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FINAL REPORT
AIRCRAFT SERIOUS INCIDENT

Law on Aircraft Accident Investigation, No. 35/2004

Smoke in flight deck and cabin, engine shut down and an emergency landing

M-01409/AIG-09

TF-FIJ
Boeing 757-200
Icelandair
85 NM south-south-east of London Gatwick Airport (EGKK)
June 4, 2009

AIRCRAFT ACCIDENT INVESTIGATION BOARD

The aim of the aircraft accident investigation board is solely to identify mistakes and/or deficiencies capable of undermining flight safety, whether contributing factors or not to the accident in question, and to prevent further occurrences of similar cause(s). It is not up to the investigation authority to determine or divide blame or responsibility. This report shall not be used for purposes other than preventive ones. In accordance with law on aircraft accident investigation, No. 35/2004 and Annex 13 to the Convention on International Civil Aviation.

Contents

Forewords

The field investigation and the initial investigation of this serious incident were performed by the United Kingdom Air Accident Investigation Branch, with the Icelandic Aircraft Accident Investigation Board (IAAIB) appointing an accredited representative.

The investigation of this incident was then passed on to the Icelandic Aircraft Accident Investigation Board.

Synopsis

Icelandair B757-200, TF-FIJ, departed Paris Charles de Gaulle airport (LFPG) France at 11:39 UTC (13:39 local time) on June 4th 2009 for its flight to Keflavik airport (BIKF) Iceland.

Seventeen minutes into the flight the flight crew noticed white smoke entering the flight deck. The smoke intensified rapidly to such an extent that the flight crew could barely see their instruments. Shortly after, smoke also entered the whole cabin section and intensified rapidly. The commander noticed engine #1 surging and shut it down. Shortly thereafter the smoke started to decrease. The airplane diverted and made an emergency landing at London Gatwick airport (EGKK) United Kingdom.

The investigation revealed that the low pressure fuel pump installed on engine #1 had failed due to extensive internal wear damages. This allowed fuel to leak into the engine's oil system. Fuel/oil mixture entered the engine's main bearing chambers, where the seals could not contain it. The fuel/oil mixture then leaked into the compressor section of the engine. Inside the compressor the fuel/oil mixture generated smoke. The smoke propagated to the engine's HP2 port and from there entered the engine's bleed air system. Once in the bleed air system the smoke entered the left air conditioning pack and from there was distributed to the flight deck and the cabin.

The investigation revealed that the low pressure fuel pump had never undergone inspection, repair or overhaul.

The manufacturer of the low pressure fuel pump, as well as the manufacturer of the engine, had issued maintenance requirements for the low pressure fuel pump. The investigation revealed that the operator of the airplane had not implemented into its maintenance program tasks that would individually monitor the low pressure fuel pump utilizations and ensure its required maintenance was being performed.

Several safety recommendations are issued.

1 Factual information

Factual information	
Place:	About 85 miles south-south-east of London Gatwick Airport (EGKK) at FL 320
Date:	June 4th, 2009
Time[1]:	11:56
Aircraft:	
• **type:**	Boeing 757-200
• **registration:**	TF-FIJ
• **year of manufacture:**	1991
• **serial number:**	25085
• **CoA:**	Valid
• **Nationality:**	Icelandic
Type of flight:	Scheduled commercial flight
Persons on board:	8 crew members 149 passengers
Injuries:	Some of the passengers and cabin crew members had minor eye and respiration problems
Nature of damage:	Minor
Short description:	Intense smoke in flight deck and in cabin
Owner:	Siglo FIJ Limited
Operator:	Icelandair
Weather:	Sunlight with few clouds
Meteorological conditions:	Visual Meteorological Conditions (VMC)
Flight rules:	Instrument Flight Rules (IFR)

[1] All times in the report are UTC and where applicable local times are shown in ( ).

1.1 History of the flight

Icelandair B757-200, TF-FIJ, departed Paris Charles de Gaulle airport (LFPG) France, as flight FI543, at 11:39 UTC (13:39 local time) on June 4th 2009. The flight was scheduled for Keflavik airport (BIKF) Iceland.

The initial segment of the flight was uneventful and the flight crew had switched from Paris ATC[2] over to London ATC. The first officer was the pilot flying.

About 17 minutes into the flight, when approaching the south coast of England, climbing through flight level 320, about 85 NM south-south-east of London Gatwick Airport (EGKK), the flight crew noticed white smoke entering the flight deck. The flight crew donned its oxygen masks. The first officer then reached for his smoke goggles and put them on. The commander momentarily looked for his smoke goggles, but could not locate them and decided after two trials that he had more important tasks to perform at this time. The commander then took over as pilot flying and the first officer started working the “Smoke or Fire or Fumes” checklist from the QRH[3]. See Appendix I for details of this checklist.

Seventeen seconds after the smoke was initially noticed in the flight deck, the flight crew advised London ATC that they had smoke in the flight deck. At this time, the smoke had intensified rapidly and the flight crew had difficulty seeing the instruments on the control panels as well as each other. A few seconds later, three loud bangs were heard by the flight crew coming from an engine as it most likely surged[4]. Due to the dense smoke, by leaning forward in his seat, the commander was barely able to recognize on the EICAS[5] in the centre control panel that the parameters for engine #1 (LH engine) were irregular and its EGT[6] was rising. At this time the first officer did not see the EICAS due to the thickness of the smoke and had difficulty seeing the control panels that were a bit closer and directly in front of him. See Figure 1.

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[2] Air Traffic Control
[3] Quick Reference Handbook
[4] Surge in turbofan engine occurs when the blades in its compressor section stall
[5] Engine-Indicating and Crew-Alert-System
[6] Exhaust Gas Temperature

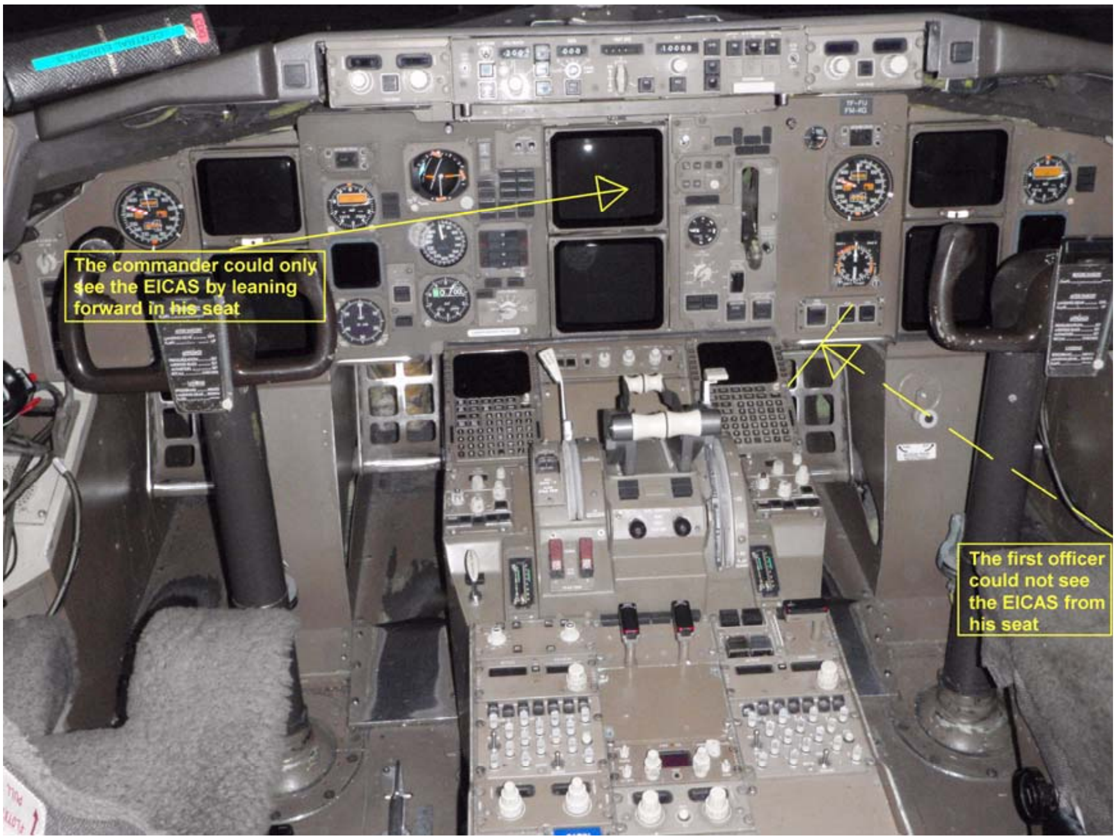

Figure 1 – View of the EICAS panels (commander leaning forward in his seat)

In the cabin area, the senior cabin attendant was attending to meal service in the forward galley, along with the third[7] cabin attendant who was getting ready to prepare the meals for the flight deck. Suddenly one passenger, who was a commander with the airline travelling back to Iceland after duty abroad, rushed into the forward galley declaring that there was smoke in the cabin. The cabin attendants looked into the cabin and noticed a wall of smoke moving rapidly forward to the galley area, while increasing simultaneously. According to the senior cabin attendant the smoke was of light grey colour and smelt of kerosene.

Thirty seconds after the initial smoke was detected, the third cabin attendant reported to the flight deck that smoke was entering the cabin. At this moment, the flight crew declared emergency to ATC ("Iceair 543 MAYDAY MAYDAY MAYDAY").

[7] The cabin attendants have a ranking of: Senior-, second-, third- and fourth cabin attendant

The senior cabin attendant located an oxygen bottle and donned the mask, while leaving the PBE[8] as it would limit field of vision.

The third cabin attendant triggered the cabin alarm, located a portable fire extinguisher and passed it to the senior cabin attendant. The senior cabin attendant looked at both the oxygen bottle and the portable fire extinguisher and decided that it would be too cumbersome to carry both. The senior cabin attendant therefore left the oxygen bottle and headed back into the cabin with only the portable fire extinguisher to locate the source of the smoke. The smoke seemed evenly distributed throughout the cabin and the field of vision went down to about two meters.

According to a cabin crew member in the aft cabin area, the smoke seemed to initially start in the wing area, but then very rapidly distributed evenly over the whole cabin area with visibility reduced to 3 seat rows. One of the cabin attendants in the aft cabin area grabbed a portable fire extinguisher and headed forward to locate the source of the smoke. The remaining aft cabin attendants removed smoke hoods from their stowed position and kept them within easy reach. The senior cabin attendant met up with a cabin attendant from the aft galley area, who was also performing the same task, without either of them having located the source of the smoke. None of the cabin attendants on board the flight donned PBE's during the incident.

Forty-six seconds after the smoke was initially noticed in the flight deck, the commander shut down engine #1 by moving its fuel lever to cut-off position. At the same time the commander was ready to discharge the fire bottles for engine #1 as he suspected an engine fire. No fire message did appear on the EICAS, so the fire bottles were not discharged. Shortly after engine #1 was shut down the smoke intensity in the flight deck stopped increasing and slowly started decreasing.

The auto-throttle disengaged when engine #1 was shut down. The commander, who was now pilot flying, felt the airplane's autopilot had difficulty controlling the airplane as it started to bank/roll and yaw. The commander therefore disengaged the autopilot and manually flew the airplane during most of the

[8] Protective Breating Equipment

remaining flight. According to the flight data recorder the autopilot was re-engaged for about 20 seconds, ten minutes after the initial smoke was detected.

About two minutes after the initial smoke was detected, the flight crew requested diversion to a suitable airport. Five seconds later, ATC advised "Iceair 543" that Gatwick[9] was located 75 miles in their 10 o'clock position. The flight crew radioed back to ATC that they wanted to descent and received permission to commence descent and approach for runway 26L at Gatwick airport.

Two minutes and twenty four seconds after the smoke was initially detected in the flight deck, the third cabin attendant reported through the interphone system to the flight deck that a passenger had seen smoke emanating from the left wing. The commander replied that he had shut off the left [#1] engine and was going to land the airplane.

As engine #1 had been shut off, it also shut off the left air conditioning pack[10], which receives bleed air from engine #1. The remaining right air conditioning pack could not maintain cabin pressurization and the cabin altitude started to rise[11]. Due to engine #1 shut down, the remaining right air conditionion pack is prevented to automatically go to High Flow mode in order to reduce the amount of bleed air from the operating engine. As a result of this, about 7 minutes after the initial smoke was detected when descending through 20,000 feet altitude, the cabin high altitude alert horn activated. The first officer noticed that the airplane's actual altitude was also descending rapidly and determined that the cabin's oxygen masks did not need to be deployed. Four minutes later the cabin high altitude alert horn stopped as the airplane had descended through 10,000 feet.

About eleven minutes after the initial smoke was detected, the smoke in the flight deck had reduced to such an extent that the flight crew removed their oxygen masks.

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[9] London Gatwick airport (EGKK)
[10] Air conditioning packs are used to supply temperature controlled air to the cabin
[11] During flight, cabin altitude is kept much lower than the external altitude

Nineteen minutes after the initial smoke was detected, at 12:15 (UTC), TF-FIJ landed on runway 26L at Gatwick airport and was met by the fire brigade which inspected engine #1 for possible fire.

1.2 Injuries to persons

According to cabin crew attendants, some passengers and cabin crew members had minor eye and respiration problems.

1.3 Damage to aircraft

The low pressure fuel pump, located in the high speed external gearbox module on engine #1, contained internal damage.

1.4 Other damages

None.

1.5 Personnel information

Commander	
Age, sex:	Male, 39 years old
License:	ATPL/A
Medical certificate:	Class 1
Ratings:	SE Piston (Land) B757/B767 – IR Training instructor B757/B767
Experience:	Total all types: 6844 hours Total on type: 4408 hours Last 90 days: 77 hours Last 24 hours: 3 hours
Previous rest period:	Had not slept particularly well the night before, but was reasonably well rested

The commander of the flight also worked as a trainer in the airline's pilot simulator training program. As such he was familiar with the various in-flight incidents set up for flight crew during simulator training, amongst it the flight deck smoke training.

First Officer	
Age, sex:	Male, 32 years old
License:	ATPL/A
Medical certificate:	Class 1
Ratings:	B757/B767 – IR
Experience:	Total all types: 3807 Total on type: 2112 Last 90 days: 3 hours Last 24 hours: 3 hours
Previous rest period:	Had slept well the night before

The first officer had recently undergone flight simulator training, which amongst other things included a flight deck smoke drill.

The cabin crew consisted of the regular four members, plus two trainees who were on their second flight leg after having returned to duty for the company.

In the forward area of the cabin there were also four company flight crew, two commanders and two first officers, returning (deadheading) back to Iceland after their duties abroad.

1.6 Aircraft Information

At the time of the incident, the aircraft had no deferred defects and its Certificate of Airworthiness was valid until July 31st, 2009.

1.7 Meteorological information

Visual Meteorological Conditions.

1.8 Aids to navigation

Five seconds after the flight crew of TF-FIJ requested a diversion to nearest suitable airport, after having declared emergency, ATC advised the flight crew that Gatwick airport was at their 10 o'clock position, at a range of 75 miles.

During the descent to Gatwick airport ATC asked the flight crew if they needed any information on the ILS frequency for runway 26L or the weather. The flight crew requested the frequency and the inbound course for the ILS approach to runway 26L.

1.9 Communications

Communications between the airplane and ATC were kept on a separate frequency from other traffic.

London and Gatwick ATC kept the flight crew of TF-FIJ actively informed and updated with regards to information relating to the descent, approach and landing.

According to the flight crew and the cabin crew, the communications between the flight deck and the cabin during the incident were good. Furthermore, the commander noted that he was very satisfied with the support from ATC during the incident.

1.10 Aerodrome information

Figure 2 and Figure 3 show the layout of London Gatwick (EGKK) airport and highlight runway 26L as well as remote stand 140.

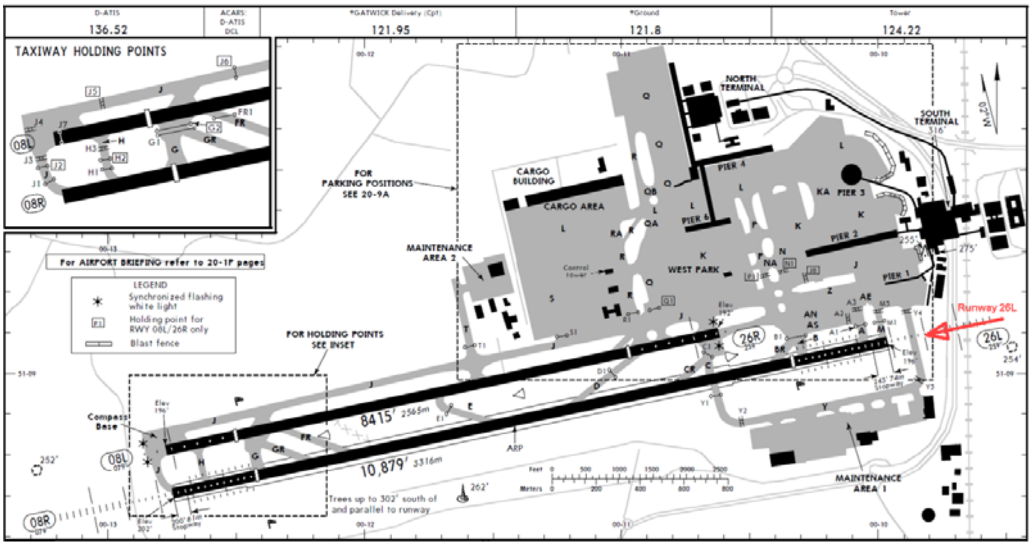

Figure 2 – Overview of London Gatwick airport and runway 26L

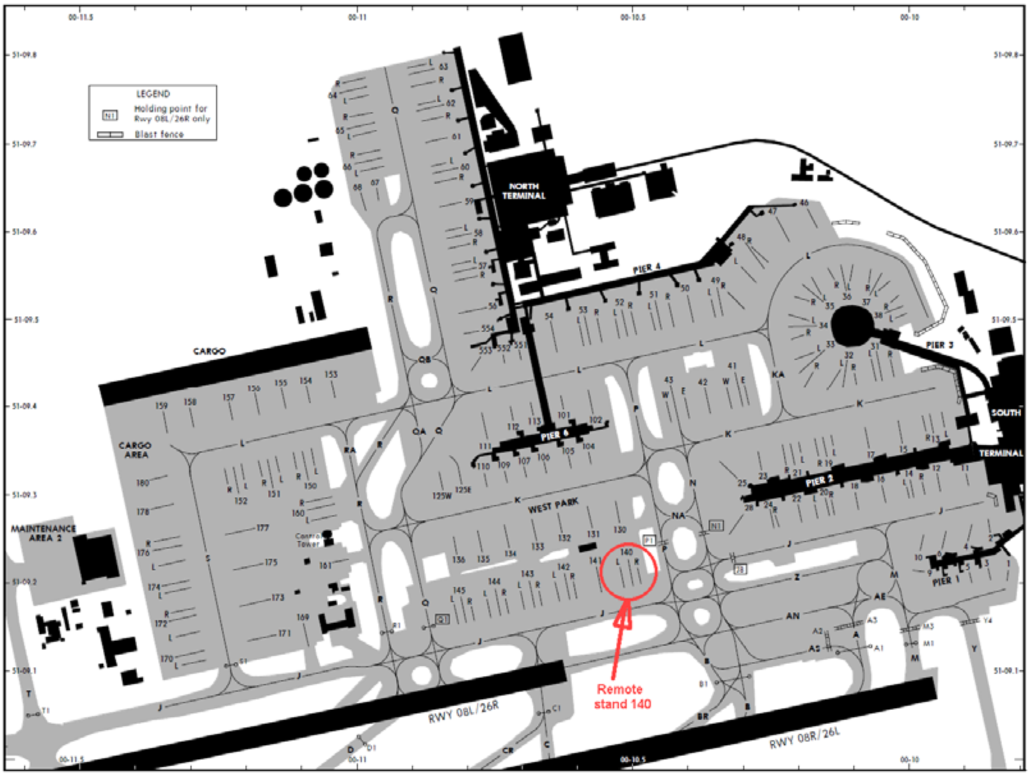

Figure 3 – Location of remote stand 140 at Gatwick airport

1.11 Flight Recorders

The flight data recorder (FDR P/N 980-6022-001 and S/N 3468), the cockpit voice recorder (CVR P/N 980-4700-042 and S/N 6768) and the quick access recorder (QAR P/N 804-0001 and S/N 13245) were all removed from the airplane at the request of the United Kingdom Air Accident Investigation Branch. The FDR and the CVR were downloaded for analysis, while the QAR was not downloaded as it only contained a copy of data on the FDR.

The CVR was difficult to analyse initially as the flight crew was wearing their oxygen masks with built in microphones. The Flight data recorder section of the United Kingdom Air Accident Investigation Branch removed noise from the recording, which allowed the recording to be analysed properly.

The CVR and the FDR recorder provided good information regarding the incident flight. The FDR's parameters were successfully downloaded and were helpful to the investigation. Appendix II provides details of a few of the flight data recorder parameters during the incident flight.

1.12 Wreckage and Impact information

N/A.

1.13 Medical and pathological information

N/A.

1.14 Fire

N/A.

1.15 Survival aspects

The airplane landed on runway 26L. After landing, the airplane cleared the runway and was stopped on a taxiway where the fire brigade inspected the left engine for possible fire.

One minute after landing the fire brigade informed the commander that it had ensured that no fire was present in the area of the left engine. The flight crew then contacted Gatwick Ground Control and requested a clearance to taxi to a stand.

The airplane was cleared by Gatwick Ground to taxi to a stand 140. The flight crew requested, and received, progressive taxi assistance to stand 140.

The fire brigade also followed the airplane to stand 140 and upon request during the taxi, informed the commander that no external damage was evident on the airplane.

During the taxi to stand 140, nine minutes after landing, the commander contacted Gatwick Ground Control and asked if there would be air stairs and buses available at stand 140 to transport the passengers to the terminal.

The aircraft was not evacuated at the stand. Instead the doors were opened to clear the remaining smoke from the cabin. No slides were deployed during the opening of the doors.

Eleven minutes after the commander contacted Gatwick Ground Control and asked if there would be air stairs and buses available at stand 140, and 20 minutes after the emergency landing, the air stairs and buses arrived at stand 130 to pick up the passengers.

According to Gatwick airport Full Emergency Procedure, Part 4, Section F, Paragraph 5, the action required for stand allocation is:

ACTION BY STAND ALLOCATION

5. On receipt of a **'FULL EMERGENCY'** message from the Airfield Operations Controller:

   5.1 Pass the full contents of the message to:

   a) Airfield Duty manager;

   b) Determine the location of the Ground Equipment Assembly Point (GEAP) if required and inform Airfield Operations Controller

   c) Handling Agent (give location of GEAP);

   d) Engineering Duty Manager;

   e) Airfield Operations Manager (who will inform the Head of Airside Operations).

The procedure does therefore ensure that handling agent is given the location of the ground equipment assembly point, which was stand 140 in this case.

According to Gatwick Airport Limited the coaches were assembled on stand 130 and not 140, and their arrival at the stand was prior to the November and Papa taxiway crossing being closed. This decision to hold the buses on stand 130 was made by the airfield duty manager to ensure the passengers were moved away from the aircraft side, quickly. In order to achieve a safe route for the passengers, airside roads were closed and safeguarded by airfield operations, this included closing the taxiway November and Papa crossing. Passengers were directed by airfield operations who had deployed illuminated evacuation signage installed on top of their vehicles.

When the airplane was disembarked, it was done using the doors on the right side of the airplane. This was at the request of the airport's fire brigade, as the incident was believed to be caused by engine #1 on the left side.

1.16 Test and research

During the field investigation, fluid was found leaking onto the apron under engine #1 cowlings. See Figure 4.

Figure 4 – Fluid seen leaking onto the apron under engine #1

The engine cowlings were opened and fluid smelling of fuel was seen leaking from the location of two Magnetic Chip Detector (MCD)[12] plugs on the high speed external gearbox located in the lower part of the engine. When the MCD plugs were removed the leak continued and the MCD plugs were found to contain extensive debris. This can be seen in Figure 5 and Figure 6. The seats for the magnetic chip detectors in the high speed gearbox should be self-sealing.

[12] Magnetic chip detectors, installed in the oil system on the external gearbox module, collect small magnetic metal particles that break loose from engine parts and circulate in the engine's oil during service. This serves as an indication of the wear and tear of the engine and its subcomponents that are serviced by the oil.

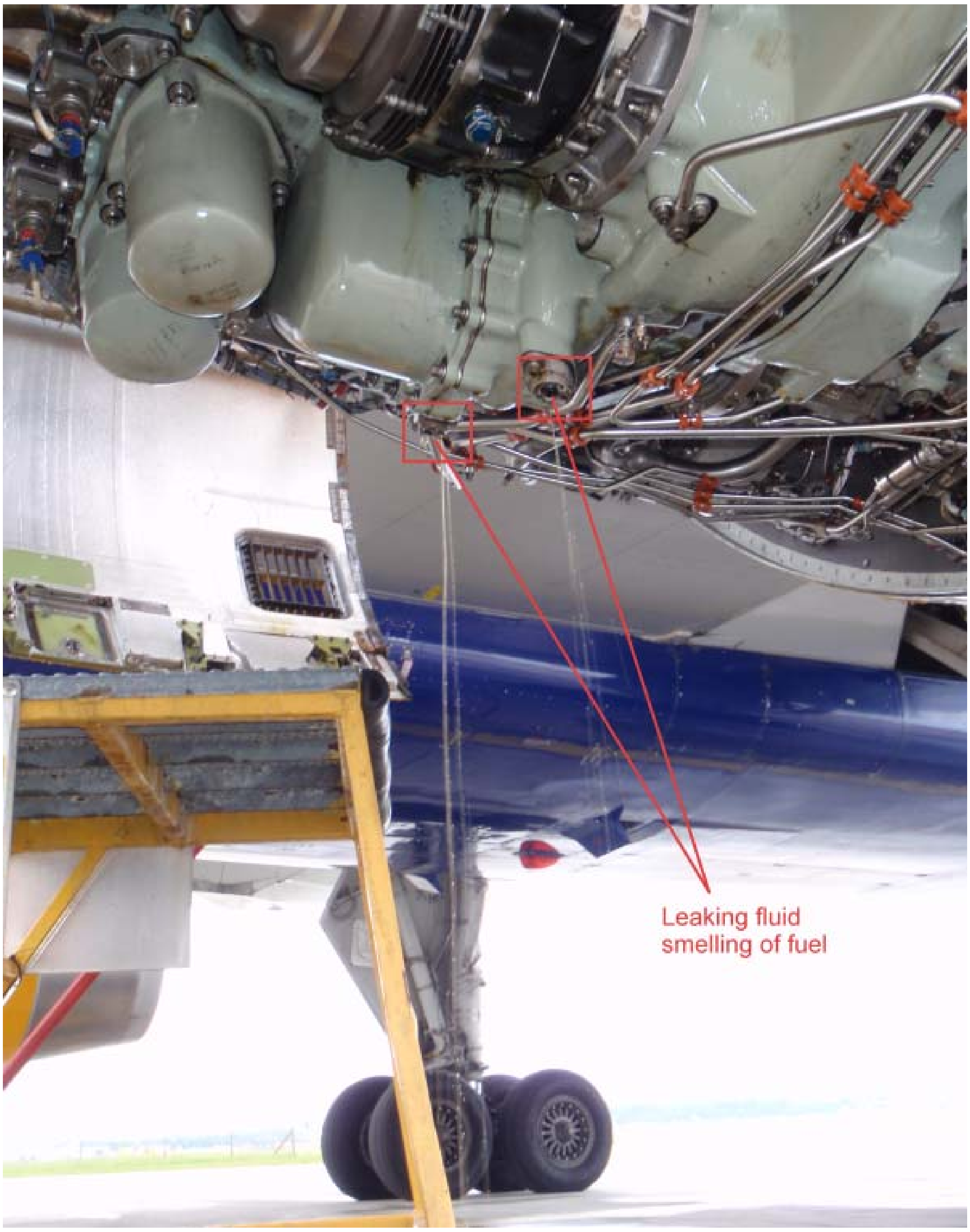

Figure 5 – Fluid leaking from the MCD plug locations on the high speed external gearbox

Figure 6 – Debris found on one of the MCD plugs

The oil reservoir was also checked and it was found to contain fluid that smelled of fuel.

Engine #1, P/N RB211-535E4-37 and S/N 30741, was removed from the airplane and sent to its manufacturer, Rolls-Royce located in the city of Derby in England, where the engine was inspected.

In the flight deck the field investigation revealed the following EICAS messages, as seen in Figure 7:

- R PACK BITE
- L ENG BB VIB
- L ENG VIB BITE
- L ENG SURGE BITE
- OVBD EX VAL OPEN

Figure 7 – EICAS messages

The "R PACK BITE" EICAS indicates that the Right Pack Temperature Controller had a critical controller fault or any LRU fault stored in its last flight fault memory.

EICAS message "L ENG BB VIB", indicated that the left engine incurred broad band engine vibration greater than 2.5 aircraft units for more than nine seconds. EICAS message "L ENG VIB BITE" indicated that the left engine vibration monitor registered a channel fault. EICAS message "L ENG SURGE BITE" indicated that the system had detected a fault with the left engine airflow system or that the left engine surged.

Surge in turbofan engines occurs when the blades in the compressor section of the engine stall as a result of instability of the engine's operation cycle. This is accompanied by a loud bang from the engine, as well as vibration and airplane yaw as a result of dropped engine thrust during the surge.

The last EICAS message, "OVBD EX VAL OPEN", indicates that the overboard exhaust valve was open. When the first officer worked on the "Smoke or Fire or

Fumes" checklist, he turned off the left recirculation fan[13]. As the left recirculation fan was turned off, the equipment cooling system of the B757-200 airplane automatically latched the overboard exhaust valve to the smoke position (partially open)[14] to allow smoke to be vented from the airplane cabin and flight deck.

1.16.1 Engine inspection

At the time of the incident, the engine had accumulated at total of 63,434:40 flight hours and 17,811 flight cycles. It was installed as engine #1 on TF-FIJ in May 2006. In May 2005 the engine underwent repair, where cracked HPT[15] blade was replaced. The last restoration/overhaul of the engine (level 3 performance restoration) was performed in February 2003.

Fuel/oil combination was found everywhere in the oil system of the engine, where only oil should have been found. In the engine oil tank, samples of the fluid analysed by Rolls-Royce laboratory showed the fluid containing 70% fuel and 30% oil mixture.

1.16.2 High speed external gearbox

The high speed external gearbox had been removed from another airplane and installed on TF-FIJ in September 2008, due to debris found on both the magnetic chip detectors and inside the gearbox it replaced (S/N DM4354). The high speed external gearbox replacement was performed shortly before the airplane entered C-check[16].

During teardown of the S/N DM4354 high speed gearbox at Rolls-Royce in October 2008, no obvious findings were located inside the gearbox which could explain the debris found on the magnetic chip detectors. Icelandair Engineering had therefore requested that the magnetic chip detectors on the engine as well as its radial drive shaft be inspected at first opportunity to check if the debris material was coming from other parts of the engine.

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[13] Item #8 on page 8.12 in the Boeing 757 flight Crew Operation Manual in Appendix I
[14] Boeing 757 Flight Crew Operations Manual D632N001-29ICE(ICE), page 2.20.3
[15] High Pressure Turbine
[16] C-check inspection is a periodic heavy inspection on aircraft to be repeated after certain time or useage (often every 18-24 months) based on the aircraft's maintenance program

During C-check in late October 2008 the magnetic chip detectors were re-inspected and found to have minor debris on them, although within the Rolls-Royce limits As a result of this the radial drive shaft in the high speed external gearbox installed on engine #1 was inspected by Mexicana during C-check in late October 2008. No indication was found of wear on the radial drive shaft.

Several subcomponents installed on the high speed external gearbox, were also inspected as part of the investigation. See Figure 8.

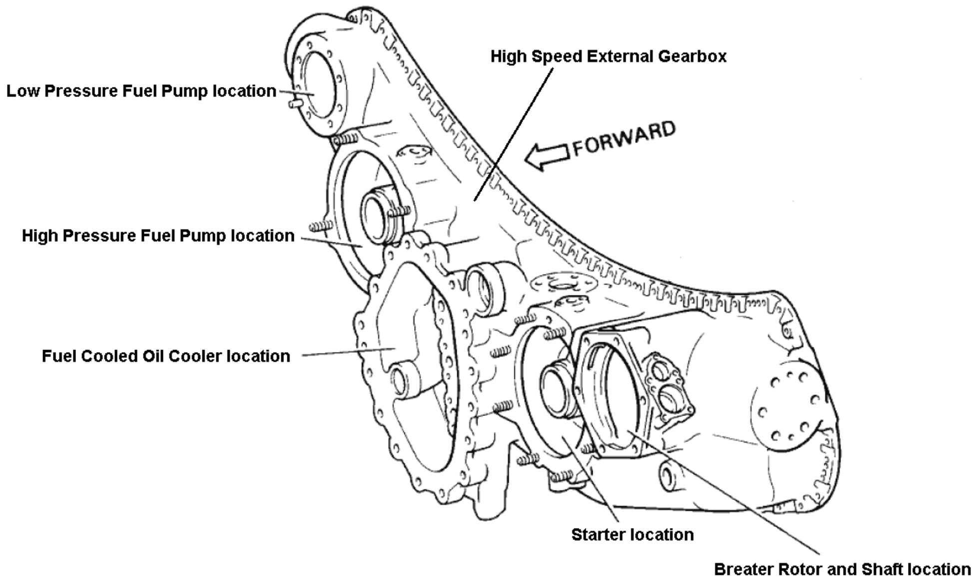


Figure 8 – The high speed external gearbox and the locations and its subcomponents

1.16.3 Fuel cooled oil cooler

The fuel cooled oil cooler (FCOC), P/N 45731-1262 of S/N FC23100, was sent to its manufacturer, Serck Aviation in Birmingham, for leak test. It passed the leak test, but fuel/oil mixture was found in its oil system. The fuel cooled oil cooler was flushed and it was then determined to be serviceable.

The fuel cooled oil cooler (S/N FC23100), had undergone an overhaul by Serck Aviation in July 2008. It was installed onto engine #1 on TF-FIJ in December 2008, to remove and return a loan unit (S/N FC23105) which had been installed onto the airplane during C-check in November 2008. The S/N FC23105 loan unit had been installed during the C-check to replace a previously installed FCOC unit (S/N FC23225). This unit had been removed from TF-FIJ as it was believed to be the cause of smoke coming from the high speed gearbox breather during two engine runs performed as part of the C-check.

1.16.4 High pressure fuel pump

The high pressure (HP) fuel pump, P/N GP202MK1 of S/N B296, was sent to Goodrich, for inspection. It was manufactured by Aero Engine Controls. It passed leak test and was determined to be serviceable.

1.16.5 Magnetic chip detectors

The magnetic chip detectors were removed and analysed by Rolls-Royce laboratory. The debris found on the MCDs consisted of large thin strands of debris, up to 10 mm long. The laboratory had difficulty identifying some of the material types found due to the percentage of alloy elements. According to the laboratory, the material found that could be identified on the MCDs was likely from a locking nut, a stepped sleeve, a carbon face seal and from a cup washer.

The last inspection of the magnetic chip detectors on engine #1 on Icelandair B757-200 TF-FIJ, prior to the incident, was accomplished on April 30th 2009.

1.16.6 Low pressure fuel pump

The low pressure (LP) fuel pump, P/N BPU200MK2 of S/N B1167, was sent to its manufacturer, Goodrich in Birmingham, for teardown. The low pressure fuel pump was found to have internal damage as seen in Figure 9.

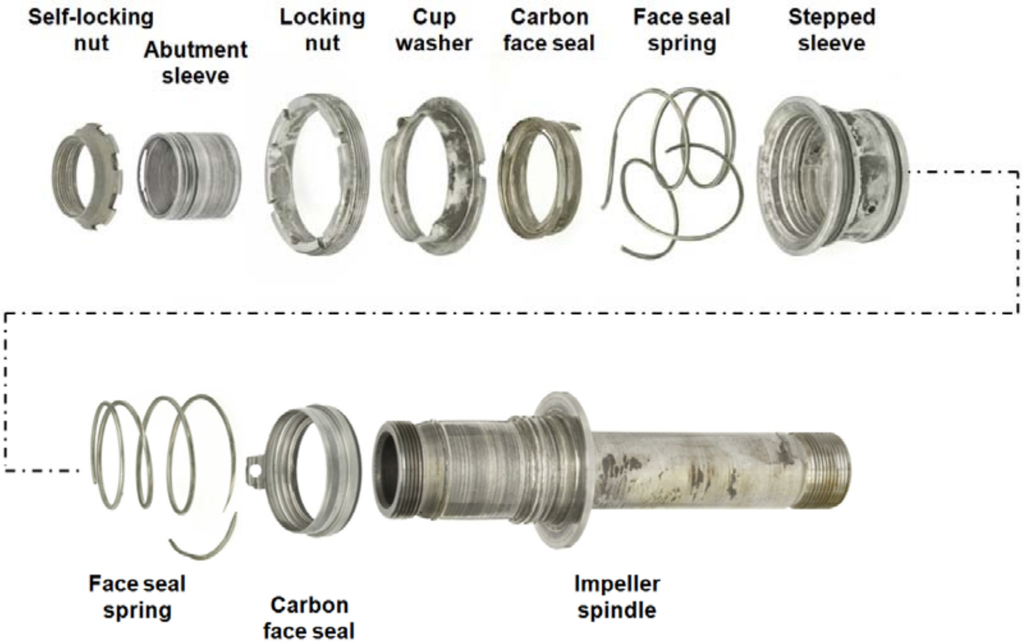


Figure 9 – Internal damage of the low pressure fuel pump

Inside the low pressure fuel pump, the self-locking nut, abutment sleeve, cup washer, carbon face seals, face seal springs, stepped sleeve and retaining pin were all found to be damaged. It is likely that the debris which was identified on the magnetic chip detectors came from these parts. In addition, 15 cm long blockage of carbonaceous material was discovered in the fuel drain tube for the low pressure fuel pump. See Figure 10 for details on the internal parts of the low pressure fuel pump.

The teardown analysis of the low pressure fuel pump at the manufacturer indicated that the failure was initiated with the breakup of the carbon seal insert in the seal assembly between the low pressure fuel pump and the high speed gearbox.

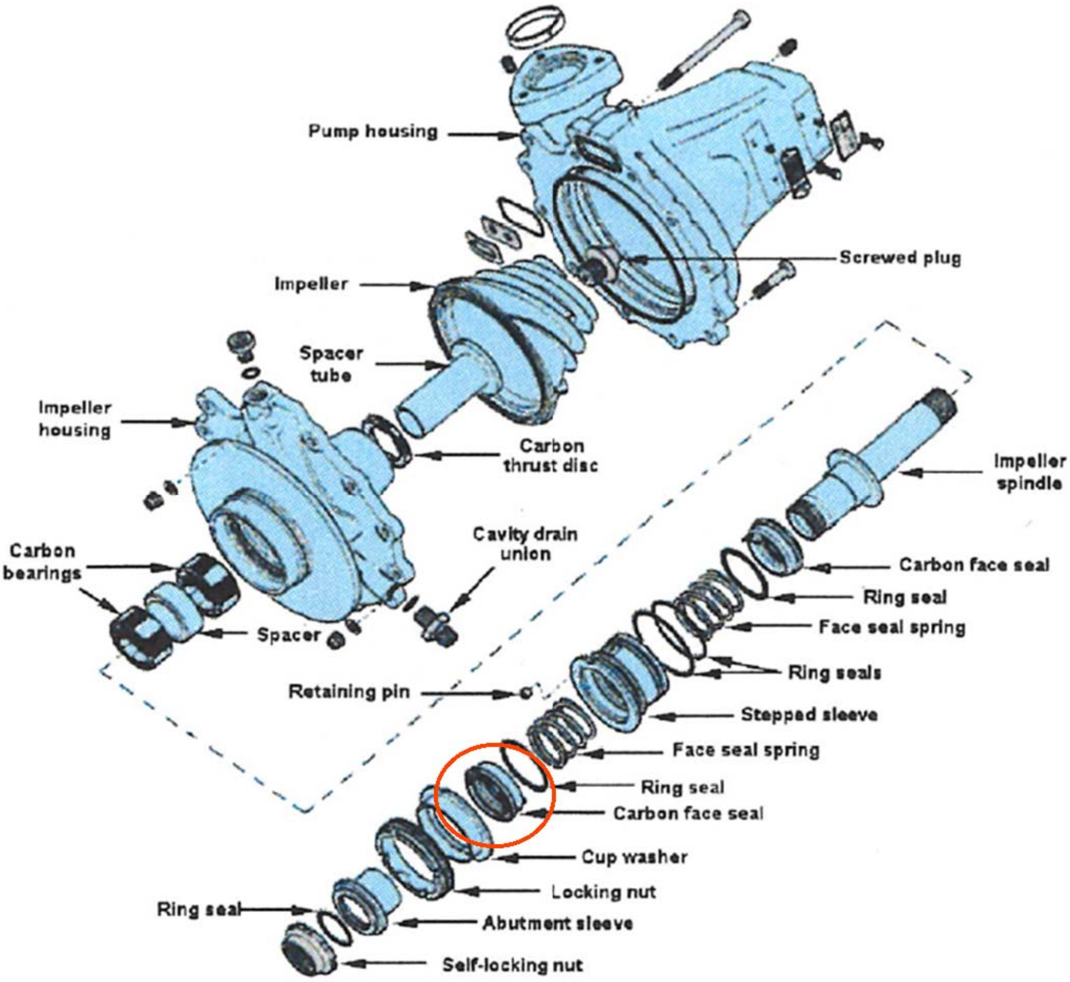


Figure 10 – Component setup of the low pressure fuel pump (primary damage in red circle)

1.17 Organizational and management information

Not applicable to this incident.

1.18 Additional information

Not applicable.

1.19 Useful or effective investigation technique

Not applicable.

2 Analysis

2.1 Flight operation

The flight was a scheduled passenger flight between Charles de Gaulle airport (LFPG) in Paris, France, and Keflavik airport (BIKF) in Iceland. Nothing was found with regards to flight operation of the airplane during this flight that could have led to this incident.

According to the commander he had incurred an engine surge the previous winter and immediately recognized the abnormalities as such. The commander's awareness and quick problem recognition regarding engine #1 surging as its EGT rose above normal, under very poor visual conditions in the flight deck due to the smoke, and his response to immediately shut down engine #1, avoided the situation where visibility would have been completely lost in the flight deck and in the cabin. Due to the sudden appearance and thickness of smoke in the flight deck, the opportunity to follow the emergency procedures in details was difficult.

During the incident, when the auto-throttle disengaged as engine #1 (left engine) was shut down, the airplane started to bank/roll and yaw. Output from the flight data recorder shows the initial bank to be 12° to the left. At the same time, and for the first two and half minute after the engine shutdown, the flight data recorder showed left rudder displacement varying between 0°and 3°. See Appendix II for details. Further analysis of the flight data recorder verified the left rudder pedal being applied during this period.

After the engine shutdown the rudder was being applied in the wrong direction. This could explain why the airplane's autopilot had difficulty controlling the airplane as it started to bank/roll and yaw. According to the commanders description the intensity of the smoke and difficulties in seeing the instruments caused this initial reaction.

2.2 Crew qualification

At the time of the incident the commander also worked at the airline as a trainer for pilot's simulator training. He was therefore very familiar with the simulator smoke drill training. The first officer was only on his second flight leg after having returned to flight duty for the airline. A few days earlier he had undergone smoke drill training in a simulator.

The smoke drill consists of flying in the flight simulator while wearing scraped smoke goggles, which hinder visibility. In the past smoke had been used during flight simulator training at the airline, but that had been stopped. Generally, smoke is not used in flight simulator training today due to health reasons.

According to the pilots, the scraped goggles used during training did not duplicate the effects of the real smoke, nor did they project how rapid and intense the real smoke felt in the flight deck during the incident.

2.3 Operational procedures

During the incident the first officer worked on the “Smoke or Fire or Fumes” checklist. According to him this checklist, which was four pages long, proved to be too long with respect to how rapidly the smoke accumulated in the flight deck. The first officer only managed to finish the first two pages of it.

During the approach to Gatwick airport, the commander assessed the gravity of the situation to be such (suspected fire) that they decided not to delay the landing by reading the “Engine Failure or Shutdown” checklist.

According to the operator’s Cabin Crew Manual, the cabin attendants should use PBE if smoke and/or fumes make breathing difficult[17].

2.4 Air traffic control

The flight crew of TF-FIJ was very satisfied with the service they received from ATC.

2.5 Communication

Communications between the airplane and ATC were kept on a separate frequency from other traffic. This helped the flight crew immensely with concentrating on the task at hand of landing the airplane safely.

[17] Icelandair Cabin Crew Manual Vol. II, Revision 2, Chapter 3.5.6

The London and Gatwick ATCs were also proactive in feeding information to the flight crew during the descent to Gatwick airport. This reduced the work load of the flight crew.

2.6 Aerodrome

The fire brigade response was quick and they had ensured that there was no fire in the area of the left engine within one minute after touchdown.

The handling agent were informed of the emergency by Gatwick Control Centre at 12.15 UTC. During the taxiing to the stand, nine minutes after landing at 12.24 UTC the commander contacts Gatwick Ground Control and asked if there would be airstairs and buses available at stand 140. Aircraft was still taxiing to the stand at this point, it then arrived at the stand and parks on 140. Coordination between the airfield operations team and the airport fire service would then have taken place on stand 140 before permitting any service personnel or equipment to approach the aircraft. The passengers begin to disembark at 12.35 UTC and walk to the buses positioned on stand 130.

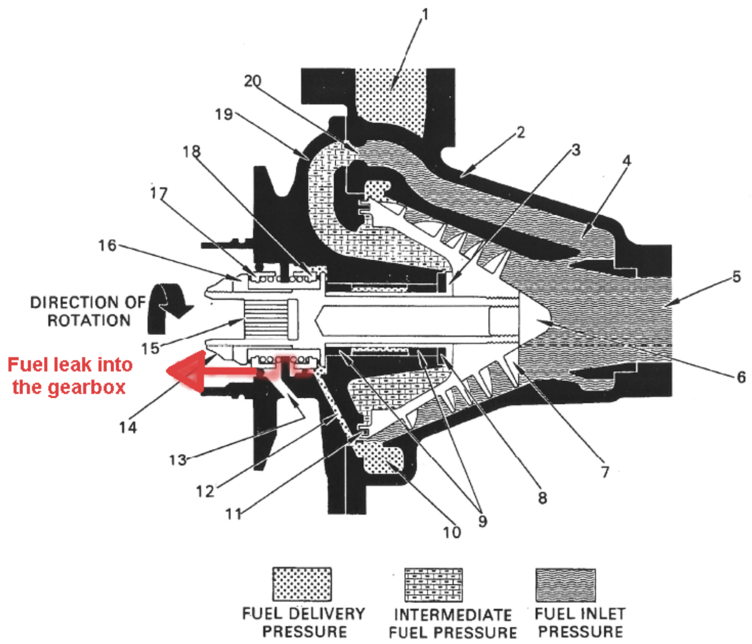
2.7 Aircraft maintenance

The investigation and the analysis of the low pressure fuel pump revealed several discrepancies with regards to maintenance.

2.7.1 Low pressure fuel pump

The fuel drain for the low pressure fuel pump could have provided a “tell-tale” sign of impending failure of the fuel pump seal. As the fuel drain tube was blocked, no such indication could be noted. It was not possible to establish at what time the fuel drain tube became blocked. Inspection of and cleaning of the drain tube was to be accomplished as part of the low pressure fuel pump shop visit. Similar drains are also installed on the high pressure fuel pump, the starter motor, the fuel flow governor, the hydraulic pump and the integrated drive generator (IDG) on the RB211-535E4 engine.

The analysis of the low pressure fuel pump indicated that the failure initiated with the breakup of the carbon seal insert in the seal assembly between the low pressure fuel pump and the high speed gearbox. It is believed that this lead to metal-to-metal contact between the seal body and the abutment sleeve, which then due to increased friction caused torsion loading that generated rotation of the spring and the seal body. It is also believed that this lead to heavy wear in the area until the seal spring had turned to such an extent that the abutment shoulder in the stepped sleeve was passed. This caused the preload in the seal spring and the carbon seal assembly to be released, which resulted in a fuel leak into the seal cavity. As the fuel drain tube was blocked, the fuel passed from the cavity and into the high speed gearbox, contaminating the engine oil system. See Figure 11 for details.



1. FUEL OUTLET PORT
2. PUMP HOUSING ASSEMBLY
3. FLANGED SPACER TUBE
4. RETURN TO INLET PASSAGE
5. FUEL INLET PORT
6. SCREWED PLUG
7. IMPELLER
8. THRUST DISC (CARBON)
9. JOURNAL BEARINGS (CARBON)
10. PUMP OUTLET VOLUTE
11. LABYRINTH SEAL
12. BEARING LUBRICATING PASSAGE
13. SEAL DRAIN PORT
14. SELF LOCK RING NUT
15. IMPELLER SPINDLE
16. ABUTMENT SLEEVE
17. CARBON FACE SEAL ASSEMBLY (OIL SEAL)
18. CARBON FACE SEAL ASSEMBLY (FUEL SEAL)
19. IMPELLER DRIVE HOUSING ASSEMBLY
20. RESTRICTOR PLATE

Figure 11 – Cross section view of the low pressure fuel pump and the leak path into the gearbox

According to Rolls-Royce this incident was the fourth incident where this type of pump wear and failure incurred.

2.7.2 Prior indications of internal wear damage

In September 2008 debris was located on the magnetic chip detectors and inside the high speed external gearbox on engine #1. This resulted in a replacement of the high speed external gearbox with removal of S/N DM4354 and installation of S/N DM4698. During teardown of the S/N DM4354 high speed gearbox at Rolls-Royce in October 2008, no obvious findings were located inside the gearbox which could explain the debris found on the magnetic chip detectors.

In late October 2008 during C-check the magnetic chip detectors were re-inspected and found to have debris on them, although within limits. As a result of this the radial drive shaft in the high speed external gearbox on engine #1 was inspected by Mexicana during C-check in late October 2008. No indication was found of wear on the radial drive shaft. At that time, less than two months had passed since the replacement of the high speed external gearbox, which should have been an indication that the problem of internal wear damage of a component in the engine still persisted.

In late November 2008, during the same C-check, two engine runs resulted in smoke coming from the high speed gearbox breather. The fuel cooled oil cooler (S/N FC23225) was replaced as a result of this, as it was believed to be causing the smoke. The fuel cooled oil cooler was sent for maintenance to a 3rd party maintenance shop. This shop did not provide any tear down report of the fuel cooled oil cooler and Icelandair did not request such report to ensure that the engine component that was causing the engine debris had indeed been located and removed.

2.7.3 History of the low pressure fuel pump

Low pressure fuel pump of S/N B1167 was delivered new to Icelandair in January 1998, fitted to engine S/N 31513. It was then removed from engine S/N 31513 and stored serviceable when the engine main gearbox was sent for maintenance in November 2002. At that time the low pressure fuel pump had accumulated 21,181 flight hours and 6129 flight cycles. The low pressure fuel pump was then removed from stock and fitted to engine S/N 30741 and remained there until it failed during the incident on June 4th 2009.

At the time of the incident, low pressure fuel pump S/N B1167 had accumulated 41,443 flight hours and 11,978 flight cycles without undergoing any inspection, repair or overhaul.

2.7.4 Maintenance program

The Icelandair computerized maintenance system, Amicos II, tracked the location, flight hours, flight cycles and calendar days of low pressure fuel pump of S/N B1167.

At the time of the incident, the Icelandair Boeing 757 maintenance program, ICE/757/MP, which is incorporated in the computerized maintenance system, did not include maintenance tasks for engines and engines sub-components. Instead a separate engine maintenance program (EMP) was used by Icelandair based on the Rolls-Royce engine management program, document RM1872.

According to page 34 of the Rolls-Royce engine management program for Boeing 757 airplanes, document RM1872 issue 2, the soft life of the low pressure fuel pump is 12,000 flight hours at any shop visit. It therefore includes repair visits.

This means that if the engine needs to undergo shop visit, then the low pressure fuel pump is to undergo maintenance if it has accumulated 12,000 flight hours since its last maintenance.

The soft life maintenance consists of rig test and refurbishment of the drive seal ends in the case of the low pressure fuel pump having accumulated between 12,000 and 20,000 flight hours. In the case of the low pressure fuel pump having exceeded 20,000 flight hours the Rolls-Royce engine management program RM1872 requires a complete overhaul.

It is therefore apparent from the Rolls-Royce engine management program for Boeing 757 airplanes that the low pressure fuel pump should not have been removed serviceable in November 2002, as a complete overhaul of the pump was already required[18]. Furthermore, during an engine repair in May 2005, a second required maintenance of the low pressure fuel pump was missed according to this program.

At the time of the event there were conflicting maintenance requirements for the low pressure fuel pump from the pump manufacturer and the engine manufacturer. The pump manufacturer and engine manufacturer, both recommended maintenance action at 12,000 flight hours but the pump manufacturer placed stricter requirements than those of the engine manufacturer (pump overhaul at 12,000 hours against inspection and repair at 12,000 hours and an overhaul at 20,000 hours). This situation was rectified in 2008 (and published in 2009) with the pump manufacturer's requirements being incorporated into the engine manufacturer's maintenance plan documentation.

2.8 Aircraft systems

The investigation revealed an aircraft system design weakness, with respect to how the smoke could travel unnoticed and unhindered from the engine and to the flight deck and the cabin.

2.8.1 Fuel/oil mixture path

Once the fuel was in the engine oil system, the fuel contaminated oil travelled from the oil tank to the main bearing chambers of the engine, where it is believed that the main bearings oil seals could not contain the contaminated fuel/oil mixture.

2.8.2 Source of the smoke

Engine pneumatic bleed air comes from two ports located on the engine, the HP2 port[19] and the HP6 port. The ducting connected to the HP2 port has an intermediate pressure check valve installed and the ducting connected to the HP6 valve has a high pressure shutoff valve installed[20].

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[18] 21,181 accumulated hours > 20,000 hours which require an overhaul
[19] High Pressure Port 2
[20] Boeing 757 AMM, chapter 36-00-00, page 5

During high engine power settings, such as during take-off and climbing, the high pressure shutoff valve closes and engine pneumatic bleed air is provided via the HP2 port only.

As the incident occurred when climbing through FL 320, the engine was in high power setting. As a result the bleed air was provided by the HP2 port.

Based on this and the cooling air path of the engine[21], shown in Figure 12, the probable path of the smoke can be backtracked from the HP2 port back to main bearing and/or front bearing seal in the Intermediate Pressure (IP) compressor section of the engine.

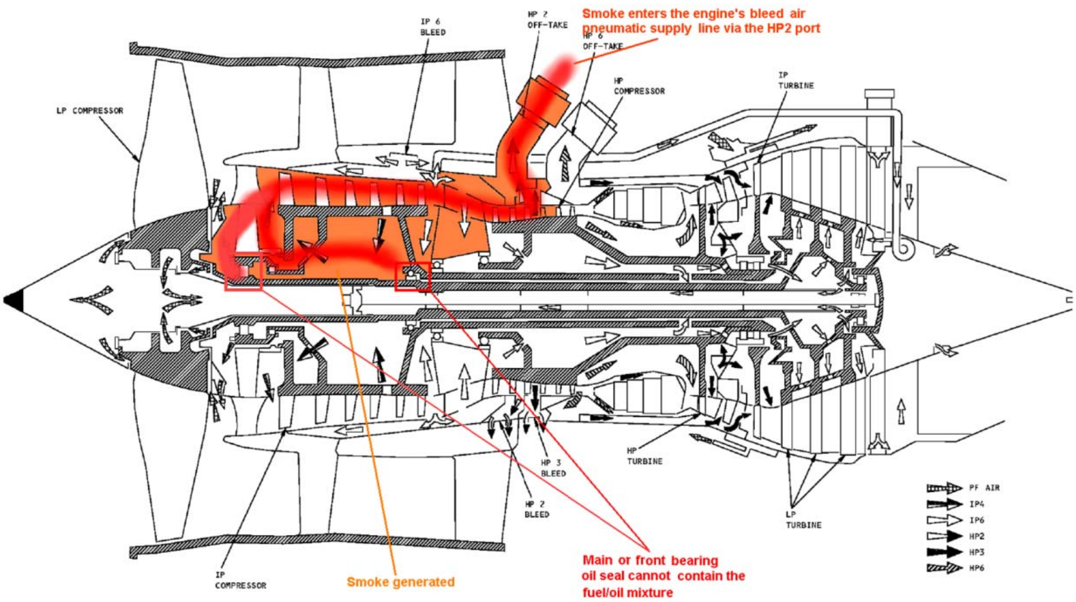

Figure 12 – Smoke propagates to the bleed air valves and enters via the HP2 port

It is therefore believed that the fuel/oil mixture entered the compressor section of the engine as the main bearings and/or front bearing oil seals could not contain the contaminated fuel/oil mixture. Inside the engine's compressor, the fuel/oil mixture generated smoke. From the compressor section of the engine the smoke distributed via the air paths of the engine. Once at the HP2 port, smoke entered the bleed air system of the engine and then propagated to the airplane's left air conditioning pack. See Figure 13 for details.

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[21] Boeing 757 AMM, chapter 72-02-00, page 2

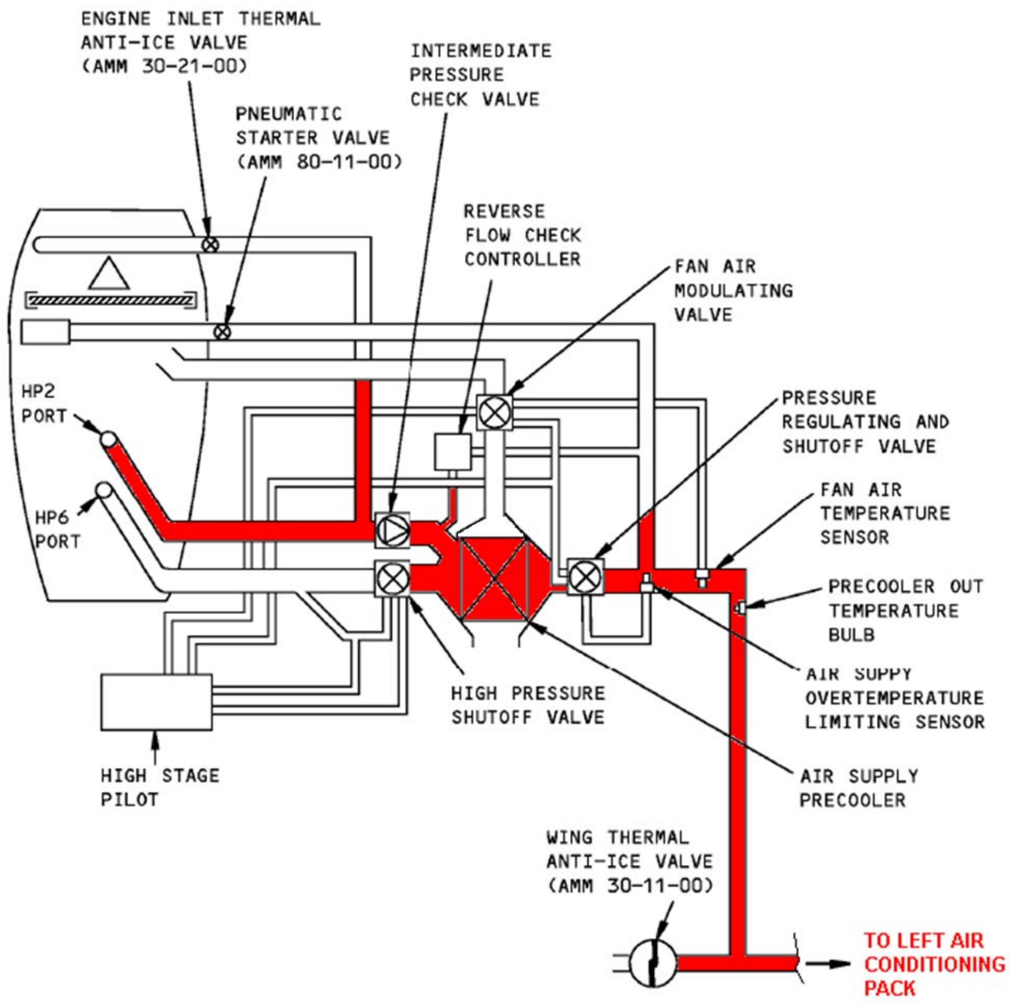

Figure 13 – Smoke propagates from the HP2 port to the left air conditioning pack

2.8.3 Smoke propagation into the air conditioning system

Once in the left engine bleed air pneumatic supply line, the smoke travelled to the left air conditioning pack and then towards the mix manifold.

On the Boeing 757-200 airplane, the cabin is provided with conditioned air from a common mix manifold connected to both the left and the right air conditioning packs.

Under normal conditions, the flight deck is provided with 100% fresh conditioned air from the left air conditioning pack only[22], before it enters the

[22] Boeing 757 Flight Crew Operations Manual D632N001-29ICE(ICE), page 2.20.2

mix manifold[23]. This explains why the smoke entered the flight deck prior to entering the cabin.

When the left air conditioning pack is inoperative the flight deck receives air from the mix manifold. Figure 14 shows this in detail.

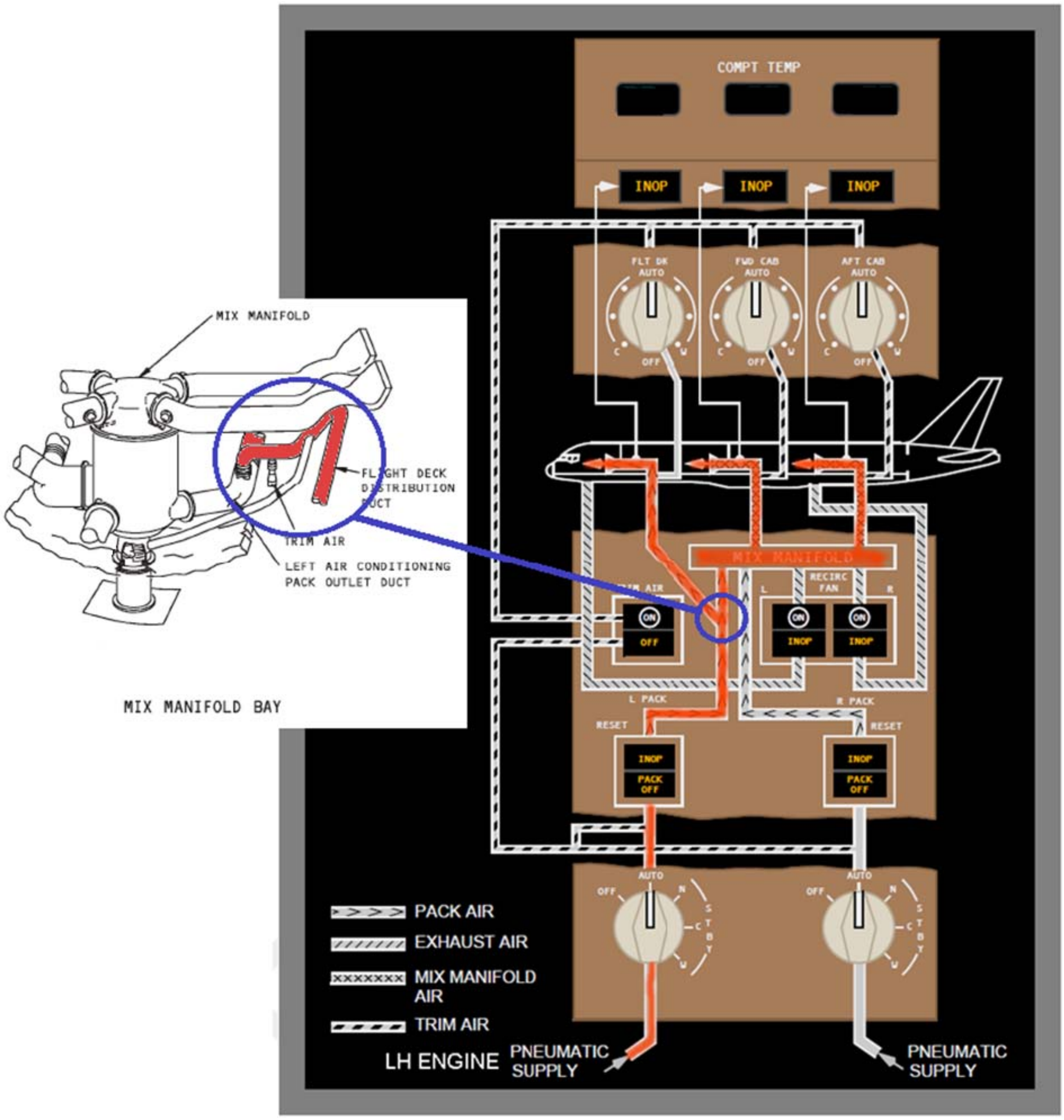

Figure 14 – Smoke travels to the left air conditioning pack and then to the flight deck and cabin

2.9 Aircraft performance

As has been explained previously, surge in turbofan engines occurs when the blades in the compressor section of the engine stall as a result of instability of

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[23] Boeing B757 Airplane Maintenance Manual (AMM), chapter 21-22-00, pages 1-2

the engine‘s operation cycle. It is believed that the three surges that occurred to engine #1 were the result of fuel/oil mixture that entered the engine gas path.

During flight at high altitude, the internal pressure of the aircraft cabin is kept higher than the external pressure outside the aircraft by the use of the air conditioning pack and by keeping the overboard exhaust valve closed. This has the effects of the cabin being at lower altitude than the actual altitude the aircraft is flying at.

According to the aircraft manufacturer, the B757-200 is not capable of maintaining cabin pressure with one air conditioning pack operating, if the overboard exhaust valve is opened to the smoke position and the remaining air conditioning pack is not operating in High flow mode. Since the left engine was commanded off, this prevented the operating air conditioning pack from automatically switching to High flow mode (this is to reduce the bleed air requirements on the remaining operating engine). In addition when the cabin high altitude alert horn sounded during the incident, the right engine (#2) was at idle power as the airplane was descending.

Therefore, the high altitude warning was the result of the right air conditioning pack not being able to maintain sufficient cabin pressure when the overboard exhaust valve automatically latched open, as the left recirculation fan was turned off.

2.10 Flight crew smoke goggles

At the time of the incident, there were two kinds of smoke goggles installed in the B757 fleet of Icelandair. Smoke goggles that were part of the pilot’s oxygen masks and smoke goggles that were separate from the oxygen masks.

Airplane TF-FIJ was at the time of the incident equipped with flight crew smoke goggles that were separate from the pilot’s oxygen masks.

At the time of the incident, the commander looked for his smoke goggles, but could not locate them. An internal investigation conducted by Icelandair revealed that the smoke goggles were often difficult to locate in storage bins beside the flight crew, as they were often buried underneath manuals and handbooks.

2.11 Aircraft instrumentation

The flight crew had difficulty monitoring the flight instruments due to the density of the smoke in the flight deck.

2.12 Actions already taken as a result of this incident

Rolls-Royce issued Notice to Operators #544 on June 30th, 2009. The purpose of this NTO was twofold:

- To advise operators of the incident and the importance of engine sub-component inspections when performing on-wing maintenance on RB211-535 engines.
- To advise operators to monitor the sub-components utilization to ensure their required maintenance is performed.

In addition, Rolls-Royce has update engine management program RM1872 to ensure the sufficient and proper inspections and cleaning off all engine subcomponent's drain tubes during in-service and scheduled aircraft maintenance.

Icelandair internal investigation into this incident has resulted in the following company safety recommendations:

- Safety Recommendation 01-2009
  Icelandair should check history of all LP Fuel Pumps and take appropriate action if they have excessively exceeded the optimum life TSN or TNO. This check should be completed no later than 30 November 2009.

- Safety Recommendation 02-2009

  Icelandair should implement a procedure that ensures compliance with CMP 040 recommended work packages following line maintenance removals of BPU 200 LP Fuel Pumps. Procedures should also be implemented to ensure compliance of other accessory units of the Rolls-Royce Engine Management Program.

- Safety Recommendation 01-2011

  Icelandair should review its current smoke and fire training where emphasis is placed on how quickly smoke may appear and intensify.

- Safety Recommendation 02-2011

  Icelandair should include in its maintenance program the requirement to periodically check the general condition of the smoke goggles.

- Safety Recommendation 03-2011

  Icelandair should equip aircraft that do not have smoke goggles attached to the quick-donning oxygen masks with designated storage boxes or brackets. Where the goggles can be easily accessed and are provided with sufficient damage protection.

- Safety Recommendation 04-2011

  Icelandair should install designated placards on aircraft that have smoke goggles attached to the quick-donning oxygen masks in order for pilots to positively distinguish them from the aircraft that do not have smoke goggles attached.

Icelandair Technical Services has added to its maintenance program an inspection of the fuel drain tube of the low pressure fuel pump, due at every C-check. The purpose of this inspection is to prevent dirt build-up in the fuel drain tube.

Icelandair made a modification to the storing compartments located at the outboard side of the pilots where an inner box was made for the quick reference handbook and the route manuals, leaving separate space for the smoke goggles.

3 Conclusion

There are numerous findings. Most of the findings are traced to the low pressure fuel pump installed on engine #1 at the time of the incident. There are also several findings with respect to the crew response during the incident, emergency equipment location and its use, as well as to the pilot's smoke simulator training.

3.1 Findings

- ★ The operator's engine maintenance program had an omission, where the low pressure fuel pump did not have a task assigned to it, requiring soft life maintenance when the engine was removed for shop visit.
- ★ The low pressure fuel pump installed on engine #1 had never undergone its recommended maintenance.
- Metal debris was found on chip detectors, but its origin was not identified.
- ★ The low pressure fuel pump installed on engine #1 failed due to internal wear.
- Fuel leaked from the low pressure fuel pump and into the oil system of engine #1.
- The fuel/oil mixture in the oil system could not be contained by the seals in the main bearing chambers of engine #1.
- The fuel/oil mixture entered the compressor gas path of engine #1, where it generated smoke.
- The smoke entered the bleed air system at the HP2 port.
- The smoke travelled to the left air conditioning system from engine #1.
- Aircraft system design weakness was revealed, as smoke could travel unnoticed and unhindered from the engine and to the flight deck.
- The smoke entered the flight deck and the cabin from the air conditioning system.
- The smoke filled up the flight deck rapidly and hindered the visibility to the flight instruments.
- Emergency (MAYDAY) was declared due to smoke entering the flight deck and the cabin.
- The flight crew donned their oxygen masks.
- The first officer donned his smoke goggles.
- The commander could not locate his smoke goggles.
- The smoke goggles were in a compartment shared with items such as manuals and handbooks.

- None of the cabin crew members donned Protective Breathing Equipment.
- Engine #1 surged three times.
- Following the surge of engine #1 the commander shut it down.
- Incorrect rudder was applied by the commander during the first moments after engine #1 was shut down, resulting in difficulty controlling the airplane. According to the commander the intensity of the smoke and difficulties in seeing the instruments contributed to these initial reactions.
- According to the first officer, the “Smoke or Fire or Fumes” checklist was too long for this type of incident.
- The right air conditioning pack could not maintain the required cabin pressure as the overboard exhaust valve automatically latched open when the left recirculation fan was turned off as part of the “Smoke or Fire or Fumes” checklist.
- Diversion was made to London Gatwick airport.
- During the approach to Gatwick airport, the flight crew did not carry out the “Engine Failure or Shutdown” checklist.
- According to the flight crew, the operator’s simulator smoke drill training did not duplicate the rapid influx of smoke into the flight deck, as was the case during the incident.
- According to the flight crew, the operator’s simulator smoke drill training did not duplicate the effects of the real smoke by using scraped goggles.

3.2 Causes

- The operator’s engine maintenance program had an omission, where the low pressure fuel pump did not have a task assigned to it, requiring soft life maintenance when the engine was removed for shop visit.
- The low pressure fuel pump installed on engine #1 had never undergone its recommended maintenance.
- The low pressure fuel pump installed on engine #1 failed due to internal wear.

4 Safety Recommendations

Icelandair:

- Review engine's sub-component maintenance manuals and instructions to ensure that their recommended maintenance is incorporated into the Icelandair maintenance program.

- Extend as required the recently added inspection of the fuel drain tube of the low pressure fuel pump, due at every C-check, to similar drains installed on the high pressure fuel pump, the starter motor, the fuel flow governor, the hydraulic pump and the integrated drive generator on the RB211-535E4 engines.

- Review the pilots' simulator smoke drill training to include rapid influx of smoke into the flight deck and the possibility of performing the smoke drill training with oxygen masks as well as goggles donned, under actual smoke condition.

Boeing:

Due to the fact that the flight deck filled up with smoke almost instantaneously, with reduced visibility to flight instruments, investigate the possibility of installing smoke warning system in the bleed air ducting of the Boeing 757-200 airplane, to allow the flight crew to take preventive action prior to smoke propagating into the flight deck.

ICAA:

Sample operators for maintenance of engine's subcomponents, as recommended by the subcomponents manufacturers, which are not included in the type certificate holder´s maintenance program.

EASA and ICAO:

Set guiding rule for airframe and engine manufacturers such that Maintenance Planning Document (MPD) and Engine Maintenance Manual (EMM) clearly include recommended maintenance information from subcomponent Component Maintenance Manuals (CMM).

5 Appendix I

Smoke or Fire or Fumes

Condition: Smoke, fire or fumes is identified.

1 Diversion may be needed.

2 Don oxygen masks, as needed.

TF-FII, TF-FIJ, TF-FIN, TF-FIO, TF-FIP, TF-FIV, VP-BFI

3 Don smoke goggles, as needed.

4 Establish crew and cabin communications.

5 Advise the cabin crew to turn off main IFE power switches.

6 Advise cabin crew that main cabin lighting will be turned off.

7 UTILITY BUS switches (both) . . . . Off

8 L RECIRC FAN . . . . Off

9 APU BLEED AIR switch . . . . Off

10 **Anytime** the smoke or fumes becomes the greatest threat:

▶▶Go to the Smoke or Fumes Removal checklist on page 8.26

▼ Continued on next page ▼

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▼ Smoke or Fire or Fumes continued ▼

11 Choose one:

◆Source of the smoke, fire or fumes is both **obvious and** can be **extinguished quickly**:

Isolate and extinguish the source.

If possible remove power from the affected equipment by switch or circuit breaker in the flight deck or cabin.

►►**Go to step 12**

◆Source of the smoke, fire or fumes is **not obvious or cannot be extinguished quickly**:

►►**Go to step 13**

12 Choose one:

◆Source is visually **confirmed** to be extinguished **and** smoke or fumes are **decreasing**:

Continue flight at the Captain's discretion.

Restore unpowered items at the Captain's discretion.

►►**Go to the Smoke or Fumes Removal checklist on page 8.26 if needed**

■ ■ ■ ■

◆Source is visually **not confirmed** to be extinguished **or** smoke or fumes are **not decreasing**:

►►**Go to step 13**

13 EQUIP COOLING switch . . . . ALTN

▼ Continued on next page ▼

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▼ Smoke or Fire or Fumes continued ▼

14 Initiate a diversion to the nearest suitable airport while continuing the checklist.

15 Consider an immediate landing if the smoke, fire or fumes situation becomes uncontrollable.

16 Do **not** delay landing in an attempt to complete all of the following steps.

17 ISOLATION switch . . . . .Off

18 R PACK control selector . . . . OFF

19 **Wait** 2 minutes unless the smoke or fumes are increasing.

20 Choose one:

◆Smoke or fumes do **not continue** or are **not increasing**:

►►**Go to step 27**

◆Smoke or fumes **continue** or are **increasing**:

►►**Go to step 21**

21 R PACK control selector . . . . AUTO

22 L PACK control selector . . . . OFF

23 **Wait** 2 minutes unless the smoke or fumes are increasing.

▼ Continued on next page ▼

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▼ Smoke or Fire or Fumes continued ▼

24 Choose one:

◆Smoke or fumes do **not continue** or are **not increasing**:

►►**Go to step 27**

◆Smoke or fumes **continue** or are **increasing**:

►►**Go to step 25**

25 L PACK control selector . . . . AUTO

26 Consider an immediate landing.

27 **If** needed:

►►**Go to the Smoke or Fumes Removal checklist on page 8.26**

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

UTILITY BUS OFF

PACK OFF

RECIRCULATION FAN

■ ■ ■ ■

APU BTL DISCH

APU BOTTLE

Message: APU BTL

Condition: The fire bottle pressure is low.

■ ■ ■ ■

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6 Appendix II