton, in combination with a flashing master warning caption, an ECAM message and an aural warning.

Whilst the initiation and duration of the fire warnings are recorded by the flight data recorder, the specific sensor that triggers a warning is not identified.

1.6.15 Engine fire management system

In the event of an engine fire warning, the ECAM checklist requires the pilot to retard the thrust lever, select the engine master switch to OFF and press the relevant engine fire pushbutton located on the fire panel of the overhead instrument panel. Pressing the fire button commands the LPSOV, located in

the wing near to the engine pylon, to the CLOSED position. This isolates the fuel in the fuel tank from the engine. It also closes the hydraulic system fire shutoff valve, isolating the engine hydraulic system from the main aircraft hydraulic fluid reservoirs.

Adjacent to each engine fire pushbutton are two agent discharge buttons. The aircraft is fitted with a fire suppressant system designed to extinguish external engine fires which occur between the engine and its cowlings. Two pressurised reservoir bottles of liquefied Halon are located in each engine pylon. Pressing the relevant agent discharge button activates an explosive squib in the base of the reservoir, which penetrates the seal, allowing Halon gas to expand into the distribution pipework around the engine. In normal operation the gas rapidly and effectively chemically disrupts the fire, even in low concentrations, before venting overboard. After both bottles for the specific engine have been discharged, no other engine extinguishing capability is available until the aircraft lands and the AFRS respond with external resources.

1.6.16 Overnight maintenance activity

(Note: times quoted in this section are local, corresponding to UTC +1)

Technicians A and B were two members of the operator's Terminal 5A short haul line maintenance shift assigned to complete overnight maintenance between 1845 hrs on 23 May and 0645 hrs on 24 May 2013. Technician A clocked-in for duty at 1840 hrs and Technician B clocked-in at 1857 hrs. Both were working on the shift as LMA technicians, within the approved scope of work for an LMA technician, despite Technician A holding a B1 licence, as both were working overtime and it was not their regular shift.

The work scheduled across the entire overnight shift included 44 aircraft, requiring a total of 44 Daily Checks and nine Weekly Checks, not including any additional defect rectification work required. The allocation of maintenance tasks to individuals on the shift was performed by a shift planner and Technicians A and B, working as a two-man LMA team, were assigned six aircraft, each requiring a Daily Check and two (Airbus A319 G-EUOE and Airbus A321 G-EUXI) that also required Weekly Checks. During subsequent AAIB interviews, neither technician stated that they considered this workload to be unusual or excessive, nor did they consider it unachievable. The work allocation was provided to the technicians on a printed work allocation table (Figure 13), which they used to plan their shift's work and track progress during the shift.

By Owner: [REDACTED]

Reg	ETA	Arr Stand	Type	Test	LMA	B1	B2
UUD	22:06	524			☒	☒	☒
UJZ	21:44	561			☒	☒	☒
UOE	21:38	568	WEEKLY	books	☒	☒	☒
UOP	21:58	568			☒	☒	☒
UXI	21:51	564	WEEKLY	books	☒	☒	☒
NHB	19:36	564	img pins		☒	☒	☒

Figure 13

The work allocation sheet⁴

Technicians A and B began their work by travelling together, in a single vehicle, to a Boeing 767 on Stand 546 (Figure 14), where they completed a Daily Check. During this check Technician A noticed that the QAR datacard reader at the stand was missing and he logged a defect report via telephone with the operator's IT department. Technician A made an entry for the Weekly Check in the aircraft technical log at 2100 hrs and both technicians then proceeded to Stand 513 to await the arrival of their second aircraft of the shift, G-EUOE, which arrived at 2138 hrs.

G-EUOE was scheduled for both Daily and Weekly Checks, which required, amongst other checks, a visual inspection of the IDG oil levels on both of the aircraft's engines. Shortly after the engines had been shut down, Technician A opened the inboard fan cowl of the left engine and raised it by hand sufficiently high to allow him to visually inspect the IDG oil level. Having observed that the IDG oil level was below the green band on the sight-glass (meaning that the IDG required servicing with oil), he lowered the fan cowl door onto the hold-open device, but did not close or latch it. Technician B had performed the same inspection on the right engine and, having also determined that the right engine's IDG required oil replenishment, he also lowered the engine's outboard fan cowl onto the hold-open device, leaving it unlatched, before walking back to the left engine to discuss his findings with Technician A. Neither technician had placed warning notices in the cockpit prior to opening the fan cowls, as prescribed in the applicable AMM 71-13-00-010-010-A procedure.

Servicing the IDGs with oil required an IDG oil gun and oil, neither of which were in their vehicle. They therefore agreed to complete the remaining Daily and Weekly Check tasks on G-EUOE and to return to the aircraft later during the shift, once they had drawn the required equipment from stores. Technician A stated that, as the IDG oil check was an inspection, and it was his experience

⁴ Note that the times listed on this work allocation sheet are local time which was one hour ahead of UTC. The identities of individuals shown on the sheet have been redacted.

that they rarely needed refilling, it was not his standard practice to have an IDG gun or associated oil in his vehicle when undertaking Weekly Checks on Airbus A320-family aircraft.

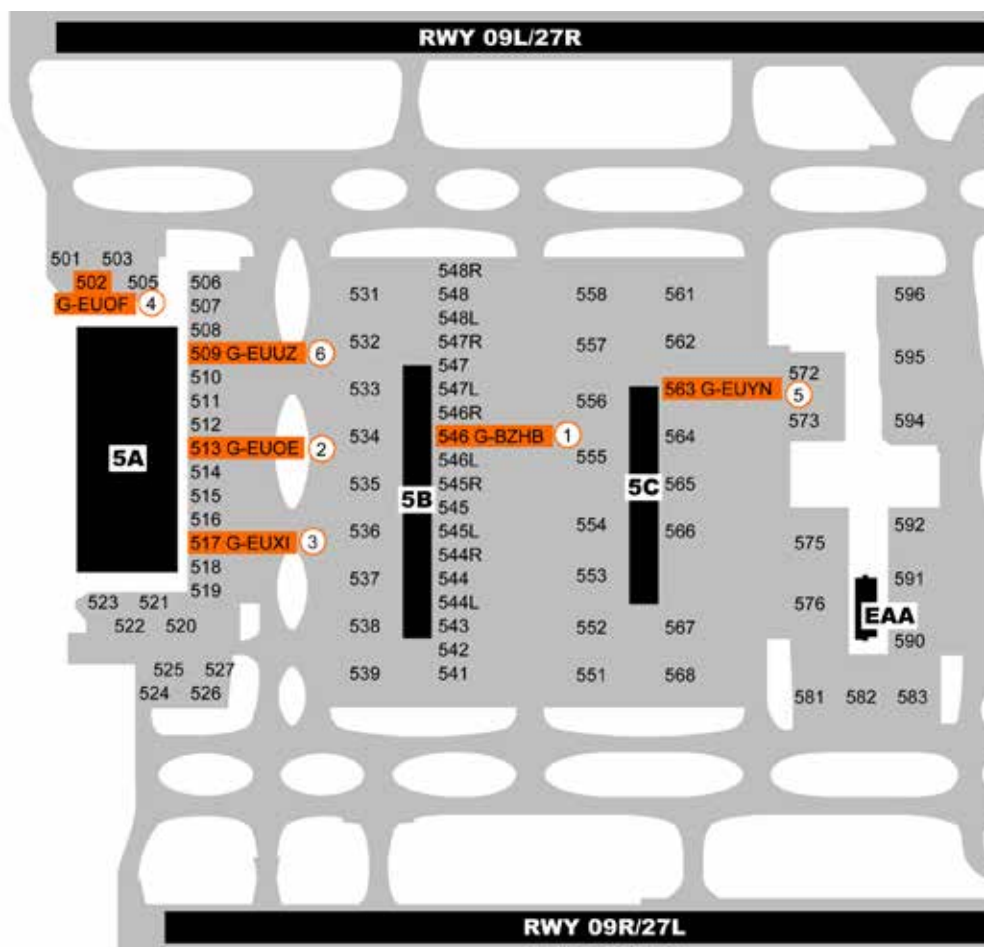


Figure 14

Location of the Technicians' aircraft during the nightshift;
circled numbers refer to the order in which aircraft were visited

Having completed the remaining items of the Daily and Weekly checks, Technician A went to G-EUOE's flight deck and completed a technical log entry for the Daily Check with a time of 2300 hrs. He also made an open entry for the incomplete Weekly Check; he did not, however, make a second open entry for the low IDG oil levels. As there were no defects with the aircraft that required the attendance of the B1 engineer assigned to G-EUOE for the shift, Technician A telephoned the B1 engineer to tell him that he did not need to visit the aircraft.

Whilst attending G-EUOE, Technician A noticed that another QAR datacard reader was missing from Stand 513. He logged a second defect report via

telephone with the operator's IT department and whilst doing this he was informed that they required additional information relating to his earlier report. This would require his return to Stand 546 later during the shift.

Both technicians then travelled to Stand 517 where they completed Daily and Weekly checks on an Airbus A321, G-EUXI. Technician A was unable to record the work carried out in G-EUXI's technical log as, in accordance with a local working procedure for Weekly Checks, the aircraft technical log had, by this stage of the evening, been removed from the flight deck for administrative checks in the Terminal 5A south maintenance office. He therefore made the technical log entries for the Daily and Weekly Check later during this shift, when he was able to access the technical log during his break back in the T5A southern crew room. The certifying entries for these checks were made with a time of 2330 hrs.

The technicians then drove to Stand 502 where they completed a Daily Check on an A319, G-EUOF, which had arrived on stand at approximately 2200 hrs. Technician A completed the technical log entry with a time of 2350 hrs.

The technicians could not locate their fourth planned aircraft, an A320, G-EUUD, and after contacting the maintenance office by phone, they were advised that this aircraft had night-stopped overseas. They were instructed instead to perform a Daily Check on an A320, G-EUYN, on Stand 563 at Terminal 5C. They completed this with the certifying entry being made in that aircraft's technical log at a time of 0030 hrs.

Stand 563 is close to the Terminal 5C engineering offices where a number of company vans are parked overnight, so they decided to collect a second vehicle for Technician B from this location. The two technicians then both drove back to the Terminal 5A southern crew room for a break, during which Technician B checked the Terminal 5A southern store for an IDG gun and found that none were available at this location.

After completing his break, Technician B offered to drive his van to the Eastern Ancillary Area (EAA) stores, where he believed the required IDG gun and oil would be available, before then driving back to G-EUOE to complete the IDG oil servicing. Technician A requested that, following collection of the IDG gun and oil, Technician B should meet him at their final aircraft of the night, A320 G-EUUZ on Stand 509, before they travelled together to G-EUOE to complete the oil servicing. Technician B complied with this request and returned to Stand 509 to assist Technician A with the completion of the Daily Check on G-EUUZ, which was certified as complete with a technical log entry at 0130 hrs.

Technician A was then shown how to clear '*Acceptable Deferred Defects*' in another aircraft's records by a B1 engineer, during which Technician B again asked if Technician A wanted him to return to G-EUOE to complete the IDG oil servicing task. Technician A stated that he wanted Technician B to wait for him to return and on doing so, both technicians drove from Stand 509 southwards along Terminal 5A, towards the stand where they believed G-EUOE was located. Technician A was driving the lead vehicle, with Technician B following behind in the second vehicle. Technician A drove past Stand 513, where G-EUOE was parked, and drove further on to Stand 517, where G-EUXI was parked. Believing this aircraft to be G-EUOE, he drove beneath the jet-bridge and stopped facing the left engine. Technician B parked next to his vehicle. They did not check the aircraft registration to confirm that they were at the correct aircraft. Both technicians saw that the fan cowl doors on both engines were closed and latched. They thought this was strange, but they reasoned that a third party must have closed the fan cowls during their absence of approximately three hours. (Technician B had recently experienced fan cowls being closed during his absence on an engine that he had been working on.)

Technician A opened the inboard fan cowl door on the left engine, which by this time was at ambient temperature, and saw that the IDG oil level was within the green band and therefore did not require servicing. Technician B opened the outboard fan cowl door on the right engine and also found its IDG oil level to be satisfactory. During the ensuing discussion they rationalised that the IDG oil levels had risen, as the engines had cooled down, and residual oil had drained back into the IDG oil sump, since the engines had been shut down some four hours previously. As the oil level in both IDGs was now acceptable, the technicians closed and latched the fan cowl doors on both engines whilst working together, with Technician A latching the forward pair of latches and Technician B the rearward pair. After all four latches on each fan cowl were secure, the technicians followed the company 'verification check' procedure by checking the security of each other's latches, to ensure that they were correctly fastened. By this time G-EUXI's technical log had already been taken to the office for the necessary administrative checks.

Technician B then drove to the EAA store to return the IDG gun and unused oil, before meeting Technician A in the Terminal 5A southern crew room where they completed the Weekly Check worksheet for G-EUOE, including completion of the aircraft technical log, shortly after 0200 hrs. They mentioned to colleagues in the crew room their experience of finding the fan cowls closed on what they thought was G-EUOE, and how the IDG oil levels had apparently risen significantly, but nobody present questioned whether they had attended a different aircraft. Inspection of G-EUOE's IDG oil levels following the accident showed that both IDGs required oil servicing, due to low oil levels.

1.7 Meteorological information

On the night of the 23 to 24 May 2013 the weather was dry, with a temperature of about +6°C and the dew point varying between +2°C and +3°C. The surface wind was from the west at about 5 to 10 kt, with greater than 10 km visibility and no low cloud. The moon was 99% full, rising at 1920 hrs and setting at 0336 hrs.

The Heathrow METAR for 0620Z, estimated as the closest to the time of the co-pilot's pre-flight inspection, was reported as:

Wind from 280° at 09 kt, greater than 10 km visibility in light rain, cloud scattered at 1,300 ft broken at 1,700 ft temperature +6°C dew point +4°C, temporarily rain with a cloud base of broken at 1,400 ft.

The closest METAR to the time of departure, reported at 0720Z, was:

Wind 290° at 12 kt, greater than 10 km visibility, cloud scattered at 1,400 ft, broken at 2,200 ft, temperature +7°C, dew point +4°C.

Sunrise was at 0358Z.

1.8 Aids to navigation

Not applicable.

1.9 Communications

Communications between the aircraft and ATC were conducted on various routine aeronautical VHF radio frequencies, with no issues reported.

Communications between the aircraft and the AFRS were conducted on 121.6 MHz, with no issues reported.

1.10 Aerodrome information

Heathrow Airport Runway 27L has a declared Takeoff Run Available (TORA) of 3,660 m. Runway 27R is 3,902 x 50 m, with a declared Landing Distance Available (LDA) of 3,884 m. It is equipped and approved for CAT 3 Low Visibility Operations, with appropriate Instrument Landing Systems and lighting.

The airfield declares a rescue and fire-fighting capability of CAT A10, the highest ICAO standard, allowing the operation of the largest aircraft in commercial service. The service is distributed between two fire stations: one located slightly west of the central terminal area and a second near the threshold of Runway 27R.

1.11 Flight recorders

The aircraft was fitted with a Flight Data Recorder (FDR) and a Cockpit Voice Recorder (CVR), recording the last 25 hours and two hours of operation, respectively. Data was also recovered from the on-board Digital ACMS⁵ Recorder (DAR) and maintenance data from a number of other avionics systems, including the CFDS, BSCU, FDU and EECs. A recording of the radio transmission and radar was also sourced.

Both the FDR and CVR captured the accident flight and, as designed, ceased recording once the left engine was shut down at the end of the flight. As a result, the evacuation was not captured on the CVR.

1.11.1 Data from onboard avionics

1.11.1.1 Engine EECs

The download from the left engine EEC revealed no in-flight failures. The right engine EEC download is shown in Table 1.

No	UTC	Description
1	0716:42	P2/T2 probe heater disagreement EEC commands the P2/T2 probe heater to ON but the monitoring by both EEC channels indicates that the heater is OFF.
2	0717:12	T2 not available in channel in control T2 is not reliable for the controlling channel, declared due to possibility of probe heater being inoperative.
3	0739:48	Aircraft 28V power supply fail Loss of 28V supply to the EEC
4	0739:48	Reverser LVDT failure LVDT position is out of range or there is a disagreement between the EEC channels

Table 1

Right engine EEC data download

⁵ Aircraft Condition Monitoring System.

1.11.1.2 Fire Detection Units (FDU)

The right engine FDU contained the following messages for the accident flight:

GND
26-12-15
CHECK ENG2 FIRE LOOP A
26-12-15
CHECK ENG2 FIRE LOOP B

These messages refer to the loss of Engine 2 fire detection loops A and B. The 'GND' signifies that these failures were detected on the ground, after the accident flight.

1.11.1.3 Post Flight Report (PFR)

A copy of the PFR for this flight is included in Appendix 1; relevant entries for the accident flight are listed in Table 2.

No	UTC	ECAM warning/caution	Failure message
1	0716	<u>DOOR</u> R EMER EXIT	
2	0717	<u>AUTO FLT</u> A/THR OFF	P2 T2 SENS/HC/EEC2
3	0717	<u>ENG 2</u> EPR MODE FAULT	
4	0717	<u>HYD</u> Y RSVR LO LVL	AFS:HYD Y 3151GN
5	0719	<u>HYD</u> Y ENG 2 PUMP LO PR	
6	0719	<u>HYD</u> Y SYS LO PR	
7	0739	<u>ENG 2</u> FIRE	CHECK FIRE HANDLE 2 RESET GEN 2 A/C 28V POWER/EEC2
8	0739	<u>ENG 2</u> SHUT DOWN	
9	0739	AUTO FLT AP OFF	
10	0739	<u>ENG 2</u> EIU	CHECK N4 BRG SCAV PRESS XMTR2 CIRCUIT 4005 EN REV LVDT CHA/HC/EEC2
11	0739	<u>ENG 2</u> FADEC	
12	0740	<u>BRAKES</u> A/SKID N/WS FAULT	BRK NORM SERVOVLV1(15GG) ¹
13	0744		TACHOMETER4(22GG)/ BSCU(10GG)
14	0744	<u>HYD</u> Y RSVR LO AIR PR	

Table 2

Relevant extracts from the Post Flight Report

Footnote:

¹ The items in parentheses are the aircraft manufacturer's circuit component identifiers, known as Functional Item Numbers (FINs).

1.11.2 Timeline

By combining the data sources, a timeline of the main aircraft-related events throughout the flight was generated (Figure 15). Cockpit effects and built-in test equipment (BITE) messages recorded in the PFR are only to the nearest minute; however, correlating the messages to the FDR data allows a more accurate timing to the nearest second to be established. A complete list of inoperative aircraft systems encountered during this accident is listed in Appendix 2.

Takeoff power was set at 0716:06 hrs, autothrust engaged, the aircraft accelerated and rotated at 0716:39 hrs. Three seconds later, EEC2 detected a P2/T2 probe heater disagreement; this was the first failure message corresponding to damage caused by the loss of the fan cowl doors.



Figure 15

G-EUOE flight routing and timeline

1.11.2.1 0716 - DOOR R EMER EXIT ECAM message

This message is triggered when a sensor in the right overwing exit detects that the interior panel has been removed. Although an exact time could not be established, passenger reports suggest that this occurred just after takeoff.

At 0716:50 hrs, shortly after the landing gear was selected UP, the cabin crew call tone can be heard on the CVR, signifying the attempt by the cabin crew to call the cockpit and speak to the flight crew. This continued until 0717:07 hrs but was not answered.

1.11.2.2 0717:20 Autothrust involuntary disconnection and EPR mode fault

As the aircraft climbed through a radio altitude of 1,482 ft, there was an involuntary disconnection of the autothrust due to the right engine reverting from EPR mode to N1 mode. This generated the AUTO FLT A/THR OFF and ENG 2 EPR MODE FAULT ECAM messages, accompanied by an ECAM caution, single chime alert and master caution light.

The reversion to N1 mode was caused by the Engine 2 EEC detecting the failure of the right engine P2/T2 probe heater. The autothrust system cannot operate in N1 mode and so was unavailable for the remainder of the flight, which was flown using manual thrust. At 0719:07 hrs, the FDR recorded manual switching of the right engine to N1 mode and nine seconds later, the same for the left engine, as a result of the crew following the associated ECAM checklist.

1.11.2.3 Loss of the Yellow hydraulic system

The first ECAM message associated with the loss of the Yellow hydraulic system was the HYD Y RSVR LO LVL, at 0717 hrs. This is triggered when the Yellow hydraulic supply reservoir reduces to a volume of three litres⁶. Despite this low level warning, Yellow hydraulic pressure was maintained until 0719:17 hrs, after which the pressure decreased to 0 psi over the next 18 seconds. The two ECAM messages, HYD Y ENG 2 PUMP LO PR and HYD Y SYS LO PR are triggered by a reduction in the Yellow hydraulic supply pressure at the engine-driven pump and at the Yellow system hydraulic manifold sensors respectively. At the engine-driven pump, this is below 1,750 psi and for system pressure, below 1,450 psi. Nominal hydraulic pressure is 3,000 psi.

Loss of Yellow hydraulics renders the alternate braking system, Spoilers 2 and 4 on each wing, the right engine thrust reverser and Yaw Damper 2 inoperative. In addition, there will be loss of redundancy on some flight control surfaces. Flap operation will be slower than normal and the Power Transfer Unit is required to be disengaged.

⁶ Maximum gauge level is 18 litres.

1.11.2.4 Fuel leakage

The left and right wings (sum of the inner and outer tanks) contained 3,687 kg and 3,701 kg of fuel respectively, at takeoff. Approximately 90 seconds after takeoff, at 0718:09 hrs, analysis of the recorded data indicated a fuel leak at an average rate over the next minute and 40 seconds of 61 kg/min.

Once at the assigned SID altitude of 6,000 ft, the thrust levers were reduced from the CLIMB detent and the leakage rate increased to an average of 127 kg/min. Nearly eleven and a half minutes after the leak started, the flight crew were alerted to a fuel imbalance. The FDR data recorded the Fuel Page SD page being displayed at 0729:28 hrs and three seconds later, the co-pilot remarked "RIGHT WE'VE GOT A FUEL ISSUE HERE, WE MIGHT HAVE A FUEL LEAK DON'T YOU THINK?". At this stage, it was calculated that a total of 1,500 kg of fuel had leaked overboard, the quantity required to generate the ECAM fuel imbalance warning.

Fuel continued to leak from the right engine at approximately the same rate and was monitored by the flight crew using the quantities shown on the Fuel Page. Once the right engine was shut down, at 0739:39 hrs, the fuel supply from the right wing was isolated via the low pressure shutoff valve (LPSOV) and no further fuel leakage was observed.

At this point, there was 333 kg of fuel remaining in the right wing, with touchdown four minutes later. Had the engine continued to run, assuming an average leakage rate of 127 kg/min, it is likely that the fuel supply to the right engine would have been exhausted prior to landing.

The total fuel consumption, calculated by integrating fuel flow rate over time, revealed that both engines had used approximately the same quantity of fuel and the aircraft manufacturer confirmed that the consumption rate of fuel for both engines was as expected. Calculations suggest that a total of 2,887 kg of fuel had leaked from the right engine.

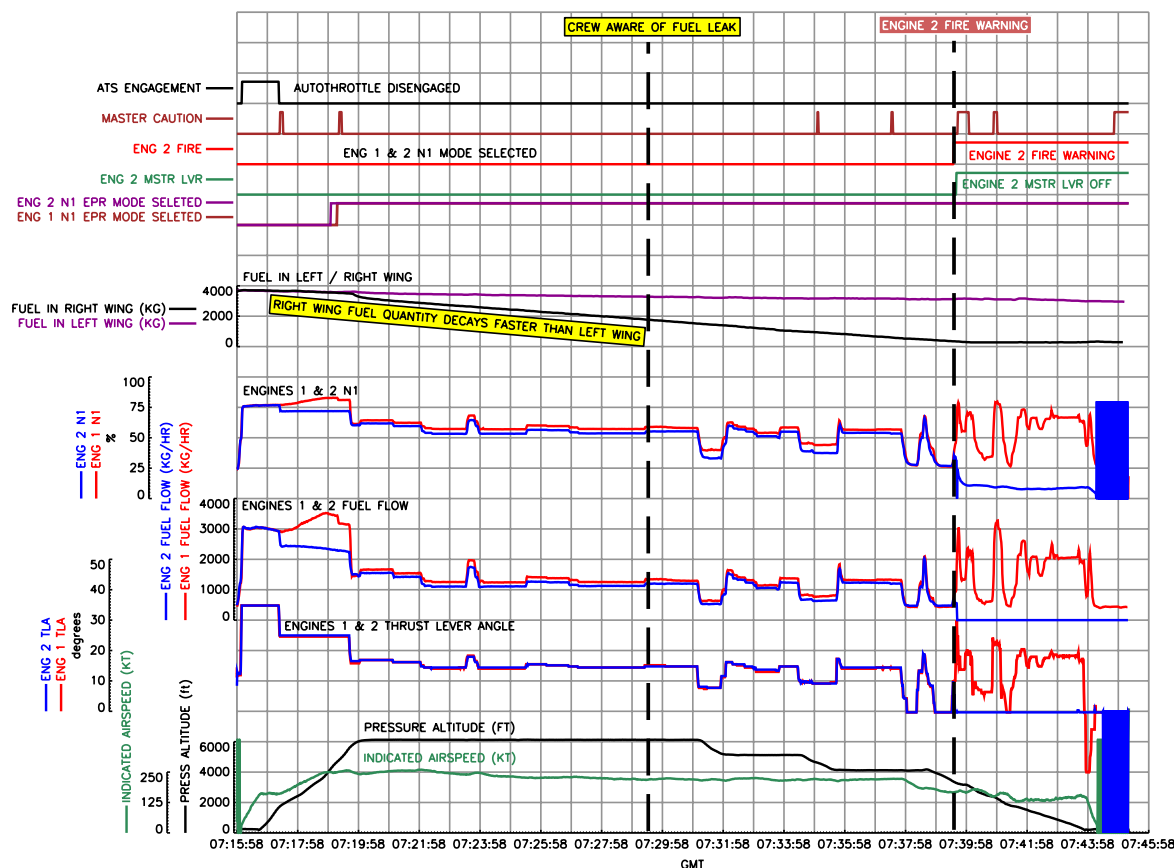


Figure 16

G-EUOE engine and fuel usage data

1.11.2.5 Engine fire and shutdown

At 0739:27 hrs, the aircraft was established on the ILS at a radio altitude of 3,200 ft, indicated airspeed of 168 kt, heading 280° T, with both engines at flight idle at an N1 of 26%. At this time, the recorded background noise on the cockpit area microphone (CAM) increased marginally in amplitude and a slight reduction in recorded normal acceleration can be seen. At the same time the commander said "RIGHT, <INAUDIBLE>. WE'RE GONNA <INAUDIBLE>, SHUT THAT ENGINE DOWN, SHUT THAT ENGINE DOWN EH. I THINK ITS THAT ENGINE THAT'S GONE". As this statement was finished, the Master Warning is audible on the CVR (associated with the ENG 2 FIRE warning on ECAM) and the commander continued "YEP, ENGINE FIRE 2", with the right engine fire warning recorded on the FDR at 0739:33 hrs.

Two seconds later, the right thrust lever was retarded to the IDLE position and a further three seconds later, the right engine master lever was selected to OFF.

As this was accomplished, the commander talked through his actions stating "THRUST LEVER, MASTER". No confirmation with the co-pilot was audible on the CVR.

When the right engine fire pushbutton is pressed, power to the corresponding EEC is removed, triggering the A/C 28V POWER/EEC2 fault message. Even though the engine is shut down, the EEC continues to monitor engine systems. It subsequently detected two further failures 10 seconds after the right engine was shut down; these related to failures of the N4 Bearing scavenge pressure transmitter circuit and the thrust reverser LVDT.

The commander declared a MAYDAY at 0740:12 hrs, and the recorded right engine fire warning continued until the end of the flight. This indicated that the right engine fire detection system was continuing to detect the presence of a fire. The landing gear was selected DOWN at 0740:30 hrs and flap CONFIG 3 at 0740:48 hrs.

1.11.2.6 Engine shutdown flight handling

Just after the right engine thrust lever was retarded to idle, the left engine thrust lever was advanced up to 30°, which is between the CLIMB and FLX/MCT positions (Figure 17). The left engine responded, increasing to 79% N1. Just prior to the engine fire, both engines were at flight idle (26% N1); this thrust increase caused the aircraft to yaw to the right.

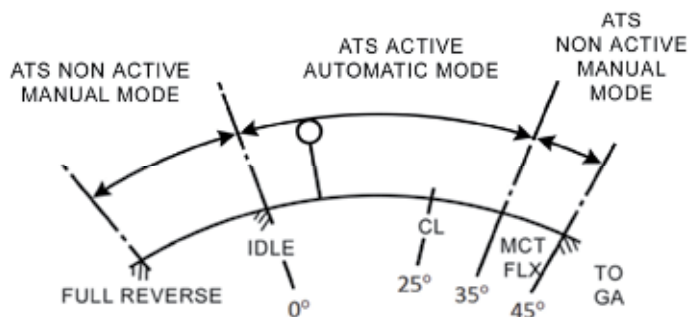


Figure 17

Thrust lever angular range

Just after the thrust lever was advanced, a maximum of 21° left rudder pedal was applied in an attempt to maintain heading. Any rudder pedal input in excess of 10° will trigger an autopilot disconnection; this subsequently occurred at 0739:44 hrs, 11 seconds after the engine fire warning, with a corresponding AUTO FLT AP OFF ECAM message. This message is only displayed for an involuntary autopilot disconnection.

The left engine thrust lever was then brought back to 13° (between the IDLE and CLIMB detents) and the left engine N1 responded accordingly. However, over the next two and a half minutes, the heading fluctuated between 250° (T) and 296° (T). This stabilised at 0742:16 hrs, with the aircraft at a radio altitude of 1,045 ft, 3.1 nm from the Runway 27R threshold.

1.11.2.7 Approach and landing at Heathrow

1.11.2.7.1 Braking system pre-land test

After the landing gear was lowered at 0740:30 hrs, the braking system functional test commenced. After commanding a brake pressure of 80 bar on the normal braking system, the system expected to measure at least 20 bar at each brake, but only 0.5 bar was detected at the Wheel 1 brake. This triggered the `BRK NORM SERVOVLV1(15GG)` fault message. Pressure on Wheel 2 was 30 bar which was lower than expected, but was still within the limits of the test.

The effect of detecting loss of braking capability on Wheel 1 was for the system to switch to Alternate braking and to render the autobrake inoperative. As the Yellow hydraulic supply had failed, the only braking available was Alternate braking without antiskid, using the remaining pressure in the hydraulic accumulator. This triggered the `BRAKES A/SKID N/W S FAULT` ECAM message; however, nosewheel steering was still available.

1.11.2.7.2 EGPWS warning

Flap CONFIG 2 had already been selected prior to the engine fire. CONFIG 3 was selected at 0740:48 hrs. At 0743:32 hrs, at a radio altitude of 236 ft and just over 0.5 nm from the runway threshold, the CVR recorded a "TOO LOW FLAPS" EGPWS audio warning. This is triggered when the aircraft is not in the normal landing flap configuration (CONFIG 4) at a predetermined distance from the runway.

1.11.2.7.3 Approach and landing

The approach and landing at Heathrow was flown without the autothrust and autopilot engaged. The commander took control 1.3 nm from touchdown, at a radio altitude of 460 ft. Touchdown was at 0743:51 hrs, at an indicated airspeed of 149 kt and groundspeed of 138 kt. As expected, only 6 out of the 10 spoilers deployed, after which maximum reverse was selected on the left engine and pedal braking was applied. As the aircraft decelerated, recorded brake pressure at the right main landing gear brakes was approximately 1,500 psi and, with no antiskid, Wheel 4 locked and the tyre eventually burst. As a consequence, the BSCU detected a discrepancy with the Wheel 4 tachometer which produced the `TACHOMETER4(22GG)/BSCU(10GG) PFR BITE` message.

1.12 Wreckage and impact information

Debris comprising over 95% of the detached portions of the fan cowl doors was recovered from Heathrow Runway 27L, approximately 1,450 m from the start of the takeoff roll, in the area where the aircraft had rotated and become airborne. The debris field was approximately 200 m in length and 80 m wide, oriented along the takeoff direction. The largest individual piece of wreckage recovered was a section of the left engine inboard fan cowl, measuring 1.4 m in length by 2.6 m in circumference, with a mass of 37 kg. All eight fan cowl latch handles and their associated mating clevis bolts were recovered from the debris zone.

The in-situ condition of the latch handles was recorded photographically by the airport's Operations Unit shortly after the debris was removed from Runway 27L. The photographs showed that seven of the eight latch handles were in the 'latch unlocked, hook engaged' condition. The remaining latch handle was in the 'latch unlocked, hook disengaged' condition.

1.13 Medical and pathological information

Not applicable.

1.14 Fire

1.14.1 Timeline

The aircraft rotated at 07:16:39 hrs and it is at approximately this point that fan cowl door sections from both engines were observed to have departed the aircraft. Within three seconds, the engine control system on the right engine identified a fault with the P2/T2 probe heat system. At 07:17 hrs a Yellow hydraulic system reservoir low level warning occurred indicating a leak of hydraulic fluid. At 07:19:21 hrs a Yellow hydraulic system low pressure warning was triggered. Variations in the right wing fuel tank quantity versus engine fuel flow provided the first evidence, 90 seconds after rotation, that fuel was leaking from the right engine, although the crew would not have been aware of this. Evidence from passenger witness reports confirmed that as the flight continued there was a significant fuel leak from the engine, though no reports of a fire at this stage. Picture A in Figure 18 was taken at 07:23:14 hrs. Picture B was taken at 07:39:14 hrs. The recorded data shows that the leak rate was effectively the same in both pictures, but the deployment of the leading edge slats by the time the second photograph was taken had significantly changed the airflow and thus the dispersal of the fuel as it left the engine.

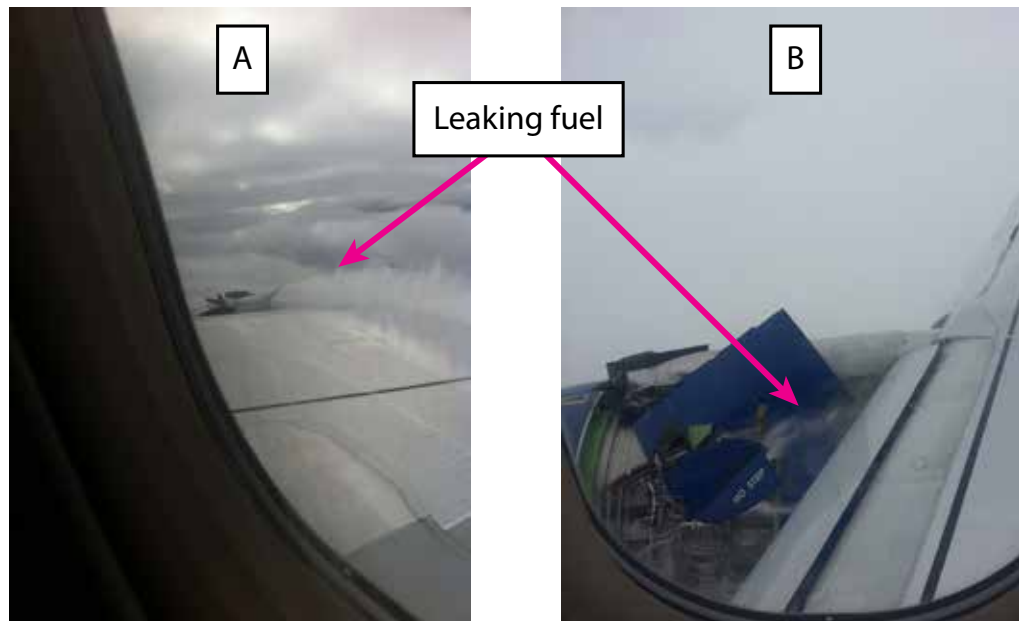


Figure 18

Passenger photographs showing the fuel leak

By 07:39:28 hrs, having identified the extent of the fuel loss, the flight crew were discussing whether to shut down the right engine. Five seconds later, the right engine fire warning activated. Passengers seated in the rows aligned with the right engine reported that a significant fire occurred, sufficient to produce an orange hue to the ambient cabin lighting and cause a variation in cabin air temperature. The crew immediately responded to the fire warning by shutting down the right engine and discharging both extinguisher bottles. Evidence from the flight data recorder, police video and passenger witness statements shows that the fire was not completely extinguished by this action, although it reduced in intensity after the engine was shut down.

A photograph, taken by a passenger during the landing roll (Figure 19), shows that a fire continued to burn in the lower section of the engine until the end of the flight. Video evidence and witness statements from the attending airfield operations staff and firefighters who attended the aircraft, describe the fire intensifying again once the aircraft came to a stop on the runway. However, it was quickly extinguished by the AFRS and London Fire Brigade (LFB) assets, who had attended as part of the pre-determined response to the ATC declaration of 'Aircraft Accident Imminent'.



Figure 19

Engine fire during landing roll

1.15 Survival aspects

1.15.1 General

The aircraft was equipped with four Type I doors; two located either side of the forward fuselage and two located either side of the rear fuselage. All four doors were equipped with self-inflating slides. The Type I doors that were opened by cabin crew were operated in accordance with the operator's Standard Operating Procedures (SOP).

The aircraft also had two Type III overwing emergency exits, one on each side of the fuselage. These passenger-operated exits comprise a plug-type hatch which is removed into the cabin before being manually ejected externally. This allows access onto the wing where a deployed inflatable slide provides an escape path to the rear of the wing.

1.15.2 Aircraft evacuation

The post-landing events, including the fire-fighting and evacuation, were video recorded by various hand-held, vehicle-mounted and fixed-point cameras (Figure 20). These were compared with recorded radio transmissions, to create an approximate timeline of the evacuation (Table 3). Only the left exits were used during the evacuation.

**Figure 20**

Still image from evacuation video
(fire-fighting continues on right side of aircraft)

The videos were time synchronised using T+0 seconds, indicating when the fire chief called: “LET’S GO FOR AN EVACUATION OF THE AIRCRAFT” on the 121.6 radio frequency. There were additional radio communications after this period but they are not available on all recordings. The following events were seen:

Exit used	First externally visible action	Slide seen fully inflated	First passenger out door	First passenger off end slide	Last passenger off end slide
L Front	T+16	T+23	T+27	T+30	T+1:02
L Overwing	T+10	T+15	T+16	T+27	T+1:06
L Rear	T+12	T+16	T+17	T+20	T+1:04

Table 3

Evacuation timeline

The video showed apparent hesitation in the opening of the forward door and the SCCM could be seen initially pushing and holding the door in the open position.

The left overwing exit appeared to open without any issues. However, the hatch was ejected to an area adjacent to the top of the slide where it remained; subsequently passengers could be seen walking round it before mounting the slide. The first passenger out of the overwing exit started to move outboard rather than aft, before the next passenger gestured them to the slide. This caused a delay of about nine seconds in their evacuation. Both lanes of the overwing dual lane slide were being used and the passenger flow rate appeared to be constrained by the exit egress flow rate, rather than the slide.

There was a pause in the exit from the rear door at T+50. One CCM was seen to check outside then move back inside the aircraft before two additional passengers deplaned. When interviewed, these passengers reported that they were called to move aft from the overwing area by cabin crew. They had, however, exited by T+1:04.

1.15.3 Passenger evacuation and exit use

The video footage allowed the exit locations of 74 of the 75 passengers to be positively identified, (Table 4). Additionally it was possible to determine whether items were carried from the aircraft and in some cases the type of exit achieved. (Definitions of the type of exit achieved are included in Appendix 3.)

	Number	Carry Off	Jump	Sit	Fall	Hybrid
L Front	20	8	0	0	0	0
L Overwing	23	10	4	4	0	15
L Rear	31	8	17	9	1	0

Table 4
Passenger exit summary

One passenger exited onto the rear slide carrying an item in each hand; the item in the left hand, a large carry-on wheeled bag, was dropped as they entered the slide. This bag fell from door height directly to the area below the aircraft where AFRS personnel were working.

One passenger fell down the slide at the rear exit. The passenger appeared to have become snagged on the person in front and was dragged forward as that person jumped onto the slide. The passenger's arm went forward, causing them to tumble down the slide in a cartwheel motion. However, the passenger was able to stand and move clear of the slide without obvious injury and no serious injuries were subsequently reported.

1.16 Tests and research

Various tests were conducted in order to determine the sequence of events and the cause of the fire on the right engine.

The first set of tests attempted to confirm the fuel source or sources for the fire. Whilst aviation fuel leaking from the damaged fuel pipe was an obvious contributor, the engine contains other flammable products such as oil and hydraulic fluid. Swabs of the soot residue on the right engine were taken and sent for laboratory analysis. This revealed that soot samples taken from around the top of the fan case and the rear of the nose cowl contained phosphate ester hydraulic fluid. The hydraulic fluid used on the aircraft has an auto-ignition temperature of 470°C and a flashpoint of 182°C. Although designed to be resistant to ignition, hydraulic fluid will burn if heated sufficiently.

A second set of tests were conducted to determine the ignition source. Based on the fault codes recorded in the aircraft Post Flight Report and additional electrical testing, three wiring looms were removed from the engine and sent for forensic analysis to identify any evidence of arcing. These were the P2/T2 signal and probe heat power supply looms, the thrust reverser Linear Variable Differential Transformer (LVDT) position feedback loom and the engine #4 bearing pressure transducer loom.

Of these looms, only the P2/T2 loom exhibited evidence of arcing. The temperatures associated with an electrical arc can reach several thousand degrees centigrade and it therefore provides a ready ignition source. The P2/T2 wiring loom contains the probe heater supply, which is 115 V AC. Mechanical damage was identified on the loom 90 mm from the connector. This damage exhibited evidence of arcing. Energy Dispersive X-ray (EDX) analysis of the copper wiring core, using a Scanning Electron Microscope (SEM), identified that it was contaminated at points 2, 3 and 4 (Figure 21) by traces of a stainless steel material, indicating that arcing had occurred between the cable and a component made from this material. The melting point of stainless steel is approximately 1,500°C, depending on the grade of steel.

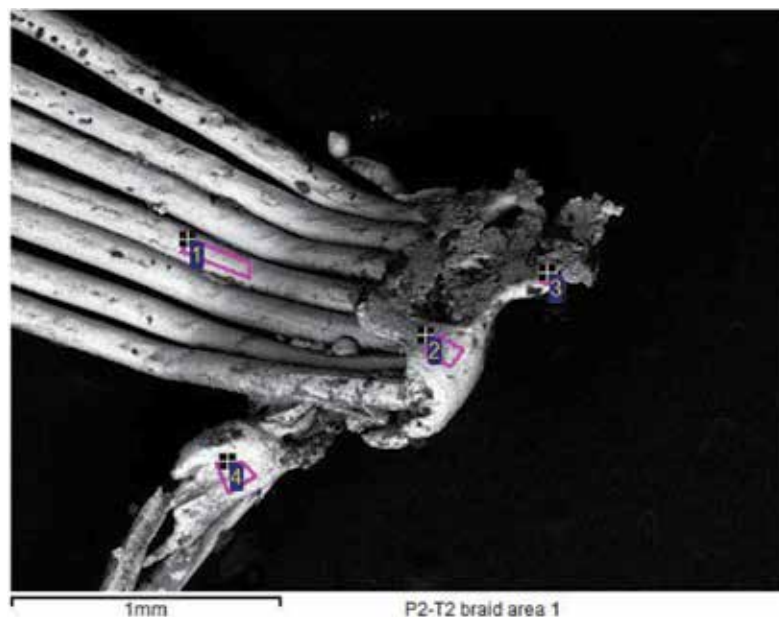


Figure 21

SEM image of the P2/T2 wiring loom

1.17 Organisational and management information

1.17.1 Scheduled line maintenance checks

Scheduled line maintenance checks for the operator's Airbus A320-family aircraft were covered by Daily, Weekly and Monthly Checks, which formed part of the aircraft's approved maintenance programme. The operator conducted maintenance activities under its EASA Part 145 Maintenance Organisation Approval.

1.17.2 The Daily Check

The required tasks for a Daily Check were listed in the operator's proforma worksheet '*DIR 10033610 Part 000*', and were sub-divided into '*Flight Deck and Internal*', '*External*' and '*Certification*' sections. The Daily Check was valid for a period of 48 hours and could be certified by an appropriately qualified LMA holder; both Technicians A and B were suitably qualified for this function. An entry had to be made in the aircraft technical log following completion of a Daily Check.

A note on the Daily Check worksheet stated that the work had to be carried out in conjunction with '*DIR 10033610 Part 001, Daily Check Instructions*', which provided more detail on the individual maintenance actions specified and, in some instances, referenced certain AMM tasks.

There was no maintenance action listed in the Daily Check that required opening the fan cowl doors.

1.17.3 The Weekly Check

The Weekly Check tasks were listed in the operator's proforma worksheet '*DIR 10033611 Part 000*', and were sub-divided into '*Flight Deck and Internal*', '*External*' and '*Certification*' sections. The Weekly Check, which did not remove the requirement to perform a Daily Check when performed concurrently, was valid for a period of seven days and could be certified by an appropriately qualified LMA holder; both Technicians A and B were suitably qualified for this function. An entry had to be made in the aircraft technical log following completion of a Weekly Check.

A note on the Weekly Check worksheet stated that it had to be carried out in conjunction with '*DIR 10033611 Part 001, Weekly Check Instructions*', which provided more detail on the individual maintenance actions specified and, in some instances, referenced certain AMM tasks.

Item 11 on the Weekly Check worksheet described a requirement to check the IDG oil levels on both engines:

'11. Check IDG oil levels in green range and filter differential indicators not protruding. Replenish if required. Record uplift in QU_X008.'

QU_X008 was the operator's document reference for the aircraft technical log. The Weekly Check instructions contained the following supplemental information regarding the IDG oil level check:

'11. IDG Oil Levels

Check the IDG oil level and inspect the oil filter differential pressure indicator IAW AMM 24-21-51-200-010. Record any oil uplift in the QU-X008 Tech Log for monitoring purposes. For any oil uplift equal to, or in excess of 1 litre, refer to AMM 12-13-24-612-011.'

If an IDG oil uplift was required, an open defect entry relating to the required uplift had to be entered in the technical log, and could only be closed and certified when the oil uplift had been completed and the additional oil quantity determined. There was no requirement to make an open technical log entry for opening the fan cowl doors.

Item 11 of the Weekly Check worksheet also contained certification sign-off boxes for '*Cowl closure*' and '*Verification of Cowl closure and correct latching*'

for both engines, with the latter check being known as the '*verification check*'. The operator introduced the verification check for fan cowl closure in 2004, following a number of fan cowl loss events at other A320-family operators (Section 1.18.2). The verification check was defined in Generic Instruction 52 of the operator's Standards Manual as:

'Verification Checks

A verification check, which is defined as a maintenance action that requires checking by two separate LMA staff to ensure airworthiness integrity on aircraft systems or components that are NOT complex in nature or require function testing. Tasks that can be certified in this manner are those of a simple repetitive nature where the additional training, experience and certification of an FMA is not necessary.'

As both Technicians A and B fulfilled the LMA requirement, they were both able to certify the verification check for fan cowl door closure without the involvement of a third party.

1.17.4 Manpower

On the night before the accident, the planned workload for the short haul overnight maintenance shift was 44 aircraft, requiring a total of 44 Daily Checks and nine Weekly Checks, in addition to any deferred and newly-reported defects. The planned and actual level of manpower deployed on the shift is shown in Table 5.

	Planned	Actual	Overtime
B1 LAEs	4	4	0
B2 LAEs	3	4	1
LMA Technicians	22	27	5
Mechanics	7	7	0

Table 5

Planned and actual manpower for the 23-24 May 2013
overnight short haul maintenance shift

The shift manager stated that the planned level of manpower for the nightshift was insufficient to meet the likely workload and he had requested additional manpower from overtime working. He stated that he would normally aim to have five or six B1 LAEs, four B2 LAEs, and up to nine additional LMAs and mechanics working on overtime, to cope with the typical shift workload without deferring planned maintenance work, defect rectification work, or causing aircraft to be unavailable due to incomplete scheduled maintenance. Information

received during the course of the investigation indicated that under-resourcing of the short haul nightshift at Terminal 5, and the commensurate availability of overtime working opportunities, was a long-standing situation.

The typical shift pattern for an individual was: two dayshifts, followed by 24 hours off, followed by two nightshifts and four days off⁷. A dayshift started at 0645 hrs local and ended at 1845 hrs local. A nightshift started at 1845 hrs local and finished at 0645 hrs local.

1.17.5 Tasking allocation and work control

Work allocation for each shift was controlled by a planner and communicated to members of the shift by a printed allocation sheet, Figure 13 (see page 31). Routine Daily and Weekly checks were assigned to LMA technicians, who usually worked as a two-person team; although they were not obliged to do so by company procedures. AB1 and a B2 LAE were also assigned to each aircraft processed by the shift. Their duties were to conduct scheduled maintenance work beyond the scope of approval of an LMA, and to clear any deferred or newly-arisen defects. Aircraft allocated to a particular two-person LMA team would not all have the same B1 or B2 LAEs assigned to them.

Certain maintenance tasks performed by the B1 LAEs on the operator's A320-family aircraft, such as servicing engine starter motors or magnetic chip detectors, required the fan cowl doors to be opened. There was no requirement for the LMAs, B1 and B2 assigned to the same aircraft to meet as a group at the aircraft, or elsewhere during the course of a shift, and liaison between these individuals was typically conducted by telephone. If no scheduled maintenance or aircraft defects requiring the presence of an LAE were called for, there was no requirement for an LAE to attend a particular aircraft.

Due to the dynamic operational environment at Terminal 5, it was normal for the arrival times and stands for the allocated aircraft to change as the shift progressed. For the shift in question, none of the six aircraft allocated to Technicians A and B arrived at the expected stand. Updated arrival times and stand information was available on the FIDSMON⁸ screens, installed on each stand, or could be relayed by telephone from the maintenance office. Telephone communications, however, were not reliable during busy periods due to workload in the maintenance office.

The technicians had no visibility of the number and scope of any recently-incurred defects of the aircraft allocated to them. This encouraged technicians to prioritise those aircraft scheduled for Weekly Checks (or larger aircraft such as

⁷ A permanent nightshift is also in operation, although neither Technician A nor B worked on this shift.

⁸ FIDSMON is a computer system that displays continuously updated data concerning the arrival status and stand allocation of flights.

B767s and A321s) early in their shift, to assess the magnitude of any additional work required that might impact the progress of their other tasks during the shift. This was cited by both technicians as a contributory factor in their decision to leave G-EUOE's IDG oil servicing task incomplete until later in their shift, when they had collected the required servicing equipment from stores.

1.17.6 EASA Part 145 Production Planning requirements

EASA Part 145 regulations contain the following requirements that approved maintenance organisations must follow when planning maintenance activity:

'145.A.47 Production planning

- a. The organisation shall have a system appropriate to the amount and complexity of work to plan the availability of all necessary personnel, tools, equipment, material, maintenance data and facilities in order to ensure the safe completion of the maintenance work.*
- b. The planning of maintenance tasks, and the organising of shifts, shall take into account human performance limitations.*
- c. When it is required to hand over the continuation or completion of maintenance tasks for reasons of a shift or personnel changeover, relevant information shall be adequately communicated between outgoing and incoming personnel.'*

The regulation contains the following Acceptable Means of Compliance:

'AMC 145.A.47(b) Production planning

Limitations of human performance, in the context of planning safety related tasks, refers to the upper and lower limits, and variations, of certain aspects of human performance (Circadian rhythm/24 hours body cycle) which personnel should be aware of when planning work and shifts.'

No additional guidance material relating to how organisations may comply with the 145.A.47(b) requirement is provided in the regulations.

1.17.7 Working time

Working time attendance information, based on the clocking-in and clocking-out times of individual workers, was gathered and stored electronically. Working time was defined as starting at the start of the shift, or clocking-in time if later, and ending at the clocking-out time. No allowance was made for attendance

prior to the start of a shift. An allowance of one hour and 17 minutes was assumed for meal breaks during a 12-hour shift, but this break time was not included in the calculation of working time.

Working time data was used by the operator for the calculation of salaries and for assessing compliance with the company's Working Hours Policy, set out in section J2 of the operator's Corporate Health and Safety Manual. The limitations on working time were calculated over a continuously-rolling time period and generally reflected the requirements of the EU Working Time Directive⁹. The requirements were as follows:

Limit	Details
J2.6.1.1	Workers must not work more than an average of 48 hours per week unless they have opted out [from the EU Working Time Directive]. The average is taken over the Reference Period [17 weeks].
J2.6.1.2	The minimum amount of weekly rest that an employee is entitled to is 90 hours. (Regulation restriction)
J2.6.1.3	Within (not in addition to) the 90 hours rest period the employee is entitled to two full days rest per fortnight. These days do not have to be consecutive. (Regulation restriction)
J2.6.1.4	The maximum number of hours that a Worker may work per week is 72. (Company restriction)
J2.6.1.5	The maximum number of hours that a Worker may work in a 24-hour period is 16 hours. (Company restriction)
J2.6.1.6	The maximum number of hours that a Worker may work in a 48-hour period is 29 hours. (Company restriction)
J2.6.1.7	The maximum number of hours that a Worker may work in a 28-day period is 256 hours. (Company restriction)
J2.6.1.8	Except where Workers volunteer for overtime or shift swaps, they are entitled to 11 hours continuous rest in a 24-hour period, unless collectively agreed otherwise. (Regulation restriction)

Management were able to view an individual's attendance data, but there was no reliable system in place to indicate, to either a worker or a manager, that a working time limit could be breached during a shift, once a worker had clocked-in.

⁹ The Working Time Directive, EC Directive 2003/88/EC.

Section J2.2 of the operator's working hours policy stated:

'Line managers must therefore ensure that an adequate compliance process is in place to ensure adherence to this policy.'

Section J2.3 stated:

'All Workers have a responsibility to comply with any requirements specified by their line manager in enforcing this policy. If a Worker believes that they may breach any limits referred to in this Policy, they should immediately bring this to the attention of their line manager.'

Apart from the working time limitations described above, there were no other means of assessing the level of fatigue in maintenance workers, based on their actual attendance record including any overtime worked.

1.17.7.1 Attendance records for Technician A

Attendance data for Technician A, for the three-week period preceding the shift in question, are listed at Appendix 4. These data show that in the seven-day period up to the end of the shift in question, Technician A's working time was 70.2 hours. He had worked four planned shifts and three overtime shifts during this period.

1.17.7.2 Attendance records for Technician B

Attendance data for Technician B, for the three-week period preceding the shift in question, are listed at Appendix 5. These data show that in the seven-day period up to the end of the shift in question, Technician B's working time was 55.8 hours. He had worked four planned shifts and two overtime shifts during this period.

1.17.8 Ground Occurrence Reporting system

The operator collected ground-based incident occurrence reports as part of its maintenance error-capturing process, and in order to fulfil the EASA Part 145.A.60(b) requirement for occurrence reporting within approved maintenance organisations:

'145.A.60(b) The organisation shall establish an internal occurrence reporting system as detailed in the exposition to enable the collection and evaluation of such reports, including the assessment and extraction of those occurrences to be reported under paragraph (a). This procedure shall identify adverse trends,

corrective actions taken or to be taken by the organisation to address deficiencies and include evaluation of all known relevant information relating to such occurrences and a method to circulate the information as necessary.'

The occurrence reports were collected and stored electronically in a system called eBASIS. The system was checked for any previous reports of fan cowl doors found unlatched before flight. The results showed that, prior to the G-EUOE accident, there had been one report in 2013, two reports in 2010 and a further two reports in 2007. The 2013 event was reported because the fan cowl latch verification check had not been carried out prior to aircraft operation, although the latches were securely fastened in this case. The 2010 events involved fan cowls left open following maintenance that were spotted during pre-departure walk-around inspections. There were also numerous reports of smaller engine oil filler access panels either being found open prior to departure or detaching during flight.

The eBASIS system did not contain any reports of maintenance inadvertently being conducted on a different aircraft from that intended.

1.17.9 Location of aircraft technical logs

One of the Daily Check tasks for the operator's A320-family aircraft was a review of the aircraft technical log on board the aircraft to ensure that the deferred defect records, held in the log, replicated those stored electronically in the maintenance planning system. The review of the technical logs was also to ensure that the deferred defects were compliant and would continue to be so during the period of flight operations until the next Daily Check. A second check of the technical log was made to ensure that there were sufficient paper copies of the log sheets available.

In May 2011, the operator introduced a local procedure to its short haul operations at Terminal 5 that required the technical log to be removed from an aircraft undergoing a Weekly Check, so that the log could be checked. This check was similar to that described above for a Daily Check, and was conducted in the maintenance office in Terminal 5A. One of the maintenance personnel assigned to the aircraft for the nightshift was tasked with removing the technical log from the aircraft. The time of removal was dependent on workload, but was normally before midnight. The technical log was normally returned to the aircraft an hour prior to its first flight of the day.

The short haul local procedure described above was at variance with the operator's long haul fleet, where technical logs remained on board aircraft for Daily and Weekly Checks.

1.17.10 Provision of tooling

The technicians' normal operating base was in the northern end of Terminal 5A. This comprised a small technical office, a crew room and a line-side store containing consumables and tooling, including IDG guns. On the night before the accident, however, these facilities were closed for refurbishment and both technicians were temporarily operating from the main engineering facilities at the south end of Terminal 5A where the maintenance control office is located. The southern end of Terminal 5A also houses a line-side engineering store that stocks IDG guns suitable for use on the operator's A320-family aircraft. The number of guns available at this southern store on the night before the accident was not accurately determined, but was estimated at two. Neither of these was available when one was required by Technician B.

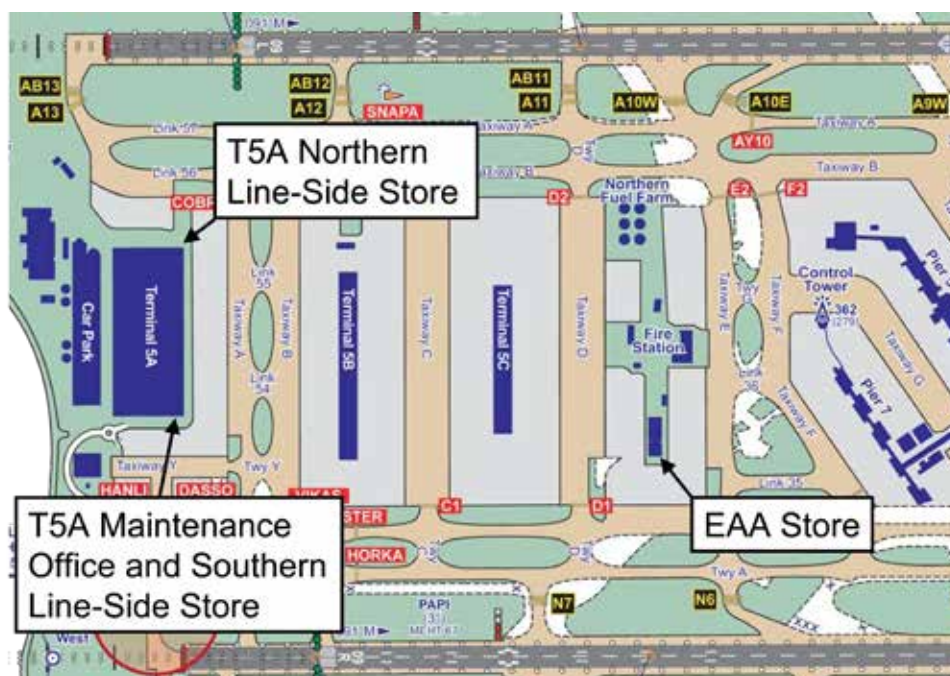


Figure 22

Location of stores

The operator's main engineering store was located at the Eastern Ancillary Area (EAA), adjacent to Stand 590. Access to this store was via the airside road system. It took approximately five minutes to drive to the store from the southern end of Terminal 5A. Four suitable IDG guns were estimated to have been available at the EAA that night.

Technicians did not normally load an IDG gun and oil into their vehicles prior to starting a Weekly Check and there was no company work instruction that required them to do so.

1.17.11 Quality Assurance and Audit Process

1.17.11.1 Internal audits

The operator's EASA Part 145 approved maintenance organisation was required, under regulation EASA Part 145.A.65(c)(1), to establish a quality system that includes the following audit requirements:

'1. Independent audits in order to monitor compliance with required aircraft/aircraft component standards and adequacy of the procedures to ensure that such procedures invoke good maintenance practices and airworthy aircraft/aircraft components. In the smallest organisations the independent audit part of the quality system may be contracted to another organisation approved under this Part or a person with appropriate technical knowledge and proven satisfactory audit experience; and

2. A quality feedback reporting system to the person or group of persons specified in 145.A.30(b) and ultimately to the accountable manager that ensures proper and timely corrective action is taken in response to reports resulting from the independent audits established to meet paragraph (1).'

The operator's Engineering Quality Department conducted annual compliance audits to fulfil this requirement. Compliance was typically verified by sampling the outputs of various processes, such as 'product samples', where aircraft were physically checked for any non-conformances, or, for example, by sampling job task cards and worksheets to ensure that they had been completed by personnel with the correct authorisation. The audits therefore tended to examine the outputs of the various activities rather than how the tasks were actually performed. They were, by their nature, a 'snapshot' of a small part of the overall organisation, recorded at the time of the audit. Non-conformances detected during audits were categorised according to the following definitions, and closing actions were required to be taken to correct any findings:

Level	Definition	Action Plan Due (days)	Closure Due (days)
1	A non-compliance with EU-OPS/EASA/NAA, other national requirements or Company Quality Standard requirements that poses a significant threat to Airworthiness or Flight Safety, or poses a significant risk of damage, death or injury.	1	7
2	A non-compliance with EU-OPS/EASA/NAA, other national requirements or Company Quality Standard requirements that poses a moderate threat to Airworthiness or Flight Safety, or poses a moderate risk of damage, death or injury.	7	30
3	A non-compliance with Company process or procedures or a non-compliance that poses a low risk of damage or injury.	30	90

The results of the operator's internal audits for 2011, 2012 and 2013 were reviewed to assess whether any previous audit findings, relevant to the G-EUOE maintenance error, had been recorded. There were no recorded findings relating to non-compliance with AMM procedures for fan cowl doors, nor were there any findings relating to incorrectly-certified maintenance actions resulting from aircraft swap errors.

One finding was recorded in relation to the requirement of EASA Part 145.A.47(b):

'145.A.47(b) The planning of maintenance tasks, and the organising of shifts, shall take into account human performance limitations.'

The finding, categorised as Level 2, was generated from an audit of the line maintenance activity at Terminal 5 conducted in July 2011; it stated:

Non-conformance evidenced by:

'(a) Each area audited could not demonstrate use of a procedure detailing how manpower planning is carried out on a daily basis.

(b) During the audit process within T5 it could not be demonstrated that manpower levels meet the established requirements. This is reinforced by the levels of overtime currently being worked within T5 A/B and C concourses. Upon review of the T5 long haul daily resource plan, it is evidenced that there are shortages of B1 and B2 category staff. Upon review of the overtime book in T5C, this shortage is reflected.

(c) Within T5, it could not be demonstrated that a review is carried out on how many hours individuals are working overtime, to assist managing engineer fatigue.'

The closing action relating to audit finding (a) referred to a relevant existing company procedure and that for (b) stated that the company intended to recruit an additional 40 FMA staff to address the identified shortage of B1 and B2 certifying staff within the Terminal 5 operation.¹⁰

The closing action for finding (c), which focused on the joint responsibility of individuals and management in ensuring compliance with the company's existing working time limitations, stated:

'(c) The responsibility for not working excessive hours is a joint responsibility of the individual and their manager. We have made all the employees who are working overtime aware of the limitations and pinned the limitations to the notice boards. Also all the owning line managers are checking for anyone likely to go out of compliance.'

An audit of the line maintenance office at Terminal 5B, conducted on 13 May 2013, made the following observation:

'Standards 145.A.47(b) – Compliant. FSDEs [shift planners] are required to attend continuation training which includes human factors training.'

¹⁰ The operator achieved this recruitment target in 2012 but this did not materially affect the amount of overtime available to the operator's Technician-grade employees at Terminal 5.

1.17.11.2 External audits

The Civil Aviation Authority also conducts audits of Part 145 approved maintenance organisations in the UK in order to provide regulatory oversight, in addition to Aircraft Continuing Airworthiness Monitoring (ACAM) audits as prescribed in EASA Part M, M.B.303. The frequency of CAA Part 145 audits is specified in section B of EASA Part 145, '*Procedure for Competent Authorities*', in Part 145.B.30:

'145.B.30 Continuation of an Approval

The continuation of an approval shall be monitored in accordance with the applicable "initial approval" process under 145.B.20. In addition:

The competent authority shall keep and update a program listing the approved maintenance organisations under its supervision, the dates when audit visits are due and when such visits were carried out.

Each organisation must be completely reviewed for compliance with Part-145 at periods not exceeding 24 months.

A meeting with the accountable manager shall be convened at least once every 24 months to ensure he/she remains informed of significant issues arising during audits.'

The requirement to completely review each Part 145 organisation at periods not exceeding 24 months is interpreted as a fixed window of 24 months, during which each area of the organisation's Part 145 approval must be audited by the CAA, after which a subsequent 24-month window opens. It is possible, therefore, that the time period between CAA audits for a particular area of a Part 145 organisation may be as short as one month, or as long as 48 months. The CAA audits generally assess the conformity of aircraft and associated airworthiness documentation following maintenance on a 'product-sampling' basis, and again therefore, they tend to examine the outputs of the various activities rather than examining how the tasks were actually performed. Prior to the G-EUOE event, the majority of CAA Part 145 audits were announced to the maintenance organisation in advance.

The last CAA Part 145 audit of the operator's line maintenance operation at Terminal 5, before the accident, was conducted on 12 October 2010; this CAA audit did not result in any findings.

A total of 15 of the operator's aircraft were subjected to ACAM audits between November 2011 and March 2013, resulting in 42 findings, many of which were minor in nature. The ACAM audits, however, are not intended to monitor how maintenance is performed. They are a check on the conformity and continued airworthiness of aircraft following maintenance and no findings were recorded that related to fan cowl door maintenance practices.

1.17.12 External walk-around

1.17.12.1 FCOM external walk-around procedure

The flight crew pre-flight external walk-around procedure was detailed in the manufacturer's Flight Crew Operating Manual (FCOM). The FCOM instructions for the external walk-around made specific reference to checking the security of the fan cowl doors on each engine as follows:

'Fan cowl doors..... CLOSED/LATCHED'

The FCOM was available on the aircraft for crews to consult. For this operator, and many others, the walk-around is typically conducted from memory, without reference to the FCOM instructions.

1.17.12.2 Operator's external walk-around training

The operator provided training in the conduct of the pre-flight external inspection by requiring flight crew to watch an eighteen-minute video, during type conversion training. This video was provided as part of self-study Computer Based Training (CBT) and the trainee was required to self-certify that the video had been watched. A walk-around was then demonstrated; either during a specific aircraft visit or during line training.

The following extracts from the voiceover and relevant stills from the operator's video are shown below.

Approximately halfway through the video, a pilot is seen approaching the No 2 (right) engine. The voiceover states:

'Start with the left hand side. Remember you're always looking for skin damage, the access doors for the magnetic chip detector (IAE engines only) and the oil filler are here. Now check the fan cowl doors, it's the latches that need special attention here, [Figure 23]. They're weighted and painted red [Figure 24] so they'll hang down and should be easily seen if they're not properly closed. Make sure that you see that they are all flush. The cowls should be faired with

the engine intake like this [Figure 25]...an embodied structure mod just forward of the cowl door will show this gap if the doors are not properly secured....'

The video then proceeds to cover the remainder of the engine.

The fan cowl door latches are mentioned for a second time a minute before the end of the video, with a brief comment: *'remember these require special attention'*.



Figure 23

Pilot inspection of latch positions

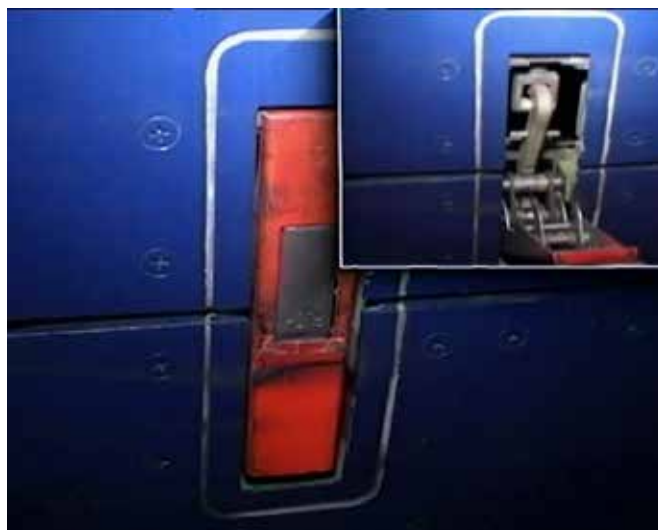


Figure 24

Latch colour and position from operator's video



Figure 25
Door “flush” from video

The operator had no examination, recurrent training, or regular checking for the flight crew external walk-around and there was no requirement for them to do so.

1.17.12.3 Co-pilot's comments on fan cowl doors

The co-pilot had observed the operator's training video on the external walk-around during his A320-series type conversion training some years previously.

When interviewed by the AAIB after the accident, he stated that he was unaware of the fact that there is a visible gap between the fan cowl door and the nacelle when the fan cowl doors are unlatched and held open by the hold-open device. He stated, in hindsight, that if he had known this, he would have stood quarter-on to the engine to look at the fan cowl door shut lines and it would have been obvious to him during his external walk-around of G-EUOE that the fan cowl doors were unlatched. However, he believed that this information had never been highlighted to him previously.

When describing his method of checking the fan cowl door latches, he stated that he would lean over but, with hindsight, he felt that he would have needed to be on his hands and knees in order to obtain a clear view of the latches.

He reported that his external walk-around of G-EUOE was not rushed and there were no obstructions caused by ground equipment.

1.17.13 Operator's Joint Procedures Manual

The operator's Joint Procedures Manual (JPM) contained information applicable to both flight and cabin crew.

1.17.13.1 Role of the SCCM

The operator defines the role of the SCCM in its Joint Procedures Manual (JPM) Part A2. It states that:

'all unusual noises...etc or smoke must also be reported to the Captain as soon as possible, as well as any observations by passengers that suggest the aircraft might not be configured or operating normally.'

1.17.13.2 Cabin crew contacting the flight deck

The JPM states that cabin crew should not contact the flight deck from engine power being applied for takeoff until the aircraft is clearly airborne and the landing gear has been retracted.

1.17.13.3 Commander's authority to deviate from SOPs

JPM Section 1 page 12 contains the following statement:

'The commander shall, in an emergency situation, that requires immediate decision and action, take any action, he considers necessary under the circumstances. In such cases he may deviate from rules, operational procedures, and methods in the interests of safety.'

1.17.14 Manufacturer's FCOM task sharing recommendations

The aircraft manufacturer's SOP relating to task sharing by the pilots in Abnormal and Emergency situations is contained in FCOM PRO-ABN-01 P 4/8. This contains the following operational recommendations in respect of task sharing:

'TASKSHARING

The general tasksharing shown below applies to all procedures. The pilot flying remains the pilot flying throughout the procedure.

The Pilot Flying (PF) is responsible for the:

- Thrust levers
- Control of flight path and airspeed
- Aircraft configuration (request configuration change)
- Navigation
- Communications

The Pilot Monitoring (PM) is responsible for:

- Monitoring and reading aloud the ECAM and checklists
- Performing required actions, or actions requested by the PF, if applicable
- Using the engine master switches, cockpit C/Bs, IR and guarded switches, with PF's confirmation (except on ground).'

1.17.15 FCOM engine shutdown procedure

The operator's FCOM Abnormal and Emergency Procedures section contains the following statement:

'The Pilot Not Flying (PNF) is responsible for..., using the engine master switches... with the PF's confirmation.'

1.17.16 FCOM fuel leak procedure

The operator's FCOM section PRO-ABN-28 contains the procedure for a confirmed fuel leak; this requires the affected engine to be shut down. The FCOM procedure for identifying a fuel leak is discussed in section 1.18.10.1 of this report.

1.17.17 Post-landing procedures

The JPM section 4.3.2 'Action After the Aircraft Has Landed' states:

'Once the aircraft has come to a halt the Captain will assess the situation. If an immediate evacuation is not required, the Captain will make the announcement:

"Passengers and Crew remain seated and await further instructions".

This call is intended to signal to the cabin that the situation has been/is being assessed and that the Flight Crew believe that there is no immediate threat to the aircraft. This should not inhibit Cabin Crew from initiating an evacuation if the situation is clearly catastrophic (Section 4.6.2 refers). Also, if on hearing this call, a Cabin Crew member at any location in the aircraft believes that there is a threat to the aircraft of which Flight Crew should be made aware, the call will prompt them to feed this information back up the chain of command to the Captain.'

1.17.18 Evacuation procedures

The Operator's JPM contains the following information regarding evacuation of the aircraft:

'4.6 Emergency Evacuation

4.6.1 Evacuation Initiated by Captain

Various emergency situations can arise, e.g. fire or smoke warnings, which may either be false or indicate an overheat condition rather than a fire. The immediate action – to carry out the appropriate emergency checklist – does not automatically conclude with an aircraft evacuation. Many in-flight emergency situations are resolved to the extent that a normal landing is possible. The primary objective is passengers' safety, and it may be undesirable to carry out an unnecessary emergency evacuation with the associated risks to passengers. Following an in-flight emergency situation, the Captain should advise the Cabin Crew in advance if an evacuation via the slides is a possibility. In the event of a passenger evacuation being initiated by the Captain, and before activating the evacuation alarm, the Captain will announce on the PA:

"THIS IS AN EMERGENCY, EVACUATE, EVACUATE"

He should give guidance concerning hazards at doors. Unless there are other compelling reasons, internal or external visual information should be taken into account before initiating an evacuation. A Flight Deck warning may be due to a faulty warning system rather than representing a compelling reason to evacuate.'

1.18 Additional information

1.18.1 Fan cowl door certification

The A319-131 aircraft received its JAA Type Certificate in December 1996 and the certification basis used was JAR 25, Change 11. Under these airworthiness regulations, in common with the currently applicable EASA CS-25 regulations, the fan cowl doors were treated as structural parts and were accordingly assessed for compliance against 'Subpart C – Structure' requirements. These require that the fan cowl doors must sustain all flight loads without permanent deformation and 150% of flight loads without rupture, as well as sustaining all flight loads without rupture if one hinge or latch has failed. The specific regulation relating to cowlings is CS 25.1193, and the more general requirements for the engine installation are covered by CS 25.901.

The structural design requirements seek to ensure that the aircraft structure can withstand any loads likely to be experienced in service. Once this has been satisfactorily demonstrated by testing, the theoretical probability of failure is zero and does not need to be considered further.

The certification of aircraft systems requires a different approach and the requirements of CS 25.1309 are applicable. As system failures cannot be eliminated entirely, a probabilistic approach to assess risk of failure, using a technique known as a System Safety Assessment (SSA), is employed. This seeks to quantify the hazard posed by the failure of a component based on its likelihood of occurrence and the level of threat to the aircraft as a consequence. Once the risks of failure have been determined, the SSA process ensures this risk is adequately mitigated, through reliability testing, warning systems, redundant systems and maintenance checks.

AMC 25.1309 requires the analysis for compliance with the CS 25.1309 requirements to consider:

'the effect of reasonably anticipated errors when performing maintenance actions'

As the fan cowl doors were classified as structural parts, no requirement to conduct an SSA was applicable. Consequently, there was no requirement to

consider the possible scenario of a maintenance error leading to the fan cowl doors being left unlatched and the aircraft departing in this condition.

By comparison, the certification requirements for fuselage doors, hatches, access panels and covers, CS 25.783(a)(2), states:

'CS 25.783(a)(2) 'Each door that could be a hazard if it unlatches must be designed so that unlatching during pressurised or unpressurised flight from the fully closed, latched and locked condition is extremely improbable. This must be shown by safety analysis.'

The term 'extremely improbable' for events in the context of safety analysis is taken to mean *'so unlikely that they are not anticipated to occur during the entire operational life of all aeroplanes of one type'¹¹*, with an average probability of occurrence of less than 1×10^{-9} per flight hour. CS-25 also contains a requirement for provision of a flight deck warning if any fuselage door is not fully closed:

'CS-25.783(e)(3) 'There must be a visual means on the flight deck to signal the pilots if any door is not fully closed, latched and locked. The means must be designed such that any failure or combination of failures that would result in an erroneous closed, latched and locked indication is remote for... (ii) each door that could be a hazard if unlatched.'

The AMC for CS 25.783 as a whole makes numerous references to reliability and preventing the likelihood of occurrence reaching *'unsafe levels'*, as well as unlatched or uncommanded opening of doors being a hazard.

1.18.2 History of fan cowl door loss events on Airbus A320-family aircraft

Prior to the G-EUOE event, there were a total of 34 previous occurrences of fan cowl door loss on Airbus A320-family aircraft, including 21 events for aircraft fitted with IAE V2500 engines and 13 events for aircraft fitted with Snecma CFM-56 engines. Following the G-EUOE event, three further instances of fan cowl door losses have occurred, bringing the total number of occurrences to 38. Following the G-EUOE event, the aircraft manufacturer's safety department sent a detailed questionnaire to selected operators representing about 45% of the A320-family fleet, to better understand the contributory factors to fan cowl door loss events. The results of the survey directly included 29 of the recorded 38 events, and when complemented by information on three other fan cowl loss events, the results showed that:

¹¹ CS-25 Book 2, Amendment 12, AMC 25.1309 System Design and Analysis.

- In all cases, cowls were opened prior to the flight and were not correctly resecured.
- 69% of the events followed cowl opening for checking of the IDG oil level, or servicing the IDG with oil.
- 9% of the events followed cowl opening for deactivation of the thrust reverser.
- 22% of the events followed cowl opening for scheduled or unscheduled maintenance actions other than those listed above, including leak rectification and troubleshooting.

The survey also revealed that about 75% of reporting operators only open the right fan cowl door when checking the IDG oil level, leaving the left door in an unlocked, low position. 50% of surveyed operators also reported that they engage the handle hooks on the fan cowl latches when the cowls are opened, reducing the prominence of unlocked latches.

The survey also showed a marked correlation between fan cowl door loss and whether the fan cowl door latches were positioned on the inboard or outboard side of the fan cowl. The V2500 fan cowls have latches attached to the right cowl of each engine, whereas the CFM-56 fan cowl latches are attached to the left cowl of each engine. The survey results showed that across both engine types, the engine with fan cowl latches positioned on the inboard side of the engine was approximately three times more likely to be the subject of a fan cowl loss than the corresponding engine on the other side of the aircraft.

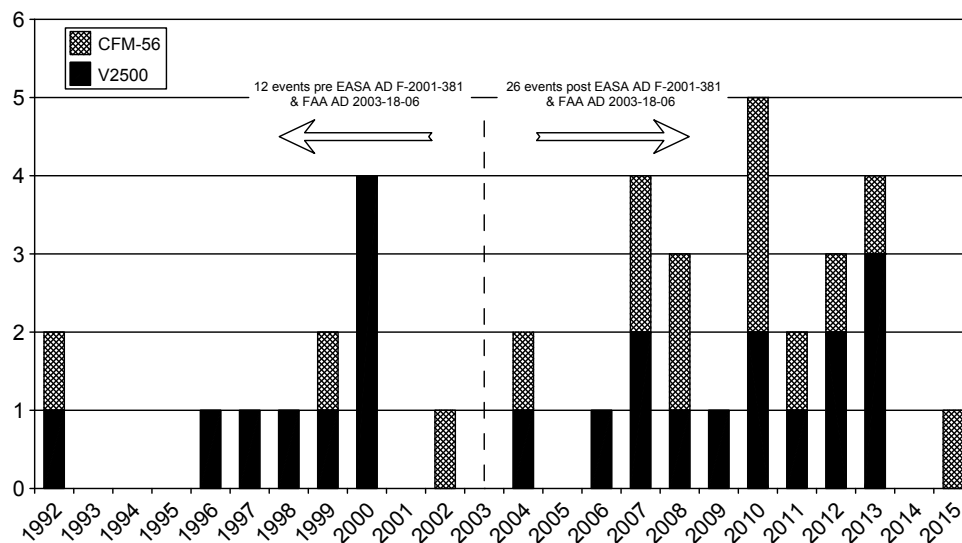
	Left engine	Right engine	Both engines
V2500	17	5	1
CFM-56	4	10	0

Table 6

Distribution of fan cowl door loss events by engine position for V2500 and CFM-56 engines

The aircraft manufacturer estimated that, up to the end of 2002, the in-service fleet of A320-family¹² aircraft had accumulated a total of 15.3 million flight cycles since 1992. There had been a total of 12 fan cowl door loss events during this period, equating to an occurrence rate of one event per 1.28 million flight cycles.

¹² 'A320-family' includes all variants of Airbus A318/319/320/321 aircraft.

**Figure 26**

Airbus A320-family fan cowl door loss events, 1992-2015

Between 2002 and 2013 inclusive, the in-service fleet of A320-family aircraft accumulated approximately a further 60.5 million flight cycles, during which an additional 25 cases of fan cowl door losses occurred; in all 25 cases the aircraft had been modified to comply with either EASA Airworthiness Directive (AD) F-2001-381 or FAA AD 2003-18-06 (see 1.18.3). The rate of fan cowl door loss for this latter period was therefore one event per 2.42 million flight cycles, or approximately half the rate observed between 1992 and 2002.

In 2000, the AAIB investigated a fan cowl door loss accident to Airbus A320 G-VCED¹³, in which the fan cowl doors detached from the left engine during takeoff. The AAIB report on this accident contained six Safety Recommendations, including Safety Recommendation 2000-29:

Safety Recommendation No 2000-29

It is recommended that the DGAC and Airbus Industrie consider the incorporation of a system to provide flight deck warning of unlatched fan cowl doors on the A319, A320, A321 and A330 aircraft types.

¹³ www.aaib.gov.uk/cms_resources.cfm?file=/dft_avsafety_pdf_501061.pdf

In July 2004, the DGAC provided the following response to this AAIB Safety Recommendation:

Recommendation	2000-029
Response	DGAC and Airbus Industrie concentrate on modifications to fan cowl doors latching systems so that, if it is not already the case, unlatched fan cowl doors could easily be spotted, without the need for a particular check during pre-flight check. DGAC considers that, for already in service aircraft, this type of modification is more appropriate than the implementation of detection systems in the cockpit. The implementation of a detection system in the cockpit could have side effects on safety (false alarms leading to aborted take-offs for instance). As concerns a potential modification of certification requirements, this subject has been integrated in the inventory list dealt with by JAA and transmitted to EASA.
Closure date	07/22/2004

1.18.3 Airworthiness actions related to fan cowl doors on Airbus A320-family aircraft

In response to the fan cowl door loss events between February 1992 and September 2000, which mostly involved aircraft powered by IAE V2500 engines (nine occurrences on V2500 engines and two occurrences on CFM-56 engines), the V2500 engine manufacturer introduced the following safety improvements:

Modification	Description and embodiment information
Painted latches	Red/orange fluorescent paint applied to the latch handles on the outer, side and inner handle faces. Incorporated on production aircraft in July 1999, aircraft manufacturer serial number (MSN) 1042 and on. Available for V2500-A1/A5 engines, via service bulletin (SB) V2500-NAC-71-0227 issued in May 1999.
Caution decals on fan cowl door	A fan cowl door latch decal stating 'MAKE SURE THE FAN COWL DOORS ARE FULLY LATCHED WHEN CLOSED' added to both left and right doors on both engines. Incorporated on production aircraft in May 1999, aircraft MSN 1022 and on. Available for V2500-A1/A5 engines, via SB V2500-NAC-71-0235 issued in March 1999.

Latch anti-swivel plates	New anti-swivel plates and weights added to the fan cowl door latches to make the latches hang down when not fully engaged and so provide greater visibility of non-engaged latches. Incorporated on production aircraft in October 1999, aircraft MSN 1098 and on. Available for V2500-A1/A5 engines, via SB V2500-NAC-71-0256 issued in May 1999.
Hold-open device	Introduction of a hold-open device to prevent the fan cowl doors from closing fully when not latched and to provide a visible gap between the fan cowl doors and the air inlet cowl. Incorporated on production aircraft in December 2000, aircraft MSN 1350 and on. Available for V2500-A1/A5 engines, via SB V2500-NAC-71-0259 issued in October 2000.

The anti-swivel plates described in SB V2500-NAC-71-0256 were mandated by a DGAC Airworthiness Directive 2000-444-156(B), issued on 10 November 2000. In response to continued occurrences of fan cowl door loss, the aircraft manufacturer issued a nonmandatory Service Bulletin SB A320-71-1028 on 23 March 2001 advising operators of the anti-swivel plates and the hold-open device, SB V2500-NAC-71-0259. A second DGAC Airworthiness Directive 2001-381(B), issued on 5 September 2001, subsequently mandated the hold-open device. This second DGAC Airworthiness Directive is subsequently referred to as EASA Airworthiness Directive F-2001-381.

Airworthiness action was also taken by the US regulator under FAA Airworthiness Directive 2003-18-06, issued on 29 October 2003, which mandated anti-swivel plates and hold-open devices for US-registered Airbus A320-family aircraft powered by IAE V2500 engines.

In August 2008, the engine manufacturer revised the service bulletin relating to painting of the latch handles, SB V2500-NAC-71-0227, to remove the requirement to paint the outside face of the handle, following reports that the paint finish was being chipped and damaged during normal maintenance.

In response to further occurrences of fan cowl door loss, in August 2012 the aircraft manufacturer revised the AMM task 71-13-00-410-010-A for closing the fan cowl doors, adding a 'CAUTION' message, stating:

'CAUTION: Do not leave this job after just closing the fan cowl doors, continue on to secure the latches. If you are called away prior to latching, then either re-open one cowl door or latch the latches before walking away from this engine.'

In September 2012, Service Bulletin SB V2500-NAC-71-0325 was issued, introducing a 'remove before flight' indicator flag and pin that attaches to the hold-open device when the fan cowl doors are open, to provide an additional visual signal that the doors are in an unlatched condition. Neither the V2500-NAC-71-0227 (painted latches) nor V2500-NAC-71-0325 (indicator flag) service bulletins have been mandated by airworthiness directive; however both have been embodied on new production aircraft from July 1999 and December 2012, respectively.

In addition to the airworthiness actions listed, the aircraft manufacturer has issued several Operators Information Telex and Flight Operators Telex communications since the first occurrence of A320 fan cowl door loss. In July 2012, the aircraft manufacturer published an article on fan cowl door loss in its 'Safety First' flight safety publication. The article included the following information:

'the crew member performing the walk-around needs to position himself on the side of the engine and should crouch to check that all latches are correctly latched and there is no gap around the cowl.'

The operator published two 'Technical News Bulletins' on the subject of fan cowl door loss and the necessary AMM procedures for opening and closing fan cowl doors; the first was published on 18 May 2007 and the second on 6 February 2009. Both bulletins were issued through the operator's 'read and sign' process, that was applicable to Technicians A and B.

The AAIB met with the EASA during the course of the investigation. On the question of the anticipated risk mitigation expected to be provided by the various fan cowl door modifications, EASA stated that as the cowls were classified using structural AMCs, such assessments of the modifications were not conducted. The intent of the hold-open device was to replicate the unlatched appearance of the cowls on the CFM-56-equipped A320-family aircraft, on the basis that these aircraft had suffered fewer fan cowl loss events up to that point. They also stated that until the G-EUOE event, fan cowl loss was not perceived to be a potentially catastrophic failure mode. However, no formal risk assessment had been undertaken to support this conclusion.

1.18.4 Continued airworthiness instructions for the latch high visibility paint

Continued airworthiness inspection instructions for the fan cowl latches were contained in AMM task 71-13-00-210-802-A and were scheduled as part of a 'General visual inspection of fan cowl latches and surrounding structure' every 7,500 flying hours, or 24 months, whichever was sooner. The AMM task required that the following items be inspected:

'Make sure that there are no signs of corrosion, cracks or damage on the latches or the surrounding structure. Make sure all installations are correct.'

Whilst the AMM task did not make any specific mention of checking the condition of the high visibility paint finish on the latches, it did state:

'If one or more of these parts are damaged, refer to SRM 542000, RDN600 for allowable damage data.'

The Structural Repair Manual 54-20-00 for the fan cowl doors contained 'Repair Number 033 – Fan cowl door latch handles paint repair', last revised in February 2012. The repair instructions described the materials and processes to be used when repairing damaged high visibility paint on the latches, and included the following diagram of which area of the latches to repaint (Figure 27):

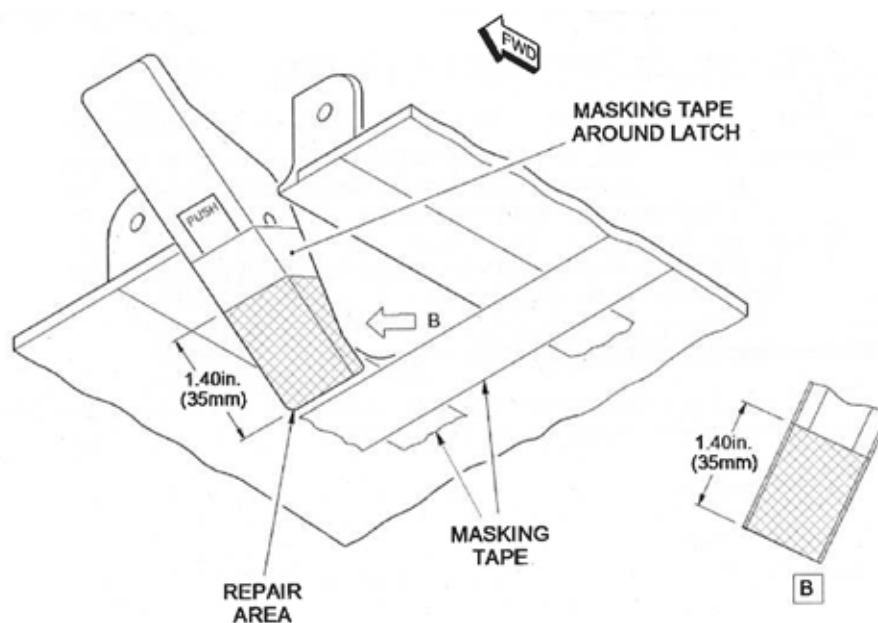
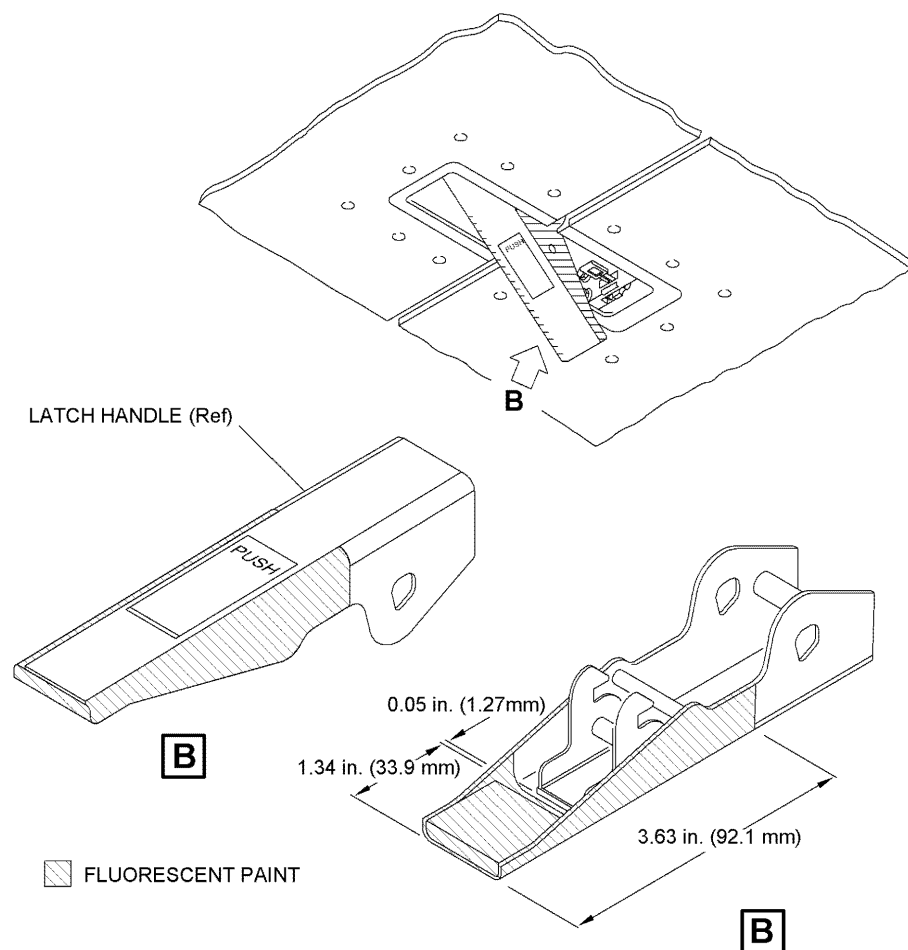


Figure 27

Latch painted area as defined by Structural Repair Manual 54-20-00, Repair Number 033

The area of the latch to repaint identified above was different from the painted area as defined in the engine manufacturer's August 2008 Revision 1 of Service Bulletin SB V2500-NAC-71-0227, which included the following diagram (Figure 28):

**Figure 28**

Latch painted area as defined by SB V2500-NAC-71-0227 Revision 1

1.18.5 Standard of latch paint on G-EUOE

Inspection of G-EUOE's fan cowl door latches, following their recovery from the accident site, revealed that none of the latches had a paint finish in accordance with Service Bulletin V2500-NAC-71-0227 Revision 1. The main differences were either missing paint, or obscuration of the fluorescent paint by blue paint overspray. Where paint was present on the latches, the areas of application generally followed those defined in the Service Bulletin.

The AAIB inspected the latch paint standard on a random sample of five of the operator's other A320-family aircraft, on 10 June 2013. These checks showed that the standard of latch paint on G-EUOE was broadly similar to other aircraft in the operator's fleet.

1.18.6 Human Factors Specialist's report

A Human Factors specialist assisted the AAIB interviews with Technicians A and B, the Maintenance Shift Manager and other employees from the operator, in addition to visiting the Terminal 5 airside environment at night and observing aircraft maintenance activities. His report is attached at Appendix 6.

1.18.7 Previous occurrences of aircraft swap errors

During interviews carried out by the AAIB in the conduct of this investigation, which were characterised by an open and willing co-operation from the interviewees, it became apparent that all five of the operator's maintenance staff interviewed had previous experience of aircraft swap errors. Aircraft swap errors were described as an occasional, infrequent occurrence. On most occasions, the swap error could be characterised as 'right stand, wrong aircraft'. These resulted in the required maintenance being carried out on an incorrect aircraft, albeit unknowingly and not by the maintenance personnel that had been assigned to the task, effectively increasing their workload for that particular shift.

An aircraft swap error had recently occurred in which Technician A, working in a pair with another technician, had completed a Daily Check on an incorrect aircraft that was parked at the stand where they expected to find their allocated aircraft. This aircraft swap error was detected when the technicians attempted to sign the technical log for the Daily Check and realised they had attended the incorrect aircraft.

Contributory factors common to previous occurrences of aircraft swap errors were stated as:

- Late stand changes for arriving aircraft that were not communicated to, or recognised by, the maintenance personnel.
- Towing of aircraft from one stand to another without the knowledge of the maintenance personnel.
- Many aircraft of a similar type (Airbus A319/320/321), painted in a similar colour scheme and parked at stands with a similar visual appearance, leading to visual confusion.

In the majority of the previous occurrences recounted to the AAIB, the aircraft swap error had been trapped at the end of the task when the maintenance personnel attempted to make a certifying entry in the aircraft technical log and they realised that they had worked on the incorrect aircraft.

1.18.8 Compliance with AMM fan cowl opening procedures

The AAIB interviews highlighted a variable level of compliance with the AMM procedures for fan cowl opening, despite a high level of awareness of the correct fan cowl opening procedure. One interviewee stated that his normal practice prior to the G-EUOE event had been to leave the fan cowl doors lowered onto the hold-open device if an IDG was found to require oil servicing and the necessary IDG gun and oil were not immediately available. Another interviewee said he normally followed the AMM procedures by leaving fan cowls open using the telescopic stays. However, he estimated that 70% of his colleagues would lower the fan cowls and leave them open on the hold-open device if unable to service the IDG immediately. A third interviewee stated that prior to the G-EUOE event, the decision whether to prop the fan cowl doors open using the telescopic stays was dependent on the presence of a second maintenance worker. The fan cowl doors are large and unwieldy for one person to open fully, and if working alone, he would lower the doors onto the hold-open device. All maintenance workers interviewed stated that as a result of the G-EUOE accident, fan cowl door working practices had changed and they had observed that AMM procedures were now being followed.

1.18.9 EASA proposals for fatigue risk management in Part 145 maintenance organisations

In response to a previous AAIB Safety Recommendation to another operator relating to management of maintenance engineer fatigue within Part 145 maintenance organisations¹⁴, EASA issued a Notice of Proposed Amendment, NPA 2013-01(C), on 21 January 2013, '*Part 145 – Embodiment of Safety Management System (SMS) requirements into Commission Regulation (EC) No 2042/2003*'. This document contained proposals for amending the Acceptable Means of Compliance (AMCs) for the current Part 145.A.47(b) requirement, to include a fatigue risk management system based solely on implementation of the EU Working Time Directive within approved maintenance organisations (Appendix 7).

Based on comments received by EASA following the publication of NPA 2013-01(C), and after seeking advice from the European Human Factors Advisory Group¹⁵, EASA is currently drafting amended 145.A.47(b) AMC material and guidance information for a more comprehensive fatigue risk management system than that contained in NPA 2013-01(C). These amended AMCs remain unpublished and in February 2014 EASA informed the AAIB that an Opinion on the amendments to Part 145 would be delayed until the second half of 2016, and that the amending Regulation might be tentatively adopted in the second half of 2017.

¹⁴ AAIB Safety Recommendation 2011-18.

¹⁵ www.easa.europa.eu/safety-and-research/european-human-factors-advisory-group-EHFAG.php

1.18.10 Fuel leak detection

1.18.10.1 Fuel leak procedures

At the time of the accident, there was no specific automatic monitoring of fuel leakage on G-EUOE, nor was there a certification requirement for one. Fuel leak detection relied on measures detailed in the 'FUEL LEAK' procedure in FCOM section PRO-ABN-28, which stated:

A fuel leak may be detected if:

- *The sum of FOB and FU significantly less than FOB at engine start or is decreasing, or*
- *A passenger observes fuel spray from engine/pylon or wingtip/sharklet, or*
- *The total fuel quantity is decreasing at an abnormal rate, or*
- *A fuel imbalance is developing, or*
- *Fuel quantity in a tank is decreasing too fast (leak from engine/pylon, or hole in a tank), or*
- *The Fuel flow is excessive (leak from engine), or*
- *Fuel is smelt in the cabin.*
- *The destination EFOB turns to amber on the F-PLN (or on the FUEL PRED) page, or*
- *"DEST EFOB BELOW MIN" appears on the MCDU scratchpad.*

If visibility permits, leak source may be identified by a visual check from the cabin.

In addition, the Standard Operating Procedures section of the operator's FCOM required a periodic in-flight check of the fuel consumption:

When overflying the waypoint, or every 30 min:

- *Check FUEL : Check FOB (ECAM), and fuel prediction (FMGC), and compare with the computer flight plan or the in-cruise quick-check table (Refer to PER-CRZ-ICQ-40 IN CRUISE QUICK CHECK M.78).*

Check that the sum of the fuel on board and the fuel used is consistent with the fuel on board at departure. If the sum is usually greater than the fuel on board at departure, suspect a frozen fuel quantity indication. Maintenance action is due before the next flight. If the sum is usually smaller than the fuel on board at departure, or if it decreases, suspect a fuel leak.

CAUTION

This check must also be performed each time a FUEL IMBALANCE procedure is necessary. Perform the check before applying the FUEL IMBALANCE procedure. If a fuel leak is confirmed, apply the FUEL LEAK procedure.

1.18.10.2 Automated fuel leak detection

The manufacturer introduced a specific automated fuel leak detection capability on the A318, A319 and A320 fleet, from MSN 2376. It operates by comparing the amount of fuel being used by the engines with the rate at which the fuel tank quantity reduces. At an appropriate threshold, a FUEL F.USED/FOB DISAGREE ECAM message appears, with a corresponding FCOM entry to apply the fuel leak procedure.

In June 2006, after a number of spurious warnings, the manufacturer elected to deactivate the leakage detection, relying instead on the alternative measures for fuel leak detection listed in the FCOM.

In early 2013, after system improvements, the fuel leak detection system was reactivated on a limited aircraft fleet for assessment. After a successful trial, it was then made available for the entire A320-family at the end of 2013 via a 'recommended' Service Bulletin No A320-28-1214. While available fleet-wide, it also required a minimum avionics hardware standard.

The manufacturer was requested to assess the FDR data, to establish at what point in the accident flight FUEL F.USED/FOB DISAGREE may have been triggered if it were installed. They responded, indicating that the warning would have been triggered between 0722 hrs and 0723 hrs, 6 to 7 minutes prior to when the crew were alerted to the fuel leak via the imbalance warning.

1.19 Useful or effective investigation techniques

Not applicable.

2. Analysis

2.1 Engineering human factors

2.1.1 Non-compliance with AMM procedures

The fan cowl doors detached from the aircraft because they remained unfastened following the overnight maintenance shift, and their unlatched condition was not detected during the pre-flight inspections by the co-pilot and the pushback tug driver. The technicians responsible for securing the fan cowl doors on G-EUOE had been trained in the required procedures for opening and closing the doors and were aware of the applicable AMM procedures, but in the interests of efficiency, they chose not to follow them. The fan cowl doors were left unlatched because the technicians intended to return to the aircraft to service the IDGs after collecting the IDG gun and oil from stores.

The AMM procedure calls for the hooks to be disengaged, allowing the handles to project lower beneath the cowl, thereby increasing their visibility. The decision by both technicians to leave the latches unlocked but with the latch handle hooks engaged was made because they perceived that, in this configuration, the latch handles do not protrude as far below the cowl, thus reducing the risk of personal injury.

The reduced vertical projection of the latch handles with their hooks engaged, combined with the absence of the majority of the high visibility paint on the latch handles, increased the probability that their unlatched condition would remain undetected during the pre-departure walk-around inspection.

In addition, the AMM procedure 71-13-00-010-010-A for opening the fan cowl doors calls for warning notices to be placed in the cockpit when the fan cowl doors are to be opened, but this was not actioned by the technicians. Such warning notices would have been seen by the flight crew of G-EUOE during their preparations for the flight and would have been considered abnormal, requiring follow-up action.

Information gathered during the course of the investigation showed that non-compliance with the AMM procedures in these aspects was a common occurrence and was not specific to either of the technicians involved in the incident, or to the aircraft operator.

2.1.2 Decision to defer the IDG oil servicing task

The infrequent need to replenish IDG oil at the Weekly Check interval, as specified in the operator's maintenance programme, led to a low expectation on the part of the technicians of the likelihood of their performing this task on

G-EUOE during their shift. This directly influenced their decision not to draw the necessary IDG gun and oil from stores prior to starting their planned work. However, it was uncertain whether this equipment would have been available to them from the Terminal 5A southern line-side store, which was closest to them when they started their shift. On finding that both IDGs required servicing, the decision to defer this task until later in the shift was taken for workload planning reasons and was influenced by a lack of visibility of unplanned defect rectification work on the other aircraft that were assigned to them.

Had an open entry for the required IDG oil uplift been made in G-EUOE's technical log, as required by the operator's procedures, it is unlikely that it would have materially affected the outcome in this instance, as the technical log was subsequently removed from the aircraft and taken to the maintenance office in Terminal 5A, where it was eventually completed by Technician A.

2.1.3 The undetected 'aircraft swap error'

When returning to G-EUOE to complete the IDG oil servicing task, both technicians, driving separate vehicles, drove past Stand 513 where G-EUOE was parked and travelled further on to Stand 517 where G-EUXI, which they had previously worked on, was parked, without realising their misidentification of either the stand or the aircraft. It is significant that the technicians did not check the aircraft registration, as this would have alerted them that they were at the wrong aircraft. Both aircraft were scheduled for Weekly Checks during the night shift.

The type of error, described in this report as an 'aircraft swap error', was classified by the human factors specialist¹ as a 'slip', in that the technicians had intended to return to G-EUOE, but their actions did not match the plan. Slips are typically the result of automatic actions - well-practised activities that are not consciously monitored by the human and are therefore vulnerable to being miscued by stimuli in the environment, such as design or layout of signs and interfaces.

Evidence gathered during the course of the investigation showed that aircraft swap errors occasionally occurred within the operator's line maintenance operation and they could be generally characterised as 'right stand, wrong aircraft'. The swap errors were usually benign; they were noticed either when a certifying entry was attempted in the aircraft technical log or when the allocated maintenance team arrived at an aircraft to find their maintenance task was being performed by a third party. The lack of reported aircraft swap error events meant that measures could not be taken by the operator to address the issue.

¹ Appendix 6.

The decision to obtain a second vehicle for Technician B to drive was made to increase the technicians' operational efficiency, allowing Technician B to travel independently to the EAA store and draw an IDG gun and oil. However, the navigation error resulting in the technicians' arrival at Stand 517 was promoted by their travelling in separate vehicles, as it removed their ability to cross-check each other's understanding of which stand and aircraft they were driving to.

The deferral of the IDG oil servicing task until the end of their shift's planned workload meant that by the time the technicians arrived incorrectly at G-EUXI (thinking it was G-EUOE), G-EUXI's technical log had been removed from the aircraft and taken to the maintenance office. This was in line with the local working procedure within the short haul line maintenance operation at Terminal 5. This working practice inadvertently removed the main safety barrier for trapping the aircraft swap error, as it is probable that the error would have been discovered had the technicians attempted to sign for the G-EUOE's Weekly Check in G-EUXI's technical log on board the aircraft.

The operator has taken the following safety actions intended to prevent the recurrence of aircraft swap errors:

- An A4-size red card marked "*AIRCRAFT IN MAINTENANCE*" and prominently showing the aircraft's registration is placed on the flight deck pedestal during short haul line maintenance.
- The legibility of the three letter registration markings applied to the operator's aircraft on the fuselage crown area is to be checked and repainted where required.
- Technical logs are now kept on board all of the operator's aircraft during line maintenance activity.
- The operator's human factors continuation training course material has been updated to reflect the lessons learned from the G-EUOE accident.
- The operator's occurrence reporting scheme has been modified to include a category for recording aircraft swap errors.

2.1.4 Fatigue

Both technicians were working in compliance with the company's working time policy. However, analysis of their working time records showed that there was an increased risk that their performance could be compromised by fatigue. This was induced by the significant level of planned and overtime working that they had carried out prior to and including the shift in question.

The opportunity for considerable levels of overtime working stemmed from a shortage of maintenance staff within the Terminal 5 line maintenance operation. Assessment of their working time records by the human factors specialist showed that Technician A's fatigue index was 39.4 and his risk index was 2.05, indicating that there was a two-in-five chance that he experienced high levels of sleepiness. Furthermore, his relative level of risk of an incident was twice that compared to his normal shift pattern, without any overtime being worked. The figures for Technician B were slightly lower, with a fatigue index of 38.0 and a risk index of 1.64 indicating a similar two-in-five chance of high levels of sleepiness whilst his relative level of risk of an incident was two-thirds higher than compared to his normal shift pattern.

The Part 145.A.47(b) regulation requires that the limitations of human performance in the context of safety-related tasks are accounted for when planning work and shifts. However, there is currently no additional guidance material provided to assist maintenance organisations in assessing whether their working time policies are effective or compliant with the 145.A.47(b) requirement. This lack of guidance material was the subject of a previous AAIB Safety Recommendation² to another organisation.

The reliance on bi-annual human factors continuation training to provide shift planners with effective tools to manage fatigue within the operator's maintenance staff appears to have been ineffective. The effect of fatigue accumulated across the normal shift pattern, and augmented by overtime working, was not accounted for or measured in an objective way.

The company's existing working time policy is closely aligned with the AMC material proposed by EASA, as published in NPA 2013-01(C). Therefore, if implemented, the AMCs in NPA 2013-01(C) would not have prevented the technicians' working patterns, and therefore their potential fatigue levels experienced in this event. The following Safety Recommendation is therefore made:

Safety Recommendation 2015-001

It is recommended that the European Aviation Safety Agency publishes amended Acceptable Means of Compliance and Guidance Material in Part 145.A.47(b) of European Commission Regulation (EC) No 2042/2003, containing requirements for the implementation of an effective fatigue risk management system within approved maintenance organisations.

² AAIB Safety Recommendation 2011-18.

2.2 Fire analysis

The manner in which the fan cowls released from the engines during aircraft rotation varied between the two engines. Both cowls on the left engine failed across their full width, just below the hinge line. This resulted in them releasing from the pylon cleanly, without causing additional damage to the engine. The cowls on the right engine also failed just below the hinge line but the inboard cowl broke into a number of sections. One of the larger pieces rotated backwards and upwards in the airflow around the engine and became lodged on the fan case. A smaller section of cowl, incorporating the aerodynamic strake, had also initially rotated upwards in the airflow, before rotating downwards with some force, causing the strake to puncture the FMU spill return pipe, creating a fuel leak.

The recorded data showed that the fuel leak was present approximately 90 seconds after rotation. The hole in the fuel pipe was in a section between the LP fuel pump and the FCOC. When the fuel LPSOV is open and the engine is operating, the LP pump provides fuel at a constant pressure to this section of pipework, fed directly from the wing tank.

From the available evidence, it was not possible to confirm why there was a discrepancy between the release of the cowls at rotation and the first indication of a fuel leak. This may have been because the section of fan cowl door that remained attached moved again after aircraft rotation and this was the point at which the fuel pipe was punctured. Alternatively, it is possible the leak started at aircraft rotation, but was not identifiable from the recorded data until 90 seconds later due to the sampling rate and accuracy of the fuel tank quantity measurement.

The release of fuel from the leak was continuous, at an average rate, after level-off, of 127 kg/min, until the crew responded to the fire warning by shutting down the engine and pressing the fire button. This action closed the LPSOV in the wing and prevented any further fuel from the tank reaching the damaged pipe.

The damage to the hydraulic pipes connected to the thrust reverser hydraulic system manifold, located in the pylon forward fairing, resulted in a rapid and extensive leak of hydraulic fluid. The leak commenced immediately after the cowls were released and it took approximately two minutes for the contents of the yellow hydraulic system to reduce to zero. This fluid was released from the top of the forward fan case onto the engine and the back of the nose cowl, in the immediate vicinity of the damaged P2/T2 wiring.

The aircraft Post Flight Report showed that the EEC identified a fault with the P2/T2 probe heat within three seconds of rotation. This is consistent with the mechanical damage identified, which resulted from the pylon forward fairing

coming into contact with the wiring loom as it was distorted by the break-up of the fan cowls. The mechanical damage resulted in a short circuit of the probe heat power supply, preventing the heater from operating. Once this was detected by the EEC, it automatically switched the right engine into N1 unrated mode as the P2 and T2 signals from the probe were no longer considered reliable by the EEC.

Forensic analysis of the damaged wiring loom showed that arcing had occurred between the power supply loom and the pylon forward fairing. The power supply is protected by a thermal circuit breaker, which tripped at some point during the flight, isolating power to the circuit. However, it was not possible to determine when this took place from the evidence available and, given the limitations that thermal circuit breakers have in responding to arcing, the power may not have been isolated for some time. The temperature within the arc was sufficient to melt stainless steel and therefore well above the auto-ignition temperatures for hydraulic fluid (470°C) and Jet A1 fuel (220°C).

For a fire to occur, three contributors must be present: a source of ignition and a mixture of fuel and oxygen in the correct ratio required to support combustion. The only evidence of an ignition source identified by the investigation was the electrical arcing between the P2/T2 probe heat wiring and the pylon forward fairing panel. Forensic testing of the soot residue around the forward fan case and rear of the nose cowl showed that the leaking hydraulic fluid had ignited at some point, whilst the magnitude of the main fire described by the passengers could only have been sustained by the volume of fuel leaking from the damaged fuel pipe.

The main fire initiated 23 minutes after aircraft rotation, as indicated by the engine fire warning at 07:39:27 hrs. However, passenger photographs taken prior to this show sooting already present in the region of the fan case adjacent to the outlet of the ventilation scoop on the nose cowl. It is likely that the hydraulic fluid which leaked in this area immediately after rotation created the correct hydraulic fluid vapour/air mixture to allow ignition by the arcing wiring early in the flight. At this stage of the flight the speed of the airflow over the engine, and the manner in which the leaking fuel was entrained in the airflow over the wing, may not have been favourable for ignition of the fuel. During the approach to land, the aircraft's airspeed reduced and the leading edge slats were deployed. These factors may have changed the fuel/air mixture in the region of the fuel leak sufficiently to create the correct ratio to allow ignition, resulting in the large fuel fire which triggered the fire warning. It is possible the source of ignition for the main fuel fire was the burning residue of the hydraulic fluid, or a very limited amount of fuel that had continued to burn within the confined area created behind the large section of fan cowl, but insufficient evidence was available to confirm this.

It was not possible to identify which of the fire detection circuits triggered the fire warning, but both the circuit around the bottom of the fan case and the circuit within the pylon were heavily sooted, suggesting both had been subjected to sufficient heat to trigger the warning. Although both fire extinguishant bottles were discharged, this was likely to have had little effect on the fire, as the system is designed to work within the enclosed space created by the engine cowlings. As these were no longer present, the extinguishant dispersed immediately in the airflow.

In normal operation, the fan cowl doors seal against the thrust reverser cowl to create a continuous aerodynamic profile to the engine nacelle. When the fan cowls were lost from the engine, a gap was exposed on the front of the thrust reverser cowl which allowed leaking fuel to enter between the translating cowl and the inner skin and collect in the bottom of the thrust reverser cowl. After the fuel fire was ignited, the flight crew stopped the delivery of additional fuel to the leaking pipe by closing the LPSOV. However, by that stage sufficient fuel had collected within the thrust reverser cowl to sustain the fire until the aircraft landed. Once the aircraft came to a stop on the runway, the airflow, which had kept the fire relatively suppressed, was no longer present and the fire intensified again, as witnessed by the firefighters and airport operations staff. However, the firefighters' immediate presence at the aircraft meant they were able to extinguish the fire rapidly.

2.3 Organisational aspects

2.3.1 Provision of tooling

The technicians' decision not to draw an IDG gun and oil from stores prior to the start of their shift's work was not directly influenced by a lack in provision of this tooling. It was more likely driven by the low expectation of their requiring the equipment during the two Weekly Checks allocated to them and the absence of a work instruction requiring them to do so.

The exact number of suitable IDG guns available between the Terminal 5A southern line-side and EAA stores was not accurately determined, but later estimated at six units. This was sufficient for the planned workload of nine Weekly Checks across the shift as a whole. However the lack of an IDG gun and oil in the technicians' vehicle, when it was required for G-EUOE, contributed to the deferral of the IDG oil servicing task. Upon realising that it was required, the short distance between Stand 513 and the Terminal 5A southern line-side store proved a sufficiently high barrier to prevent either of the technicians from attempting to draw one at this stage. When Technician B tried to draw an IDG gun some three hours later, following a routine rest break, none were available at this location.

2.3.2 Task planning, execution and workload

The quantity and scope of planned work for the technicians' nightshift was achievable. It was not excessive or unusual and was within their scope of approval as LMAs. Furthermore, adverse weather conditions were not a factor in the sequence of events. As some of the allocated aircraft arrived later than planned and all arrived at different stands, due to operational reasons, the technicians' printed work allocation sheet rapidly became out of date. This required amendment by hand, resulting in numerous corrections on the sheet. Such unstructured information management is a potential source of error as human memory may be fallible at encoding, storage or retrieval. This is particularly the case when dealing with multiple items. Using external sources of information, such as signage or cross-checking procedures, is accepted as good practice by human factors specialists in countering such fallibility.

The prioritisation of the technicians' workload during the shift was biased towards a B767 requiring a Daily Check, and the two A319/A321 aircraft requiring Weekly Checks. These aircraft represented a relatively higher and more uncertain workload, particularly in terms of the unknown level of newly-arisen defects requiring rectification by the technicians. This uncertainty inadvertently increased the likelihood that maintenance tasks requiring parts or tooling remote from the aircraft would be deferred until later in the shift, when the overall workload was better understood. There was no formal method for recording incomplete or interrupted maintenance tasks, other than by making open technical log entries. These required the technical logs to be present onboard the aircraft. The technicians, however, relied on their memory of the incomplete IDG oil servicing task and a hand-written annotation on the work allocation sheet.

Despite the annotated note, Technician A relied on his memory of the location of the aircraft in guiding his actions when returning to the aircraft later in the shift. The failure to return to the correct aircraft was not a simple lapse, as both technicians were aware of the need to complete the IDG oil servicing task. The evidence suggests that Technician A substituted the object of the task, by confusing G-EUXI for G-EUOE. It was not apparent that he had mentally linked the task to the specific aircraft (G-EUOE) or stand (Stand 513).

It is notable that G-EUXI was the technicians' only other Weekly Check during the shift, and it is possible that the memory traces for the two Weekly Checks had become mixed during recall. It seems unlikely that the return to G-EUXI was simply a random error; it was a familiar aircraft to the technicians, as they had worked on it earlier in the shift.

2.3.3 Oversight of the maintenance activities

Overnight maintenance checks typically involved input from LMA technicians and B1 and B2 LAEs. Each party had a specific role and responsibility in the scheduled maintenance work. As described in this report, the LMA technicians were responsible for the scheduled Daily and Weekly Checks, with a limited scope of approval to rectify and certify any defects discovered either during the check or those previously reported. B1 LAEs were responsible for scheduled and defect-driven mechanical maintenance outside the scope of the LMA work, and B2 LAEs were responsible for certifying work to avionic systems.

It is possible that, during overnight maintenance, there was little or no interaction between the LMA, B1 and B2 LAE staff assigned to the same aircraft, as was the case for G-EUOE. The fragmentation between individuals working on the aircraft meant that no one individual had effective oversight of the work undertaken on the aircraft as a whole. Furthermore, the opportunity to cross-check the status of incomplete maintenance tasks between the team members was missed. A more integrated approach to maintenance oversight may also have promoted the possibility that the fan cowl verification check could be completed by a different member of staff from the one who was involved in closing the fan cowl doors, thereby reducing the likelihood of a common aircraft swap error being made.

The operator has taken the following safety actions in relation to maintenance task management and work structure:

- The operator has changed the organisation of its short haul line maintenance team at LHR to avoid separate LMA, B1 and B2 personnel engaging aircraft independently without effective oversight or control. Through the recruitment of 26 additional staff, the line maintenance team structure has been altered to form individual teams of LMA, B1 and B2 staff operating under the oversight of an aircraft maintenance supervisor. Aircraft assigned for maintenance will be processed by a single team providing improved supervision and oversight of maintenance tasks.
- The operator has staggered the IDG oil checks between left and right engines during Weekly Checks, to prevent the possibility of both sets of fan cowl doors having to be opened on any one occasion.
- It is now a requirement on the A320-family to make an open technical log entry when fan cowl doors have been opened.

- The operator has produced a sufficient number of weekly check 'wet kits' and 'dry kits' containing all of the tools and consumables (including IDG guns and oil) required to conduct Daily and Weekly Checks on the operator's A319/320/321 aircraft. The company's vehicles have been modified to carry the kits and a replenishment process established to enable engineering staff to collect serviceable kits prior to commencing maintenance work.
- Where interruption to an airworthiness-related line maintenance task at LHR is unavoidable, a new process has been introduced in which the individual performing the task calls the maintenance control office and the maintenance planning system is updated, showing that the particular task has been broken and remains incomplete.
- Aircraft undergoing maintenance are now fitted with a high visibility gaiter over the nosewheel to indicate that there has been a break in an airworthiness-related maintenance task, to prevent the aircraft being moved in this condition and to signal to other functions within the operator that the aircraft is not available for service. An identification number is placed on the gaiter identifying which maintenance team is working on the aircraft.
- The operator is currently introducing new aircraft into its fleet that are equipped with electronic technical logbooks capable of communicating aircraft defect reports to the maintenance operation during flight. The operator is also evaluating options for the introduction of similar technology to its fleet of A320-family aircraft.
- An engineering safety culture team has been established to conduct on-the-job competence assessments of maintenance staff across all production areas on an unannounced random sample basis. The assessment includes checking interpretation of procedures, observation of tasks accomplished and attitudes towards safety. Where areas for improvement are identified the team will focus on improvement of procedures and supporting systems. These assessments are in addition to the audits required by EASA Part 145.A.65(c)(1) under the operator's maintenance approval.

2.3.4 Organisational awareness and reporting culture

The lack of any eBASIS occurrence reports relating to aircraft swap errors, combined with the low level of reporting for unsecured fan cowl doors, meant that the organisation was not aware of either the risks inherent with both types of error, or their actual rate of occurrence. The low level of reporting of aircraft swap error events stemmed from these behaviours having become accepted as a 'norm' within the line maintenance operation. As a result, there was limited opportunity to introduce mitigating actions.

The eBASIS reports of insecure fan cowl doors were exclusively related to those discovered prior to aircraft operation, rather than deviations from the AMM procedures which left fan cowls in an unlatched configuration during maintenance.

2.4 Airworthiness and design aspects

2.4.1 Effectiveness of previous safety actions

The effectiveness of previous safety actions taken³ to prevent fan cowl door loss events has been demonstrated to have been only partially effective, as the occurrence rate was reduced by approximately 50%, from one event per 1.28 million flight cycles before their introduction, to one event per 2.42 million flight cycles afterwards. Despite the reduced occurrence rate, the growth in size of the Airbus A320-family fleet since the previous safety actions were taken has resulted in more than twice as many fan cowl losses occurring to aircraft with these measures embodied. The G-EUOE accident was by far the most serious fan cowl door loss event to date because it was the first recorded event in which the departing fan cowls damaged an engine's fuel system, causing a significant fuel leak and a subsequent uncontained fire.

The nature of the fan cowl opening and closing tasks renders them vulnerable to the limitations of human performance. Continued occurrences of A320-family fan cowl door loss, despite instructions exhorting maintenance personnel to follow AMM procedures, have shown that, in this case, procedurally-based safety actions are limited in their effectiveness and are likely to remain so.

The AAIB report into the fan cowl door loss to A320 G-VCED⁴ included Safety Recommendation 2000-29 addressed to the DGAC to incorporate a flight deck warning system to warn of unlatched fan cowl doors. The 2004 DGAC response to that Safety Recommendation stated that modifications to the fan cowl door latching system, to improve the visibility of unlatched fan cowl doors, were considered more appropriate than the implementation

³ Principally airworthiness directives EASA AD F-2001-381 and FAA AD 2003-18-06.

⁴ http://www.aaib.gov.uk/cms_resources.cfm?file=/dft_avsafety_pdf_501061.pdf

of detection systems in the cockpit. However, the continued occurrence of fan cowl door losses on A320-family aircraft, including the G-EUOE accident, shows that such preventative measures have been only partially effective. A more effective mechanical, or electronic, means of detecting unlatched fan cowl doors is therefore necessary. The following Safety Recommendation is therefore made:

Safety Recommendation 2015-002

It is recommended that the European Aviation Safety Agency requires Airbus to modify A320-family aircraft to incorporate a reliable means of warning when the fan cowl doors are unlatched.

The aircraft manufacturer has taken the following safety actions:

- The AMM has been amended with an additional requirement to make an open technical log entry when a fan cowl door is opened.
- A 'remove before flight' red flag has been made available to attach to the hold open device (V2500) or fan cowl door (CFM56) to increase visibility of unlocked fan cowl doors.
- The FCOM pre-flight walk-around inspection procedure has been revised to ensure that the fan cowl security is established from both sides of each engine.
- The FCTM has been revised to include an entry on fan cowl doors in the Preventing Identified Risks section.
- The IDG oil level check interval has been doubled to 300 flying hours since the November 2014 Maintenance Planning Document (MPD) revision, to reduce the number of occasions that the fan cowl doors require to be opened.
- An IDG oil level viewing port is available as an option in production on aircraft fitted with the CFM56 engine, to permit the IDG oil level to be established without opening the fan cowl doors. This port is planned to be available for in-service aircraft as an optional feature on the CFM56-5B by Q1 2015 and will be available through a service bulletin.
- The AMM was amended at the August 2014 revision, to require the fan cowl latches to be repainted, if necessary,

every two years. The area of the latch handle to be painted will be changed to include the external face of the latch (except on the trigger plate) and a more robust paint process will be introduced to improve service life of the paint finish.

- New decals will be proposed as an option to highlight the fan cowl door latch positions by means of an arrow positioned above each latch.
- A medium-term study has been launched to establish the feasibility of adding a mechanical lock and key (with streamer flag) arrangement to the forward fan cowl latch, such that when the latch is open, the key cannot be removed and is visible with the streamer flag below the latch. The certification of the new latch with key is planned for March 2015.
- A long-term feasibility study has been launched to establish the feasibility of providing a cockpit indication of the fan cowl latches, by electrically monitoring their position. A second long-term study will assess the feasibility of adding a light to the fan cowls that would flash when the fan cowls are open.

EASA has taken the following safety action:

Based on lessons learnt, EASA has introduced a new generic Special Condition⁵, E-45, that will add the following requirement to CS-25 for new Part 25 Large Aircraft Type Certification Approvals:

CS 25.1193(f)(3) – [Each aeroplane must] have a reliable means for effectively verifying that the cowling is secured prior to each take-off.

The application of this Special Condition is to be determined using a risk-based approach, meaning that it will be systematically applied if the intrinsic geometrical characteristics of the nacelle, as installed on the airframe, are such that the latches are not easily visible to maintenance personnel and flight crews. The cowling security detection device will be assessed against its capability to detect an unlatched cowling and its reliability will be the subject of a System Safety Assessment. This Special Condition has currently been raised against four new CS-25 Type Certification applications.

⁵ The term 'Special Condition' refers to a detailed technical specification for a product where the related airworthiness code does not contain adequate or appropriate safety standards for the product, because 'Experience from other similar products in service or products having similar design features has shown that unsafe conditions may develop' – see EASA Part 21A.16B for further information.

The Special Condition addresses the specific issue of fan cowl securing for new certification programs and accepts the need to use an SSA-based approach to assess and validate the operation and reliability of the cowl monitoring system.

Whilst it is accepted that fan cowl doors were considered to be structure and certified accordingly, this accident, and other fan cowl door loss events, show that the results of failure to latch the fan cowl doors can cause them to detach in flight, potentially hazarding the aircraft. This hazard was not identified using the structural airworthiness assessment in the original type certification.

The use of structural AMC alone to certify fan cowl doors is also at variance with the certification of other aspects of the engine installation and other doors on the aircraft. In accordance with the AMC for CS 25.901 and CS 25.783, these components are certified using an SSA approach to identify the hazards, including the effects of reasonably anticipated errors when performing maintenance actions, and ensure that they are mitigated to an appropriate level.

The following Safety Recommendation is therefore made:

Safety Recommendation 2015-003

It is recommended that the European Aviation Safety Agency amends Certification Specification 25.901(c), Acceptable Means of Compliance (AMC) 25.901(c) and AMC 25.1193, to include fan cowl doors in the System Safety Assessment for the engine installation and requires compliance with these amended requirements during the certification of modifications to existing products and the initial certification of new designs.

2.4.2 Continued airworthiness instructions for the latch high visibility paint finish

The continued airworthiness inspection requirements relating to the high visibility paint finish on the fan cowl door latches were ambiguous. The AMM inspection task 71-13-00-210-802-A, carried out every 7,500 flying hours or 24-months, did not contain any specific requirement relating to the high visibility paint finish. Although the AMM task did make reference to the Structural Repair Manual Chapter 54-20-00 for allowable damage data, there was no specific instruction to consult the SRM in relation to the paint finish. There was, therefore, nothing to alert maintenance personnel to identify and rectify any damage to the fan cowl door latches' high visibility paint finish. Furthermore, the diagram in the SRM showing which areas of the latches to repaint did not match the painted latch areas from Revision 1 of the engine manufacturer's Service Bulletin V2500-NAC-71-0227.

Inspection of the fan cowl door latches from G-EUOE showed that the latch high visibility paint was mostly missing from the latch handles. That which remained was partially obscured by blue paint overspray. In this condition, the open latch handles would have been significantly less conspicuous than if they had been painted according to SB V2500-NAC-71-0227. Therefore their condition was a contributory factor in reducing the prominence of the open latches.

A random survey of five other A320-family aircraft from the operator's fleet demonstrated that the standard of paint finish on G-EUOE's latch handles was not an isolated example. The aircraft manufacturer and the fan cowl door manufacturer are taking safety actions described previously in relation to continued airworthiness instructions for the fan cowl door latch high visibility paint.

The fan cowl door manufacturer has also initiated the following safety actions:

The fan cowl door manufacturer has amended the instructions for repainting the high visibility latch paint to align the painted area requirements as set out in SB V2500-NAC-71-0227 Revision 1, and will continue to do so for any subsequent revisions that may be issued as part of the safety actions being taken by the aircraft manufacturer. These continued airworthiness instructions have been moved from the Structural Repair Manual to the Component Maintenance Manual (CMM) and the amended CMM was published in May 2014.

2.5 Preparation for the flight

2.5.1 Fan cowl door condition prior to departure

The photographs taken by the member of ground staff during the pre-flight activities show the outboard fan cowl door on the right engine to be open and resting on the hold-open device and two of the fan cowl door latches of the left engine hanging down. These photographs show that there were visual cues that the fan cowl doors were unlatched prior to departure. These cues were not identified by either the tug driver during his aircraft inspection or by the co-pilot during his external walk-around.

To check the position of the fan cowl door latches it is necessary to bend down to look underneath the engine, as depicted in the operator's training video, or stand sufficiently far away from the engine that the latches are visible below the curvature of the cowling. The hold-open device was designed to hold the fan cowl doors apart sufficiently to produce a visible gap between the fan cowl doors and the nose cowl. This accident, and the numerous other fan cowl door

loss events on A320-family aircraft, show that the gap is not sufficiently obvious to be detected reliably. The gap is obvious once pointed out, but not so in the absence of such prior knowledge.

2.5.2 Tug driver's pre-departure inspection

The pushback tug driver was required to conduct a limited pre-flight inspection, in accordance with the operator's procedures. Although the training material for the conduct of aircraft departures contained generic references to the '*engine clips*' and '*cowling clips*', the information provided was non-specific and lacking in the relevant detail. The tug driver was therefore unaware of the visual cues that might have alerted to him that the fan cowl doors were unlatched. Given this lack of specific knowledge, it is considered that he could not be realistically expected to identify the unlatched fan cowl doors during his aircraft inspection prior to pushback.

2.5.3 Flight crew external walk-around

Once the maintenance error which led to the fan cowl doors being left unlatched had occurred, the key barrier to preventing the accident was the flight crew external walk-around.

The aircraft manufacturer's Flight Crew Operating Manual (FCOM) procedure for the external walk-around contained specific entries for checking the condition of the fan cowl door latches on both engines. However, as is typical of many operators, the walk-around was carried out from memory, without reference to the FCOM procedure.

Following previous fan cowl door loss events, the aircraft manufacturer issued various publications to operators highlighting the issue. In 2012, the manufacturer published an article in its '*Safety First*' flight safety magazine but this was not effective in prompting the operator to take any specific actions.

This accident, and the many other A320-family fan cowl door loss incidents, show that the flight crew external walk-around, as currently performed, is not a reliable barrier against an aircraft being dispatched with the fan cowl doors unlatched. This reinforces the need for the aircraft to be modified to incorporate a fan cowl door warning system.

2.5.4 External walk-around training and monitoring

The co-pilot had watched the operator's training video on the A320-series external walk-around when he undertook the type conversion course several years previously.

When interviewed, he was unaware of the need to specifically check the fan cowl door for a visible gap between the doors and the nose cowl. His described method of how he checked the latches did not enable him to identify that the fan cowl doors were unlatched. This suggests that either the operator's training video was ineffective, or that he had been aware of this at some point, but had forgotten it with the passage of time.

The co-pilot had not been tested in his conduct of the walk-around and the operator did not carry out periodic checks of how flight crews were performing the external walk-around (nor was there any requirement for them to do so). Thus it was not possible to ensure that flight crews were consistently performing the walk-around to the standard shown in the operator's training video and as set out in the FCOM procedure.

Accordingly, the operator conducted a review of the training content of external checks and the performance of flight crew's external checks, and took appropriate safety actions. The review considered the following:

Training:

FCOM descriptions or procedures, video and graphic representation of the tasks during ground school training. Following this, the operator has placed additional exterior inspection training on the training sites available to pilots. An additional requirement was included for all A320 pilots to complete the exterior walk-around training video as part of the simulator check starting in Q4 to ensure that all crew have reviewed this since their initial training. This was recorded as part of the recurrent check requirements.

During conversion training all crew are required to demonstrate their competence in the exterior check and this is recorded as an individual training item during the course.

Periodic checks of crews:

Periodic checks of exterior walk-around have been reviewed. Assessment of crews' performance in this area is included in a particular section of the crews' line check syllabus and extends beyond the exterior check to include interior checks and knowledge of SOPs and Ops manuals. The root cause of any degradation in this particular area will be reduced by improved behavioural performance. To address this, the operator has required all Training Captains to reinforce the importance of inspections as part of the discussion items on recurrent line checks. A new '*Leading Flight Safety*' course has been developed that references

the pilots' responsibility to maintain a high level of knowledge and their individual responsibility to conduct all operating procedures accurately and conscientiously amongst other elements.

2.6 In-flight emergency procedures

2.6.1 Initial handling of the emergency

The SCCM's unsuccessful interphone call just after the aircraft was airborne was unusual. The commander had intended to return the call once he was satisfied with the aircraft flight path, but the ECAM alerts assumed a higher priority and the call was forgotten. This was a simple failure of prospective memory (ie remembering to do something in the future) and would have been difficult to defend against, given the circumstances of high flight crew workload.

The lack of a response from the commander was interpreted by the SCCM as the pilots being busy and aware of a problem. She therefore did not call them back until some six minutes later once she had confirmed, at least in part, the reason for the passengers' unusual behaviour during the takeoff.

2.6.2 SCCM acquiring information

The operator's Joint Procedures Manual required the cabin crew to remain seated and strapped in during the takeoff. The procedure is designed to ensure the safety of the cabin crew during the takeoff phase.

The cabin crew were aware of the passenger reactions, but not what they were reacting to. The SCCM felt that the passenger reaction was unusual enough for her to deviate from the JPM instructions. She therefore tried to alert the pilots immediately. However, she received no response, as the commander was prioritising monitoring of the aircraft's flight path and there was, at this stage, little information she could have passed.

Once the aircraft was clear of the ground the SCCM, prompted by CCM2's interphone call about something unusual at the right overwing emergency exit, went to investigate. Once in the vicinity of the exit, passengers drew her attention to the damage to the right engine. As the SCCM was standing in the aircraft's central aisle, her view of the engine was limited to the top few inches of the engine.

The SCCM believed she had to report this damage immediately and did not conduct any further investigation or examination of the engine. She was not aware of the fuel leaking from the engine and so was not in a position to

pass this vital information to the pilots. Her observation of the engine, and interaction with the passengers, presented an opportunity to gather valuable information which would have given the pilots a fuller picture of the damage to the aircraft and the implications thereof. However, this opportunity was not fully exploited and the information passed to the commander during the SCCM's first successful interphone call, some seven minutes after takeoff, was limited to reporting her observation of the cowling damage to the right engine.

2.6.3 Passenger reports

Several passengers reported that they had attempted to inform a member of cabin crew about the leaking fluid from the right engine. It is unclear when or how the passengers attempted to draw this to the attention of the cabin crew, or indeed which cabin crew member(s) were involved, but it is evident from photographs and passenger reports that the fuel leak was clearly visible through the cabin windows. Despite these cues, information regarding the fuel leak was not assimilated by the cabin crew and not passed to the flight crew as required by the operator's SOPs.

Information not acquired cannot be passed onto the decision maker and the pilots remained unaware of the fuel leak until the ECAM fuel imbalance alert was triggered. Had the flight crew been made aware of the fluid leak from the right engine at an earlier stage, they might have been able to identify the fuel leak more quickly and could have taken appropriate action to mitigate the severity of the event.

The operator has, in its JPM, a procedure for cabin crew to report cabin emergencies to the flight crew and provides new entrant cabin crew with basic aircraft knowledge in accordance with EASA practices. However, on this occasion, the training and procedure were unsuccessful in ensuring that vital information on the state of the aircraft was acquired by the cabin crew and made available to the commander. The following Safety Recommendation is therefore made:

Safety Recommendation 2015-004

It is recommended that British Airways Plc reviews, and amends as appropriate, its pilot and cabin crew training, policies and procedures regarding in-flight damage assessments and reporting by cabin crew in light of the lessons learned from the G-EUOE fan cowl door loss event.

2.6.4 The decision to return to Heathrow

In his radio call at 0720:20 hrs (four minutes after takeoff), the commander verbalised a plan to return to Heathrow. Although his understanding of the aircraft condition at this point was incomplete, being based primarily on the ECAM, which displayed a minor engine issue and a single hydraulic system loss, the failures did not significantly compromise the operation of the aircraft. There was therefore no reason to believe that a return to Heathrow was not an appropriate decision. The fuel leak from the right engine did not factor into this decision, as the crew were unaware of the leak at this time.

Had the leaking fuel not ignited, or had the fuel leak been isolated sooner, there would have been no fire and the event would have been relatively benign. However, an external fire broke out on the right engine when the aircraft was already established on approach to land back at Heathrow. The immediate risk posed by the fire, at such a late stage, meant that a landing at Heathrow was the safest option.

2.6.5 Handling of the fuel leak

The QRH fuel leak procedure required the right engine to be shut down and, given the location of the damaged fuel pipe, this would have isolated the fuel leak, preventing the fire. The commander, however, decided that shutting down the right engine would have exposed the aircraft to an unacceptable risk, as the condition and degree of damage to the left engine was unknown and there was no certainty of its continued operation.

The commander had the authority to override the SOPs and, regardless of the outcome, his reasoning was valid. However, he did not communicate his decision effectively to the co-pilot, who remained concerned with the fuel leak.

When the fire broke out in the right engine, the risk to the aircraft presented by the fire was greater than that of the condition of the left engine and the commander responded accordingly by shutting down the engine.

2.6.6 Conduct of the No 2 (right) engine shutdown

The CVR evidence shows that, at 0739:30 hrs, the commander said: "I'LL SHUT THAT ENGINE DOWN..." This statement occurred before the fire warning is heard on the CVR recording and before the fire warning was recorded on the FDR. Having voiced his intention, the ECAM engine fire warning occurred and the commander then quickly selected the right thrust lever to IDLE, the No 2 (right) engine master to OFF and pushed the No 2 fire switch. Contrary to SOPs and training, he did not confirm with the co-pilot his identification of which

engine to shut down, nor was the co-pilot given the opportunity to confirm the commander's individual switch selections. Nevertheless, the commander shut down the correct engine but, by not adhering to the confirmatory and inclusive process, he ran the risk of misidentifying the correct controls to achieve his intentions. The steps taken to shut down an engine on a twin engine aircraft are deliberate and structured, to minimise the chances of human error. The way the engine was shut down in this instance removed this safety barrier.

Both the manufacturer's procedures and the operator's training for engine shut down were in accordance with industry best practice. The commander was trained and routinely examined on his ability to shut down engines in accordance with the procedures and the commander was both conversant with and aware of the reasoning behind the procedures. It is impossible within the training environment to fully replicate the complexities and cognitive and emotional loading that a real emergency produces and there does not appear to be any Safety Recommendation which could realistically address this.

2.6.7 Evacuation

When the aircraft was brought to a stop on the runway, the AFRS immediately attended and began attacking the fire in the right engine. The left engine remained running whilst the flight crew, following the operator's SOP, assessed the situation and communicated with ATC and the AFRS fire chief.

The fire chief was concerned about the risk to evacuation posed by the left engine which was still running. Hence, when asked by the commander if an evacuation should be initiated, the fire chief advised him to hold, resulting in the evacuation being delayed. The fire chief subsequently requested that the left engine be shut down and, once radio communications were re-established with the flight crew following engine shutdown, the fire chief requested that an evacuation be commenced. The decision to evacuate rests with the commander, the cabin crew under certain scenarios, or, rarely, the passengers. In this case, events were such that, in effect, the decision to evacuate the aircraft was transferred to the fire chief, although he had no authority to order an evacuation.

There is a risk of injury to passengers during an evacuation which has to be balanced against the risks of remaining on board the aircraft. However, when an aircraft is on fire, the time available to carry out an evacuation safely can be limited. The operator's evacuation procedures incorporate a short information gathering period to allow decision making. However, leaving an engine running during this period can hazard rescue and evacuation activities. The following Safety Recommendation is therefore made:

Safety Recommendation 2014-005

It is recommended that British Airways Plc reviews its evacuation procedures and training to take account of the potential risks of leaving engines running during on-ground emergencies.

Once the decision to evacuate was made, the evacuation was conducted expeditiously and without serious injury.

2.6.8 Flight crew task sharing

The manufacturer's SOP for flight crew task sharing in Abnormal and Emergency situations states that the Pilot Flying's (PF) responsibilities include: continuing to fly the aircraft and operating the thrust levers and the radio. The Pilot Monitoring's (PM) responsibilities include: monitoring and reading aloud the ECAM and checklists and performing the required ECAM actions.

The commander, as PM, deviated from the SOP in that in he took responsibility for operating the radio and, later, the thrust levers, diverting some of his attention from his other tasks. With the benefit of hindsight, it could be argued that had he adhered to the SOP, he might have had more mental capacity to assess the situation and decide on the appropriate actions. The ECAM/QRH procedures might have been completed more thoroughly and the fuel leak on the right engine might have been isolated, preventing the fire. On the other hand, it could also be argued that by managing the radio and operating the thrust levers (autothrust was no longer available), the commander reduced the co-pilot's workload significantly, allowing the co-pilot to concentrate solely on flying the aircraft and maintaining the required flightpath.

3. Conclusions

a) Findings

Operational aspects

1. Photographic evidence showed that the fan cowl doors were in an unlatched condition prior to the flight.
2. The unlatched fan cowl doors were not detected by the tug driver during his inspection of the aircraft prior to pushback.
3. The training and instructions for the tug driver's inspection of the aircraft did not contain the necessary detail to enable him to be able to identify a fan cowl door in the unlatched condition.
4. The unlatched fan cowl doors were not detected during the co-pilot's external walk-around.
5. The operator's training material on the conduct of the flight crew pre-flight walk-around included detailed instructions on checking the security of the fan cowl doors.
6. The co-pilot, who had completed the operator's pre-flight walk-around training several years previously, reported that he was not aware of the gap in the fan cowl doors when the doors are unlatched and held open by the hold-open device.
7. The A320-family FCOM instructions for the pre-flight walk-around contain specific entries for checking that the left and right engine fan cowl doors are closed and latched.
8. The pre-flight walk-around on G-EUOE was not conducted fully in accordance with the procedure as set out in the FCOM.
9. The operator did not conduct regular checks of flight crew's conduct of the pre-flight walk-around, nor was it required to.
10. Passengers were aware of the fuel leak from the right engine soon after takeoff and attempted to bring it to the attention of the cabin crew. The cabin crew did not assimilate this information and it was therefore not passed to the flight crew.

11. The information provided by the cabin crew to the flight crew did not accurately represent the state of the aircraft.
12. The commander did not have all of the available information regarding the damage to the aircraft to assist him in his decision making.
13. The QRH fuel leak procedure called for the right engine to be shut down; however, the commander, on considering the risks, elected to keep it operating.
14. The commander correctly identified and shut down the No 2 (right) engine after the fire warning activated, but this was not performed in accordance with the operator's SOPs and training.
15. The flight crew deviated from the manufacturer's FCOM SOP for task sharing for Abnormal and Emergency procedures.
16. The fire in the right engine continued after the aircraft came to a halt on the runway. The fire was quickly extinguished by the AFRS.
17. The left engine remained running until the AFRS requested that it be shut down.
18. The aircraft was evacuated quickly and without serious injury using only the exits on the left side of the aircraft.

Technical aspects

1. The fan cowl doors detached from the aircraft during takeoff because they remained unlatched following overnight maintenance and the unlatched condition of the fan cowls was not detected prior to the flight.
2. A section of the right engine inboard fan cowl door remained attached. This struck and punctured the FMU spill return pipe, causing a significant fuel leak on the right engine. The leaking fuel ignited during the approach to land.
3. When they decided to defer the IDG oil servicing task, the technicians responsible for servicing the aircraft did not follow AMM procedures for leaving the aircraft with the cowls either

fully open on stays, or closed and latched; nor did they place the required warning notices in the cockpit prior to opening the fan cowl doors.

4. The technicians were not required to, and did not load an IDG gun and oil into their vehicle prior to commencing planned maintenance tasks, due to a low expectation that the equipment would be required during the two Weekly Checks assigned to them during their shift.
5. The IDG oil servicing task was deferred because the technicians did not have the required IDG gun and oil when they needed them for G-EUOE. They elected to return to the aircraft later in their shift once they had completed other planned maintenance tasks and had drawn the necessary equipment from stores.
6. The technicians did not make an open technical log entry for the required IDG oil uplift prior to deferring the IDG oil servicing task.
7. When the technicians later returned to complete the IDG oil servicing task, they attended G-EUXI, an Airbus A321 on Stand 517, instead of G-EUOE on Stand 513. They did not check the aircraft's registration and did not recognise that they were at the incorrect stand or aircraft.
8. Previous cases of aircraft swap errors had occurred within the operator's line maintenance operation, but they had not been reported, and therefore no mitigating actions had been taken to prevent their recurrence.
9. The technicians successfully carried out an IDG oil level check and fan cowl closing procedure on G-EUXI.
10. The fan cowl doors on both of G-EUOE's engines remained unfastened and the IDG oil levels on both engines were below the serviceable level following the overnight maintenance shift.
11. The technicians completed G-EUOE's Daily and Weekly Check paperwork and technical log entries in the Terminal 5A southern crew room and not on board the aircraft, as G-EUOE's technical log had been removed from the flight deck in accordance with a local working procedure.

12. The technicians' working time records showed that both individuals were compliant with the company's working time limitations and legal requirements.
13. The performance of both technicians may have been compromised by fatigue, induced by the significant level of planned and overtime working undertaken prior to the overnight maintenance shift.
14. The quantity and scope of planned work for the technicians' shift was achievable, was not unusual or excessive, and was within their scope of approval as LMAs.
15. Both technicians had been trained in, and were familiar with, the AMM procedures relating to opening and closing the fan cowl doors.
16. Non-compliance with the AMM procedures for opening and closing fan cowl doors on Airbus A320-family aircraft was a common occurrence and was not specific to either of the technicians involved in the incident, or to the aircraft operator.
17. Previous safety actions taken by the aircraft manufacturer to prevent fan cowl door losses were only partially effective.
18. The high visibility paint on G-EUOE's fan cowl door latch handles was in a poor condition, with most of the paint either missing or obscured by blue paint overspray. There was no specific continued airworthiness instruction regarding maintenance of the high visibility paint finish in the AMM and repainting instructions contained in the fan cowl door SRM were ambiguous in that the areas of the latch to repaint differed from those defined in Service Bulletin V2500-NAC-71-0227.

b) Causal factors

The investigation identified the following causal factors:

1. The technicians responsible for servicing the aircraft's IDGs did not comply with the applicable AMM procedures, with the result that the fan cowl doors were left in an unlatched and unsafe condition following overnight maintenance.
2. The pre-departure walk-around inspections by both the pushback tug driver and the co-pilot did not identify that the fan cowl doors on both engines were unlatched.

c) Contributory factors

The investigation identified the following contributory factors:

1. The design of the fan cowl door latching system, in which the latches are positioned at the bottom of the engine nacelle in close proximity to the ground, increased the probability that unfastened latches would not be seen during the pre-departure inspections.
2. The lack of the majority of the high-visibility paint finish on the latch handles reduced the conspicuity of the unfastened latches.
3. The decision by the technicians to engage the latch handle hooks prevented the latch handles from hanging down beneath the fan cowl doors as intended, further reducing the conspicuity of the unfastened latches.

4. Safety Recommendations

The following Safety Recommendations are made:

- 4.1 Safety Recommendation 2015-001:** It is recommended that the European Aviation Safety Agency publishes amended Acceptable Means of Compliance and Guidance Material in Part 145.A.47(b) of European Commission Regulation (EC) No 2042/2003, containing requirements for the implementation of an effective fatigue risk management system within approved maintenance organisations.
- 4.2 Safety Recommendation 2015-002:** It is recommended that the European Aviation Safety Agency requires Airbus to modify A320-family aircraft to incorporate a reliable means of warning when the fan cowl doors are unlatched.
- 4.3 Safety Recommendation 2015-003:** It is recommended that the European Aviation Safety Agency amends Certification Specification 25.901(c), Acceptable Means of Compliance (AMC) 25.901(c) and AMC 25.1193, to include fan cowl doors in the System Safety Assessment for the engine installation and requires compliance with these amended requirements during the certification of modifications to existing products and the initial certification of new designs.
- 4.4 Safety Recommendation 2015-004:** It is recommended that British Airways Plc reviews, and amends as appropriate, its pilot and cabin crew training, policies and procedures regarding in-flight damage assessments and reporting by cabin crew in light of the lessons learned from the G-EUOE fan cowl door loss event.
- 4.5 Safety Recommendation 2015-005:** It is recommended that British Airways Plc reviews its evacuation procedures and training to take account of the potential risks of leaving engines running during on-ground emergencies.

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Appendix 1

G-EUOE accident flight Post Flight Report

A/C ID	DATE	GMT	FLTN	CITY PAIR
.G-EUOE	24MAY	7999	BAW762	EGLL ENGM

MAINTENANCE		DB/N
: POST FLIGHT REPORT :		BA31913002

A/C ID	DATE	GMT	FLTN	CITY PAIR
.G-EUOE	24MAY	0702/7999	BAW762	EGLL ENGM

WARNING/MAINT.STATUS MESSAGES

GMT PH ATA

0703 02 27-00 F/CTL

0716 04 52-00 DOOR R EMER EXIT

0717 05 22-00 AUTO FLT A/THR OFF

0717 05 77-11 ENG 2 EPR MODE FAULT

0717 06 29-00 HYD Y RSVR LO LVL

0719 06 29-00 HYD Y ENG 2 PUMP LO PR

0719 06 29-00 HYD Y SYS LO PR

0739 06 26-00 ENG 2 FIRE

0739 06 77-11 ENG 2 SHUT DOWN

0739 06 22-00 AUTO FLT AP OFF

0739 06 77-11 ENG 2 EIU

0739 06 77-11 ENG 2 FADEC

0740 06 32-00 BRAKES A/SKID N/WS FAULT

0744 09 29-00 HYD Y RSVR LO AIR PR

FAILURE MESSAGES

GMT	PH	ATA	SOURCE	IDENT.
0703	02	27-14-51	R B AIL MODE XDCR 33CE4	EFCS 1
			OR INPUT OF ELAC2	
0703	02	34-XX-XX	ATC 1 NO DATA FROM	ATC 1 ATC 2
			DAPS/ADS-B SRC	
0717	06	73-22-11	P2 T2 SENS/HC/EEC2	EIU2FADEC AFS 1
0719	06	29-32-12	AFS:HYD Y 3151GN	AFS 1
0719	06	73-21-60	AFS:FADEC1	AFS 1
0719	06	27-93-34	AFS:ELAC2	AFS 1
0739	06	73-22-34	DMC3: NO EEC2A DATA	EIS 3 EIS 2 EIS 1
0740	06	79-33-16	CHECK N4 BRG SCAV PRESS	EIU2FADEC
			XNTR2 CIRCUIT 4005 EN	
0740	06	71-51-00	A/C 28V POWER/EEC2	EIU2FADEC
0740	06	78-32-48	REV LVDT CHA/HC/EEC2	EIU2FADEC
0740	06	24-22-00	CHECK FIRE HANDLE 2	AC GEN
			RESET GEN2	
0740	06	32-42-48	BRK NORM SERVOLV1(15GG)	BSCU 1
0744	09	32-42-57	TACHOMETER4(22GG)/	BSCU 1
			BSCU(10GG)	
0744	09	32-42-57	TACHOMETER4(22GG)/	BSCU 2
			BSCU(10GG)	
7999	00	31-21-21	CLOCK	CFDS
7999	00	22-66-34	NO FAC 1 DATA	CFDS

Appendix 2**List of G-EUOE Inoperative Systems**

The following list represents the aircraft systems inoperative at landing:

1. Autothrust
2. Spoilers 2 and 4
3. CAT 3 DUAL
4. Thrust reverser 2
5. Cargo Door
6. Yaw Damper 2
7. PTU
8. Flaps slow
9. Engine 2 Bleed
10. Pack 2
11. Main Galley
12. Gen 2
13. Wing anti-ice
14. Aft Cargo heat
15. Normal braking
16. Alternate braking with antiskid
17. Autobrake
18. Antiskid
19. Braking on accumulator only
20. Left engine operating on N1 rated mode.

Appendix 3**Passenger exit use - Definitions**

Term	Definition
Carry Off	A passenger can be seen to have a bag, coat or other large item held in one or both hands.
Jump	The passenger can be seen to jump directly onto the down section of the slide in the briefed manner.
Sit	The passenger pauses to a crouch or sit at the top of the slide.
Fall	The passenger makes a tumbling uncontrolled descent of the slide.
Hybrid (overwing only)	A number of passengers went into a sitting position on a horizontal section of the overwing slide. Some passengers “jumped” to this seated position and were bounced onto the downward section of the slide. One of those passengers made an uncontrolled entry to the downward slide segment and was very close to falling clear of the slide.

Appendix 4**Attendance records for Technician A**

Shift start date	Clock-in (local time/ date)	Clock-out (local time/ date)	Gross working time (hrs)	Allowance for breaks (hrs)	Net working time	Shift type
02/5/13	06:22, 02/5/13	18:31, 02/5/13	11.77	1.28	10.49	Planned dayshift
03/5/13	06:28, 03/5/13	18:36, 03/5/13	11.85	1.28	10.57	Planned dayshift
04/5/13	18:37, 04/5/13	04:32, 05/5/13	9.47	1.28	8.19	Planned nightshift
05/5/13	18:37, 05/5/13	04:38, 06/5/13	9.88	1.28	8.60	Planned nightshift
06/5/13						Day off
07/5/13						Day off
08/5/13	06:21, 08/5/13	18:22, 08/5/13	11.62	1.28	10.34	Overtime dayshift
09/5/13	06:17, 09/5/13	18:21, 09/5/13	11.60	1.28	10.32	Overtime dayshift
10/5/13	06:21, 10/5/13	18:45, 10/5/13	12.00	1.28	10.72	Planned dayshift
11/5/13	06:18, 11/5/13	17:51, 11/5/13	11.10	1.28	9.82	Planned dayshift
12/5/13	18:30, 12/5/13	05:04, 13/5/13	10.32	1.28	9.04	Planned nightshift
13/5/13	18:36, 13/5/13	04:29, 14/5/13	9.73	1.28	8.45	Planned nightshift
14/5/13						Day off
15/5/13	18:19, 15/5/13	06:23, 16/5/13	11.63	1.28	10.35	Overtime nightshift
16/5/13						Day off
17/5/13	06:21, 17/5/13	18:22, 17/5/13	11.62	1.28	10.34	Overtime dayshift
18/5/13	06:22, 18/5/13	17:20, 18/5/13	10.58	1.28	9.30	Planned dayshift
19/5/13	06:21, 19/5/13	18:45, 19/5/13	12.00	1.28	10.72	Planned dayshift
20/5/13	18:29, 20/5/13	06:46, 21/5/13	12.00	1.28	10.72	Planned nightshift
21/5/13	18:27, 21/5/13	04:37, 22/5/13	9.87	1.28	8.59	Planned nightshift
22/5/13	18:27, 22/5/13	06:28, 23/5/13	11.72	1.28	10.44	Overtime nightshift
23/5/13	18:40, 23/5/13	06:37, 24/5/13	11.87	1.28	10.59	Overtime nightshift

Appendix 5**Attendance records for Technician B**

Shift start date	Clock-in (local time/ date)	Clock-out (local time/ date)	Gross working time (hrs)	Allowance for breaks (hrs)	Net working time	Shift type
02/5/13	06:57, 02/5/13	18:36, 02/5/13	11.65	1.28	10.37	Planned dayshift
03/5/13	06:48, 03/5/13	18:46, 03/5/13	11.97	1.28	10.69	Planned dayshift
04/5/13	18:30, 04/5/13	06:45, 05/5/13	12.00	1.28	10.72	Planned nightshift
05/5/13	18:27, 05/5/13	04:45, 06/5/13	10.00	1.28	8.72	Planned nightshift
06/5/13						Day off
07/5/13						Day off
08/5/13						Day off
09/5/13	06:37, 09/5/13	18:40, 09/5/13	11.92	1.28	10.64	Overtime dayshift
10/5/13	06:40, 10/5/13	18:31, 10/5/13	11.77	1.28	10.49	Planned dayshift
11/5/13	06:48, 11/5/13	18:39, 11/5/13	11.85	1.28	10.57	Planned dayshift
12/5/13	18:32, 12/5/13	05:06, 13/5/13	10.35	1.28	9.07	Planned nightshift
13/5/13	18:30, 13/5/13	04:29, 14/5/13	9.73	1.28	8.45	Planned nightshift
14/5/13	18:36, 14/5/13	06:36, 15/5/13	11.85	1.28	10.57	Overtime nightshift
15/5/13	18:38, 15/5/13	06:43, 16/5/13	11.97	1.28	10.69	Overtime nightshift
16/5/13						Day off
17/5/13						Day off
18/5/13	06:42, 18/5/13	18:27, 18/5/13	11.70	1.28	10.42	Planned dayshift
19/5/13	06:38, 19/5/13	18:35, 19/5/13	11.83	1.28	10.55	Planned dayshift
20/5/13	18:29, 20/5/13	05:04, 21/5/13	10.32	1.28	9.04	Planned nightshift
21/5/13	20:13, 21/5/13	04:38, 22/5/13	8.41	1.28	7.13	Planned nightshift
22/5/13	20:54, 22/5/13	06:28, 23/5/13	9.57	1.28	8.29	Overtime nightshift
23/5/13	18:57, 23/5/13	06:37, 24/5/13	11.67	1.28	10.39	Overtime nightshift

Appendix 6**Human Factors Specialist's Report****G-EUOE Fan Cowl Loss, 24 May 2013 – Human Factors Investigation****Summary**

At around 0816¹ hrs on 24 May 2013, the fan cowl doors from both engines of an Airbus A319 aircraft, registration G-EUOE, detached as it departed London Heathrow Airport. The fan cowls detached because they were not properly closed and latched following overnight routine maintenance.

This report examines the human factors issues that influenced the performance of the maintenance technicians on that night. Its scope ends when the maintenance activity ends, with the aircraft left in an unsafe condition for flight.

The fan cowl doors were unsecured because the technicians did not follow the proper procedure in securing the doors when they left the aircraft unattended, and because the aircraft was subsequently signed off as serviceable.

The procedure was not followed partly because an essential tool to maintain the engines was not readily available, and so the technicians decided to postpone the task until they had an opportunity to collect the tool from a stores building. They did not properly close the fan cowl doors or prop them open on stays when leaving G-EUOE. The investigation found that this particular procedure was routinely violated in the maintenance organisation.

The aircraft was signed off as serviceable mainly because the technicians later returned to the wrong aircraft, G-EUXI rather than G-EUOE, to complete their work on it. Although there is paperwork to keep track of their work list, the information is not presented in an optimum way, and technicians often annotate the list by hand, placing greater reliance on their memory for the task. The fact that they had carried out similar maintenance activities on G-EUXI, and that it was parked on a nearby stand that was similarly configured to the one for G-EUOE, probably contributed to the memory confusion. A key barrier designed to prevent this kind of incident was the signing and countersigning of paperwork to confirm that maintenance on the aircraft was complete. This barrier failed because the paperwork was physically separated from its aircraft at the time, having been moved to the engineering office for the purpose of the maintenance administration check. The aircraft misidentification error was not unique and had happened on previous occasions, but had not been reported, so no mitigating actions could be taken.

The investigation found that both technicians were at an elevated risk of fatigue on the night of the incident, having worked a considerable number of hours of overtime in the preceding weeks. This probably contributed to the error.

¹ All times reported in this Appendix are local times, which correspond to UTC plus one hour.

Appendix 6 (cont)**The incident**

At around 0816 hrs on 24 May 2013, an Airbus A319 aircraft, registration G-EUOE, departed London Heathrow Airport. As the aircraft took off, the fan cowl doors from both engines detached, causing significant damage to the airframe and aircraft systems. The flight crew decided to return to Heathrow and made an emergency landing. The passengers and crew were evacuated safely and nobody was seriously injured.

The fan cowls had detached because they were not properly closed and latched prior to take off. The aircraft had undergone routine maintenance overnight prior to the incident, during which the fan cowl doors on both engines had been opened to check the Integrated Drive Generator (IDG) oil levels. Although the aircraft had been signed off as ready for service by the maintenance technicians who had worked on it, the fan cowl doors were not secured at the end of the night shift.

This report focuses entirely on the overnight maintenance activities and the human factors that led to the technicians' omission in securing the fan cowl doors. It does not consider subsequent factors in the chain of events, including the walk-around checks that were the final barrier in preventing the aircraft departing with the fan cowl doors open. Thus, for the purposes of identifying causal factors later in the report, the incident under investigation here is that the aircraft was left in an unsafe condition for flight at the end of the maintenance shift.

Sequence of events

The full sequence of events is contained within the main body of the AAIB investigation report. What follows is an abridged version, focusing on the details relevant to the remainder of the current report.

For the purposes of this report, the technicians who worked on G-EUOE will be referred to as Technician A and Technician B. They were assigned six aircraft in total for the shift; their workload comprised six daily checks and two weekly checks, with one of the weekly checks being G-EUOE.

The weekly includes checking the IDG oil levels on the engines, which involves opening the fan cowl doors. The technicians found that both engines on G-EUOE needed their oil levels topping up. This required them obtaining an IDG oil gun from maintenance stores, which was located on another part of the airfield. Because of this, they decided to postpone the job until they had checked the other aircraft on their list.

They lowered the fan cowl doors but left them unlatched on both engines. Technician A checked the rest of the aircraft while Technician B went to the flight deck to check the paperwork. Technician B completed the daily check paperwork, but left the weekly check

Appendix 6 (cont)

open as the job was not yet complete. They then moved on to G-EUXI, which was their other weekly check.

The technicians then proceeded to work through their remaining aircraft. One of these was on a stand at Terminal 5C, which was close to the maintenance stores. While there, Technician B suggested picking up a second van from a pool of company vehicles located at the maintenance store, so that they could complete their work more quickly. So they split up, Technician A returning to Terminal 5A to begin working on their final aircraft, G-EUUZ, while Technician B visited stores to get the IDG gun, and met Technician A back at G-EUUZ.

In finishing the checks on G-EUUZ, both technicians were on the flight deck completing the paperwork. They discussed returning to the weekly that they had left open in order to top up the IDG oil. Since they now had a van each, Technician A led the way, with Technician B following.

They returned to the aircraft that they believed to be G-EUOE. However, they had actually returned to G-EUXI. They checked the engines and were surprised to find the fan cowl doors closed and latched, since they recalled leaving them unlatched. Both technicians believed that this may have been due to another team working on the aircraft in the interim, and latching the fan cowl doors afterwards. They also found that the IDG oil levels were now acceptable, and did not need topping up. But they explained this to themselves by assuming that the oil had drained back into the IDG sump during the time that it had been standing. Both situations were not unheard of.

Having completed the checks, they closed and latched the fan cowl doors on G-EUXI. Because it was a weekly check, the log book was in the maintenance office rather than on the flight deck (which is the case for daily checks). The technicians thus returned to the office and signed off the paperwork for G-EUOE.

The investigation

The AAIB investigation called for human factors input; this report represents the output of the human factors advisor's work on the investigation. The advisor worked under the authority of the AAIB lead engineering investigator, who arranged site visits and interviews to collect evidence. The scope of this work was limited to examining the factors associated with the maintenance technicians' activities on the night before the incident.

Appendix 6 (cont)**Sources of evidence**

- Witness statements
- Site visit and observations of similar maintenance activities
- Work planning documents
- Shiftwork records
- Company standards and procedures
- Relevant standards from other companies and industries
- Relevant human factors literature

Analysis**Background**

Maintenance errors are a significant source of risk in aviation and other safety-critical activities. Because they represent 'latent conditions', their effects are not immediately observable, and may only become apparent much later than the original action that led to them. But, like any human error, the maintenance technicians' actions were affected by myriad factors associated with the system and the environment within which they were working.

Immediate cause²

The immediate cause was that the fan cowl doors were not closed and secured following the maintenance activity.

The aircraft being in an unsafe condition for flight was a direct result of the fan cowl doors being left open. This, in turn, was caused by a combination of factors:

- the technicians did not follow procedure when leaving the aircraft unattended, and
- the aircraft was signed off as serviceable.

Each of these factors is discussed below.

² The condition, event or behaviour that directly resulted in the occurrence.

Appendix 6 (cont)**Causal factors³**

The technicians did not follow the proper procedure for either securing the fan cowl doors or propping them open on stays when leaving the aircraft unattended.

Fan cowl doors are heavy and cumbersome, and there are two stays in the engine bay to prop each door open. Even so, it takes two technicians to lift and prop the doors open. Given that the IDG can be inspected by partly opening the door, the technicians took a decision to inspect an engine each in this way, in the interests of efficiency. They then lowered the doors and left them resting on a hold-open device, rather than close and latch them properly, since they were planning to come back to top up the oil later.

In strict terms, this is a procedural violation, since the Aircraft Maintenance Manual requires that, in the event that a technician has to leave the aircraft when the fan cowl doors are open, the doors must be propped fully open using the stays, or fully re-latched. From a human error perspective, it may be termed a 'routine violation', since it was apparent in the course of the investigation that it is a common occurrence amongst many operators. Each technician is left to manage their work in their own way, and consequently each technician works in a different fashion – some use the stays, some do not.

In fact, it is possible to top up the IDG oil while leaving the fan cowl door resting on the hold-open device, making it unnecessary to use the stays altogether for this task. Thus the violation is not precluded by the design of the equipment.

Whilst the use of the stays may have affected events further down the incident causal chain (the open fan cowl doors are much more likely to have been detected by other technicians or on a pre-flight walk-around), it is less likely to have prevented the misidentification error in the first place. The only opportunity to detect the error on this basis was in the fact that the technicians drove past G-EUOE to get to G-EUXI – they may have spotted the (more obvious) doors open themselves.

Having arrived at G-EUXI, though, the memory of having left the fan cowl doors open – whether on the stays or on the hold-open device – is unlikely to have affected their actions. Both technicians were surprised to find the doors closed and latched on G-EUXI, but they rationalised this by assuming another crew had worked on the engines in the meantime. This kind of confirmatory bias – looking for evidence to support your assumptions rather than challenge them – would probably have operated whether they had left the fan cowl doors on the stays or on the hold-open device. It is the same mechanism behind their rationalisation that the IDG levels on G-EUXI were normal and did not need topping up.

³ Any condition, event or behaviour that was necessary for the occurrence. Avoiding or eliminating any one of these factors would have prevented it happening.

Appendix 6 (cont)***The aircraft was signed off as serviceable when it was in an unsafe condition.***

This was partly because the technicians returned to the wrong aircraft to complete the weekly check, and partly because the system of signing off aircraft was vulnerable to error. These factors are now considered in turn.

The technicians returned to G-EUXI to complete the weekly check rather than G-EUOE.

The type of error made by the technicians was essentially a 'slip' – they had intended to return to G-EUOE, but their actions did not match the plan. Slips are typically the result of automatic actions – well-practiced activities that are not consciously monitored. As such, they are vulnerable to being mis-cued by stimuli in the environment such as design or layout of signs and interfaces. Fatigue can make slips more likely, because it can reduce conscious monitoring of actions.

Whilst there is no formal data collection on the frequency of these types of errors, witness evidence suggests that wrong aircraft identification is quite common amongst technicians. In most cases, including this one, this is because the aircraft have not parked on their scheduled stands – stand changes are a regular occurrence for operational reasons.

Usually, the consequences of these aircraft misidentification errors are benign; they are noticed when the other (correct) team arrives to work on the aircraft and find that their work has been done for them. When such errors do occur, then, they tend to go unreported, with line management largely unaware of any problems.

Furthermore, the two technicians in the maintenance team were separated by using two vans, making it difficult to work together in identifying the correct aircraft. The use of two vans was agreed between the technicians as an operational efficiency. There is nothing wrong with this practice as it stands; the local working practices are such that technicians are largely left to manage their workload as they see fit.

The disadvantage to this approach was that they were physically separated when travelling from Stand 509, their last full check (G-EUUZ), to stand 517 (G-EUXI). Since both technicians were driving, they had less opportunity to check their annotated work list, and were relying more heavily on their memory for which aircraft to return to.

If they had been in the same vehicle, it is possible that one of the technicians would have checked the work list, or questioned which stand they were going to. As implied above and explained in detail later, Technician A automatically stopped at Stand 517 for G-EUXI, and Technician B followed suit.

Appendix 6 (cont)

The system of checking work and signing off aircraft was vulnerable to error.

On completing their maintenance activities, both technicians sign and stamp a worksheet in the aircraft's technical records and one technician signs an entry in the aircraft's maintenance logbook (the 'tech log'). For daily checks, the tech log is kept on the flight deck. However, for weekly checks, the tech log is taken into the maintenance office for checking and is signed off there. This arrangement removes the association between an aircraft and its tech log, which is the sole means of ensuring that an aircraft is fit for service.

Removing the tech logs opens the possibility of inadvertently signing off the wrong paperwork and thereby circumvents a key barrier in the prevention of these kinds of errors. Had the tech log been kept on the flight deck, the technicians would very likely have noticed their error when going upstairs to sign off the aircraft, since they had already completed and signed off G-EUXI. Instead, they completed the sign-off in the office, without the contextual cues of the aircraft around them.

The investigation found that technicians and line management were unclear as to the rationale behind leaving the daily tech logs on board while removing the weeklies. There seems to be variation in local practices within the airline on this point, even between different maintenance departments in the same airport (only short haul engineering at Heathrow remove the weeklies; other departments leave them on board the aircraft).

Underlying factors⁴

The availability of maintenance tools and equipment (including the IDG gun) was impeded by a lack of access to store rooms.

At Terminal 5A, there are engineering store rooms located at the North and South ends of the terminal. However, at the time of the incident, the North stores were undergoing a refit, meaning that no equipment was available at the North store and limited equipment was available at the South store room. Consequently, the IDG guns were located in a larger store room elsewhere on the airfield, approximately a five minute drive away.

Availability and condition of equipment is often cited as a causal factor in human error. It is possible that, if the IDG guns had been more conveniently located, then the technicians may have decided to complete the task on G-EUOE straight away. In this case, the decision to leave the doors resting on the hold-open device may have been negated. Moreover, their memory for the aircraft might not have been so affected by intervening events, and perhaps the misidentification would not have happened.

⁴ Any factors associated with the overall management systems, organisational arrangements or the regulatory structure.

Appendix 6 (cont)

Removing the need to go to the main stores would also have likely negated the need for the second van, which has been identified above as a possible explanation for one of the causal factors.

There was evidence of non-reporting of aircraft swap errors and procedural violations.

Whilst it was apparent that aircraft misidentification errors were relatively common amongst technicians, it was also clear that line management were unaware of many of these errors. Similarly, the rate of procedural violations as noted above was likely higher than the line management acknowledged. The aircraft misidentification errors and procedural violations were not seen as unusual by maintenance staff and therefore had become accepted as organisational norms.

Had more reports been received within Terminal 5 Engineering, the opportunities for detecting the error may have been greater. It is possible that the technicians involved would have been more aware of previous misidentification errors. In turn, this might have prompted them when considering why the fan cowl doors were shut and the IDG oil level was normal on G-EUXI.

Better reporting could also have alerted management to the frequency and potential consequences of these errors much earlier. In response, measures could have been put in place to mitigate such errors before an incident occurred.

The system of organising technicians' work is prone to error.

The work list printed out at the start of each shift and distributed to the maintenance teams is not presented in an optimal way for the information needs of the user. The work list is primarily organised according to stand number but, as already noted, many aircraft end up parked on different stands than originally planned. Consequently, this list rapidly becomes out of date and technicians have to annotate the list by hand, resulting in numerous corrections on the sheet.

Such unstructured information management is a potential source of error. Human memory may be fallible at encoding, storage or retrieval, particularly when dealing with multiple items, and using external sources of information is accepted as good practice in human factors to counter such fallibility.

Having to work on six aircraft at a time imposes a considerable load on working memory. On this night, Technician A was also dealing with additional workload related to further training he was undertaking. It is crucial under such circumstances that technicians have an effective means of tracking their work over the course of a shift. However, in this case, the presentation and management of that information was not effective.

Appendix 6 (cont)

In this incident, Technician A had made a note against G-EUOE that the IDG oil needed topping up, in order to return to it later. In the event, though, Technician A relied on his memory of the aircraft in guiding his actions instead of the work list. The type of memory involved in this kind of task is known as ‘prospective memory’ – in other words, remembering to remember.

The classic type of prospective memory failure is a simple lapse – forgetting to remember at all. Technician A did recall the task, but instead substituted the object of that task (ie, G-EUXI instead of G-EUOE). This type of substitution has been classified as a class of prospective memory error by some researchers, even though it did not involve a lapse.

Essentially, this was a failure of the retrospective component of prospective memory – remembering what the task was when needed. This could have been due to how the task was encoded in the first place. The evidence suggests that Technician A had mentally bookmarked the task on G-EUOE as “the IDG on the weekly” or similar. It is not apparent that he linked the task to the specific aircraft or the specific stand.

It is notable that G-EUXI was the technicians’ other weekly check for that shift, so it is possible that the memory traces for these two checks had become crossed over at recall. This was not a random error: the aircraft was familiar to them as they had worked on it earlier that night. A more effective external means of tracking their tasks would probably have prevented the error.

Road navigation around the terminal ramp area is susceptible to error, with little distinctiveness between aircraft and stands.

Given the nature of the terminal area, it seems to be optimised for navigation in an aircraft rather than a road vehicle. Stand signage for aircraft is clear and conspicuous, with large, brightly lit yellow signs (see Figure 1). The same is not true for road vehicles, with smaller, retroreflective blue signs mounted high up on the jetty (see Figure 2). For the most part, the yellow aircraft signs are not visible from a road vehicle (see Figure 3), since they are oriented towards the ramp for incoming aircraft. In some instances, visibility of the blue road signs is obscured by other structures around the stands.

Witness evidence suggests that there is little distinctiveness between aircraft stands, but a site visit by investigators found that there was some variation between stands, albeit subtle. In particular, at Stand 513 (where G-EUOE was parked) there is a large service building (a ‘pod’). Whilst this partly obscures the blue stand sign from the North approach, it also serves as a relatively distinctive landmark, since there are only three of these pods in the terminal (see Figure 4).

Appendix 6 (cont)

Furthermore, Stands 513/514 and 516/517 (G-EUXI was at Stand 517) are double stands, designed as a pair to accommodate larger aircraft. Whilst this distinguishes them from other stands in the terminal, it makes them less distinctive from each other, and may have contributed towards the misidentification error. It is also notable that these stands are in close proximity to each other.

As well as the stand identification, there is the identification of the aircraft itself to consider. The Airbus A320 family of aircraft appear quite similar to each other to an untrained eye. Witness evidence suggests that, when working in the terminal at night with an aircraft on every stand, it seems like a row of identical aircraft.

Nevertheless, there are identifiable differences between aircraft. The A321 (G-EUXI) is markedly longer than the A319 (G-EUOE), being as it is a stretched version of the aircraft. Moreover, each aircraft has its unique registration, which is marked in several places around the aircraft. For a road approach from the terminal, the nearest markings are above the flight deck windscreen (where the last three characters of the registration appear; Figure 5) and on the nose gear door (the last two characters are marked; Figure 6).



Figure 1

Yellow aircraft stand signage (Stand 517, circled)

Appendix 6 (cont)



Figure 2

Blue road signage for aircraft stands (Stand 516/617, circled)



Figure 3

View along the terminal road

Appendix 6 (cont)



Figure 4

'Pod' service building at Stand 513 (signage circled)



Figure 5

Aircraft registration markings above the flight deck (circled)

Appendix 6 (cont)**Figure 6**

Aircraft registration markings on the nose gear door (circled)

Whether or not these factors influenced the technicians' perceptions and decisions on the night is open to question. They demonstrated a good mental map of the terminal areas, only really using the stand signage to confirm the specific location when approaching the stand. Whilst the good mental map could reduce their reliance on signage, the fact that they need to use it for the last detail part of their journey suggests signage is more important. Moreover, given that their work is organised according to stands rather than registrations (as discussed earlier) implies that – if anything – they would navigate by stand number when searching for aircraft.

However, in the event it seems more likely that they were working according to their memory of the task (ie, the weekly check), rather than recalling the specific aircraft or the stand that it was parked on. G-EUXI was a familiar aircraft that they had also performed a weekly check on that evening. Thus their expectations probably drove their perceptions more strongly than the signage and registration markings.

It remains possible, though, that had the signs and markings been more prominent, then their expectations might have been overridden and the error detected. The yellow stand signs are visible from certain points around the aircraft but can be obscured when working around the wings and engines. Given that the technicians were working on the engines, it is notable that there are no registration markings on the engine nor stand numbers on the ground around the aircraft. The fact that G-EUOE and G-EUXI were both parked on double stands may have also contributed to the misidentification.

Appendix 6 (cont)***Both technicians were at an elevated risk of fatigue on their shift.***

Fatigue is a key risk factor in safety-critical work, as it affects reaction time, decision making, and other cognitive abilities. Shiftworkers are particularly susceptible to fatigue, since they are required to work when their body's circadian rhythm is normally programmed to sleep. Despite their best efforts, shiftworkers sleeping during the day tend not to get as much sleep, or as good quality sleep, as at night. One study⁵ found that maintenance workers sleep an average of five hours during the day, significantly less than the recommended 7-8 hours. The investigation found that some technicians at Terminal 5 manage a similar amount of sleep when on night shifts.

The human body clock follows a circadian (daily) rhythm, with peaks and troughs in alertness throughout the day and night. Because we have evolved to be diurnal (as opposed to nocturnal) creatures, alertness dips at night – even for shiftworkers who have adapted their sleep patterns to night work. Research⁶ shows that errors due to fatigue peak in the early hours of the morning. The investigation found that the key error (returning to the wrong aircraft) occurred at around 0130 hrs – approaching the lowest ebb of the circadian rhythm. Moreover, skill-based errors (those resulting from automatic, unconscious routines – such as the prospective memory error discussed above) are particularly susceptible to these dips in alertness.

The operator's policy in this area is largely based upon working time regulations, which limit working hours to an average 48 per rolling week over a 17-week reference period, unless workers decide to opt out in writing. The investigation found no evidence that either Technician A or Technician B had formally opted out of this limitation.

The shift records for Technician A and Technician B from 1 January 2013 to 23 May 2013 were reviewed for their potential to cause fatigue, using best practice guidance from the literature and other safety-critical sectors as benchmarks. Such comparisons are relevant because fatigue effects on human performance are generic and are not specific to a particular domain or task. For the purposes of the analyses below, working time was calculated simply as actual time on site (from clocking in to clocking out), since this is the most relevant variable for assessing fatigue.

The technicians' normally scheduled shift roster is to work two days (0645 hrs to 1845 hrs), then a 24 hour rest period, followed by two nights (1845 hrs to 0645 hrs), then four days off. However, there was evidence that the team is under-resourced, especially given an increased workload of night-stopping aircraft at Heathrow. Consequently, technicians are regularly asked to work overtime.

⁵ Johnson, W. B., Mason, F., Hall, S. & Watson, J. (2001). Evaluation of aviation maintenance working environments, fatigue, and human performance. FAA Report.

⁶ Hobbs, A., Williamson, A. & Van Dongen, H. P. A. (2010). A circadian rhythm in skill-based errors in aviation maintenance. *Chronobiology International*, 27(6), 1304-1316.

Appendix 6 (cont)

On the night of the incident, Technician A was working his seventh consecutive shift, having worked one overtime day shift before his regular schedule, plus two overtime night shifts at the end of his scheduled roster. During this shift rotation, he had been at work for nearly 82⁷ hours and had 91 hours of rest (including meal breaks taken while at work). Meanwhile, Technician B was on his sixth consecutive shift, working on two additional nights after his regular schedule. His hours on site totalled 64⁸, with 109 hours of rest (again including meal breaks taken at work). Guidelines developed for the CAA⁹ stated that workers' hours, including overtime, should not exceed 60 hours before a period of extended rest. Although this limit is not mandated in regulations and was based on academic research conducted for the CAA, it suggests that if overtime exceeds 60 hours, then workers are at a high risk of fatigue.

Elsewhere in transport, a 12-hour shift (from start to finish) is considered to be long, with 10 or even 8 hours being recommended, especially for night shifts. This is based on data that suggest the risk of an error or accident increases with shift length over 8 hours, with 12-hour shifts exhibiting a 27% increase in risk¹⁰. In the shift records for Technician A and Technician B, the majority of their night shifts were 12 hours, because this is their standard scheduled shift duration across days and nights. Fatigue guidance in comparable industries also promotes a minimum of 14 hours rest between consecutive night shifts. Again, 12-hour shifts make it difficult to meet this requirement, and so Technician A and Technician B rarely achieved those levels of rest.

A FAA report, which compared best practices in fatigue risk management for aviation maintenance, found some quite restrictive practices in other countries, where overtime is limited to 36 hours per month¹¹. By comparison, in the month leading up to the incident, Technician A worked nearly 82 hours overtime while Technician B worked nearly 69 hours overtime¹².

The same CAA guidelines referred to earlier identified that consecutive night shifts create a fatigue risk, and should be limited to two if the shifts exceed 10 hours. Moreover, if working more than three night shifts in a row, then there should be a continuous rest period of 83 hours (three successive days consecutive with a minimum 11-hour gap between shifts as stipulated in the EU Working Time Directive). This is because the sleep debt that has built up needs a minimum of two nights' unrestricted sleep to make up for it. This is

⁷ This includes a total of 2 hours 7 minutes in which Technician A had clocked in before the scheduled shift start time.

⁸ Including a total of 26 minutes in which Technician B had clocked in before the scheduled shift start time.

⁹ Folkard, S. (2003). Work Hours of Aircraft maintenance Personnel. CAA Paper 2002/06.

¹⁰ Office of Rail Regulation (2012). Managing rail staff fatigue.

¹¹ See Hobbs, A., Avers, K. B. & Hiles, J. J. (2011). Fatigue Risk Management in aviation maintenance: Current best practices and potential future countermeasures. FAA Report No. DOT/FAA/AM-11/10.

¹² In this instance, the figures are based on scheduled shift start (or clocking in time, whichever is later) to clocking out time, in keeping with the definition of overtime hours.

Appendix 6 (cont)

consistent with other transport guidance which states that there should be a maximum of three consecutive night shifts before a rest day.

Both Technician A and Technician B regularly worked three night shifts in a row, and both were on their fourth consecutive night shift on the night of the incident. On no occasion (other than when on leave) did either technician have 83 hours rest after more than three night shifts.

The CAA guidelines also stated that continuous rest periods should be for a minimum of 59 hours (two days plus the 11-hour gap). Technician A did not achieve this level of rest on the two rest periods prior to the incident. Technician B also did not achieve this level of rest in the last rest period before the incident.

The Health and Safety Executive (HSE) has published a fatigue and risk index calculator¹³ for shiftworkers in safety critical work. The calculator outputs two figures: a fatigue index, which represents a percentage probability of high levels of sleepiness for a given shift pattern, and a risk index, which is the relative risk of an incident referenced against a typical two-day, two-night, four-off rotation (normalised at a value of 1.0).

Inputting the shift records for Technician A and Technician B into the calculator for the three weeks leading up to the incident found that the probability of fatigue and the relative risk was high for both workers. On the night of the incident, the fatigue index for Technician A was 39.4, while the risk index was 2.05. Thus there was nearly a 40% chance that he would have been experiencing high levels of sleepiness, while his relative risk of an incident was more than double that for a normal shift pattern (ie, with no overtime). The corresponding scores for Technician B were 38.0 for the fatigue index, and 1.64 for the risk index.

Taken together, these findings – particularly the number of hours worked and rest obtained in the weeks leading up to the incident – strongly suggest that both technicians could have been suffering from fatigue on the night of the incident.

Working time limits are primarily targeted at protecting employees' health and safety, rather than explicitly towards fatigue management. Whilst such limits meet current regulatory requirements, recent work in this field has identified shortcomings with this kind of approach, advocating more specific fatigue risk management systems for safety-critical workers. The risk is that working time limits become standardised as acceptable, rather than seen as maximums. Best practice elsewhere is more prescriptive in an effort to manage fatigue.

¹³ Health & Safety Executive (2006). The development of a fatigue / risk index for shiftworkers. Research report 446.

Appendix 6 (cont)

In order to combat fatigue, many safety-critical industries employ formal fatigue risk management systems. These may involve more detailed constraints on working hours, as detailed above, or the use of biomathematical models such as the HSE's fatigue and risk index. The constraints and indices are used proactively by shift planners to try and design shift patterns that minimise the risk of fatigue.

The culture in the operator's engineering division instead puts the onus on the workers themselves to monitor their hours and to refuse overtime if they were suffering from the effects of fatigue or would exceed the policy limits. Hours are monitored after the shifts are worked, when timesheets are returned, and workers exceeding the limits are reprimanded.

Although formal fatigue risk management systems are still uncommon for aviation maintenance workers, the absence of such a system has to be considered as contributory in the current incident.

Conclusions

Within the scope of this report, the immediate cause of the incident was that the fan cowl doors were not closed and secured following the maintenance activity. This was partly because the technicians did not follow procedure in securing the doors when leaving the aircraft unattended, and partly because the aircraft was subsequently signed off as serviceable.

Although the technicians performed a procedural violation in not securing the fan cowl doors or propping them open on the stays, this was not uncommon amongst the team and was therefore not reported.

Meanwhile, the non-availability of equipment (the IDG gun) nearby to G-EUOE may have played a role in the error by inciting the technicians to postpone completion of the work until they had an opportunity to collect the IDG gun from stores.

The main reason that the aircraft was then signed off as serviceable is that the technicians returned to the wrong aircraft to complete the weekly check after their other work was completed. Whilst aircraft misidentification errors are not uncommon, in most cases they are benign, with other workers detecting the error if they were due to work on the aircraft as well. In this case, because the same technicians worked on the misidentified aircraft and the incident aircraft, there was no such opportunity for detecting the error.

The fact that the same technicians worked on both aircraft meant that G-EUXI was familiar to them, particularly since both aircraft were also weekly checks on their work list for the night. An opportunity to detect the error was available in the two technicians

Appendix 6 (cont)

cross-checking each other's decisions when travelling between aircraft. But this opportunity was missed because the technicians became separated by deciding to take two vans, in order to complete their work more efficiently. These factors, combined with an unreliable and confusing information system for organising engineering work at Terminal 5, probably contributed to the error.

A key barrier designed to prevent this kind of incident was the signing and countersigning of paperwork to confirm that maintenance on the aircraft was complete. This barrier failed because the paperwork was physically separated from its aircraft at the time (because it was a weekly check and hence held in the office).

Ultimately, the aircraft misidentification was probably more due to a memory error than a navigation error in the terminal area. Nevertheless, it is possible that the similarity of aircraft stands and lack of distinctive signage played a role in the error.

Underlying these factors was evidence of non-reporting of errors and procedural violations. Better reporting could also have alerted management to the frequency and potential consequences of these errors much earlier. In response, measures could have been put in place to mitigate such errors before an incident occurred.

Both technicians were at an elevated risk of suffering from fatigue at the time of the incident, and this would probably have affected their propensity for a 'slip' type of error, such as aircraft misidentification. The lack of a formal fatigue risk management system for maintenance workers, which was not a requirement at the time of the accident, meant that a key barrier to this kind of error was not in place.

Appendix 7**EASA NPA2013-01(C) AMC proposals for 145.A.47(b)****AMC1 145.A.47(b) Production planning****FATIGUE RISK MANAGEMENT**

- (a) In order to manage the fatigue related risk of personnel, as an aviation hazard, the organisation should:
- (1) as part of its safety policy develop and maintain a policy for the management of fatigue related risk and define the related procedures;
 - (2) define and use a work schedule scheme with maximum work and minimum rest hours not exceeding the limitations laid down in the Directive 2003/88/EC10. Where temporary derogations and opt-outs to Directive 2003/88/EC are agreed between the organisation and its personnel, the organisation should conduct and document a risk assessment, and take the necessary actions to mitigate the applicable risks;
 - (3) ensure existing reporting systems enable the identification of fatigue related hazards;
 - (4) assess and manage the risks of such fatigue related hazard reports in accordance with the organisation's safety risk management procedures in accordance with AMC1 145.A.65(a)(3), and monitor the effectiveness of related risk mitigation actions implemented; and
 - (5) provide training on the management of fatigue.
- (b) By derogation from point (a)(2) above, when the organisation does not apply the maximum work and minimum rest hours laid down in the Directive 2003/88/EC11, it should establish as part of its management system a fatigue risk management scheme in accordance with AMC2 145.A.65(a)(3) acceptable to the competent authority.

Appendix 7 (cont)**AMC2 145.A.47(b) Production planning****DUTY TIME SCHEDULE**

(a) The duty time schedule should address, at a minimum, the following topics:

- (1) Maximum scheduled hours/day;
- (2) Maximum hours with overtime;
- (3) Maximum hours/month;
- (4) Minimum rest between shifts (based on shift length); and
- (5) Minimum uninterrupted rest hours per week.

All of the above must consider time of day work shift.

(b) Reasonable work hour limits should not be exceeded merely for management convenience even when staff is willing to work extended hours. When maximum work hours are exceeded, the organisation and the individual staff member should have a written plan on how the fatigue risk will be mitigated. This may include:

- (1) additional supervision and independent inspection;
- (2) limitation of tasks to non-safety critical;
- (3) use of additional rest breaks; and
- (4) permission to nap in accordance with guidelines approved by the organisation.

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.