Air Accident Investigation Unit Ireland

SYNOPTIC REPORT

SERIOUS INCIDENT
Boeing 737-8AS, EI-EFB
Near Stansted, United Kingdom
18 September 2014

An Roinn Iompair
Turasóireachta agus Spóirt
Department of Transport,
Tourism and Sport

Foreword

This safety investigation is exclusively of a technical nature and the Final Report reflects the determination of the AAIU regarding the circumstances of this occurrence and its probable causes.

In accordance with the provisions of Annex 13[1] to the Convention on International Civil Aviation, Regulation (EU) No 996/2010[2] and Statutory Instrument No. 460 of 2009[3], safety investigations are in no case concerned with apportioning blame or liability. They are independent of, separate from and without prejudice to any judicial or administrative proceedings to apportion blame or liability. The sole objective of this safety investigation and Final Report is the prevention of accidents and incidents.

Accordingly, it is inappropriate that AAIU Reports should be used to assign fault or blame or determine liability, since neither the safety investigation nor the reporting process has been undertaken for that purpose.

[1] **Annex 13**: International Civil Aviation Organization (ICAO), Annex 13, Aircraft Accident and Incident Investigation.
[2] **Regulation (EU) No 996/2010** of the European Parliament and of the Council of 20 October 2010 on the investigation and prevention of accidents and incidents in civil aviation.
[3] **Statutory Instrument (SI) No. 460 of 2009**: Air Navigation (Notification and Investigation of Accidents, Serious Incidents and Incidents) Regulations 2009.

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In accordance with Annex 13 to the Convention on International Civil Aviation, Regulation (EU) No. 996/2010 and the provisions of SI 460 of 2009, the Chief Inspector of Air Accidents, on 19 September 2014, appointed Mr John Owens as the Investigator-in-Charge to carry out an Investigation into this Serious Incident and prepare a Report.

Aircraft Type and Registration:	Boeing 737-8AS, EI-EFB
Number and Type of Engines:	2 x CFM 56-7B
Aircraft Serial Number:	37532
Year of Manufacture:	2009
Date / Time (UTC):[4]	18 September 2014 @ 19.52 hrs
Location:	Near Stansted, United Kingdom
Type of Operation:	Commercial Air Transport, Scheduled Passenger
Persons on Board:	Crew - 6 Passengers - 174
Injuries:	Crew - Nil Passengers - Nil
Nature of Damage:	Nil
Commander's Licence:	Airline Transport Pilot Licence (ATPL) Aeroplanes issued by the Irish Aviation Authority (IAA)
Commander's Details:	Male, aged 26 years
Commander's Flying Experience:	3,250 hours of which 3,100 were on type
Notification Source:	Mandatory Occurrence Report from the Operator
Information Source:	AAIU Report Form submitted by the Pilot, Correspondence with the Operator

[4] **UTC**: Co-ordinated Universal Time (to obtain local time, add one hour).

SYNOPSIS

The aircraft was on a scheduled passenger flight from Almeria (LEAM), Spain, to Stansted (EGSS), United Kingdom. During the descent, at approximately 20,000 feet, the aircraft Commander became aware of an unusual smell in the cockpit. The Flight Crew donned their oxygen masks and declared a Mayday. Air Traffic Control facilitated an expeditious approach to EGSS, where a normal landing was performed. Throughout the event, there were no reports of unusual smells in the aircraft cabin.

NOTIFICATION

The Operator submitted a Mandatory Occurrence Report (MOR) which was notified by the AAIU to the UK Air Accidents Investigation Branch (AAIB). The AAIB delegated the Investigation to Ireland as the State of Registry.

1. FACTUAL INFORMATION

1.1 History of Flight

Earlier on the day of the incident flight, the aircraft operated Frankfurt-Hahn (EDFH)-EGSS-Bologna (LIPE)-EGSS with no defects reported in the aircraft technical log book.

A different Flight Crew then operated the aircraft from EGSS to LEAM. The Commander advised the Investigation that while operating the EGSS-LEAM sector, he reviewed the technical log book history in detail, and noticed multiple reports of fumes in the flight deck during the descent phase of flight. He said the Flight Crew reviewed the aircraft Quick Reference Handbook (QRH) and that he discussed with the First Officer (FO), the actions that would be required if fumes were noticed during their flight. The Commander, who was the Pilot Flying (PF), also discussed the technical log book history with the Senior Cabin Crew Member (SCCM - also referred to as the No. 1), highlighting, as he understood, that no fumes were reported in the aircraft cabin. The Commander stated that he requested the No. 1 to immediately report if any unusual smells were noticed during the flight to LEAM. Nothing unusual was reported on the flight.

The aircraft departed from LEAM at 19.55 hrs for the return sector to EGSS, with the FO operating as the PF and the Commander operating as the Pilot Monitoring (PM). The Commander said that he advised the FO to immediately report if he noticed any fumes or unusual smells.

While descending through approximately 20,000 feet, under the instructions of London Air Traffic Control (ATC), the Commander detected an unusual smell, which he later described as "*chemical type fumes*". The FO advised the Commander that he did not detect the smell, but commented that he noticed a "*cheesy smell*" on the last sector and on the ground. After some discussion, the Commander reported that he felt "*something in the back of* [his] *throat*". Due to his concerns regarding possible adverse effects, the Commander suggested that both he and the FO put on their oxygen masks. The Flight Crew donned their masks and declared a Mayday. ATC facilitated an expeditious approach to EGSS.

The Commander contacted the No. 1 using the service interphone, and a NITS (Nature, Intentions, Time, Special Instructions) briefing was conducted. The No. 1 was advised that there were fumes on the flight deck and the intention was to land at EGSS in 15 minutes time, but that there was no need to give an emergency demonstration to the passengers. The Commander requested the No. 1 to advise him if fumes were noticed in the Cabin and commenced the QRH checklist for '*Smoke, Fire or Fumes*' (See **Section 1.4.3**). The Commander informed ATC that a normal approach and landing was expected.

The FO performed a normal landing at EGSS, where the Airport Fire Services (AFS) were in attendance. During the taxi, the Flight Crew made contact with the AFS and advised them that they didn't foresee a requirement for assistance. The AFS then followed the aircraft as it taxied to its parking stand. The Commander contacted the No. 1 again and asked if everything was okay in the aircraft cabin and was advised that it was. The aircraft was taxied onto stand and the engines were shut down. The Flight Crew opened the cockpit windows and removed their oxygen masks. The Commander made a PA[5] to the passengers to explain the presence of the AFS. He advised the Investigation that he did not make a PA earlier because the approach was normal and considered that making a PA while wearing an oxygen mask would alarm the passengers.

The Operator informed the Investigation that the No. 1 reported that the Cabin Crew did not notice anything unusual during the event flight and that there were no reports of smoke or unusual smells in the aircraft cabin.

1.2 Injuries to Persons

There were no injuries.

1.3 Personnel Information

1.3.1 Aircraft Commander

Personal Details:	Male, aged 26 years
Licence:	ATPL issued by the IAA
Total all Types:	3,250 hours
Total on Type:	3,100 hours

1.3.2 First Officer

Personal Details:	Male, aged 26 years
Licence:	ATPL issued by the IAA
Total all Types:	1,402 hours
Total on Type:	1,297 hours

[5] **PA:** Passenger Address.

1.3.3 Medical Reports

The Commander noted in his written statement provided to the Investigation that during the event flight, he noticed "*chemical type fumes*" in the flight deck and felt an "*irritation/tingling sensation*" at the back of his throat. On the direction of the Operator, he attended a doctor the following day. Medical examination found his lungs to be clear with no bronchospasm[6] and no focal signs[7]. A lung function (spirometry) test was performed, with normal results. The medical report noted "*the history is of inhalation exposure*" and concluded that "*one day later there is no evidence of any medical effects to this exposure*".

The Commander reported to the Investigation that, three days later, his throat irritation was still present. He spoke to the doctor via telephone and made another appointment for 25 September 2014. He did not return to work during this time. He said that when he visited the doctor on 25 September, he was granted a further week's sick leave. The Commander reported to the Investigation that during this week he had headaches and throat irritations that eased by 2 October 2014, when he returned to flying duties.

On the direction of the Operator, the FO also attended a doctor subsequent to the event and no adverse medical findings were reported. There were no reports of smoke or unusual smells in the aircraft cabin during the event flight and the Operator informed the Investigation that the Cabin Crew did not attend a doctor following the event.

1.4 Aircraft Information

1.4.1 General

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The aircraft, a Boeing 737-8AS, was manufactured in 2009. Its Certificate of Airworthiness was issued by the IAA on 5 May 2009. The Airworthiness Review Certificate (ARC) in force at the time of the occurrence was issued on 5 May 2014 and was valid until 4 May 2015. The aircraft had operated for a total time of 17,335 hours from the date of manufacture until the occurrence date.

1.4.2 Air Conditioning System

The aircraft engines and Auxiliary Power Unit (APU) supply air from their respective bleed air systems to a pneumatic manifold, which supplies air to the air conditioning packs. Air from the air conditioning packs is supplied to the mix manifold, from where it is supplied to the cockpit and cabin at a comfortable temperature, as selected by the Flight Crew. This air is also used to pressurise the aircraft. The system design is such that, during normal operation, the left pack supplies 20% of its air to the cockpit and the remaining 80% to the mix manifold. The right pack supplies 100% of its air to the mix manifold.

Two Pressure Regulating and Shut-Off Valves (PRSOVs) regulate the bleed air pressure in the pneumatic manifold. An isolation valve, when closed, isolates the pneumatic manifold into a left and right system. The APU is the primary source of bleed air when the aircraft is on the ground and is a backup source of bleed air in flight. Bleed air from the APU is controlled by the APU bleed valve and is supplied to the system on the left side of the isolation valve. Therefore, the bleed air flow from the APU is biased towards the left pack. **Figure No. 1** refers.

[6] **Bronchospasm:** A sudden constriction of the muscles in the walls of the bronchioles.
[7] **Focal Signs:** A body function disturbance centered on a specific body system or part.

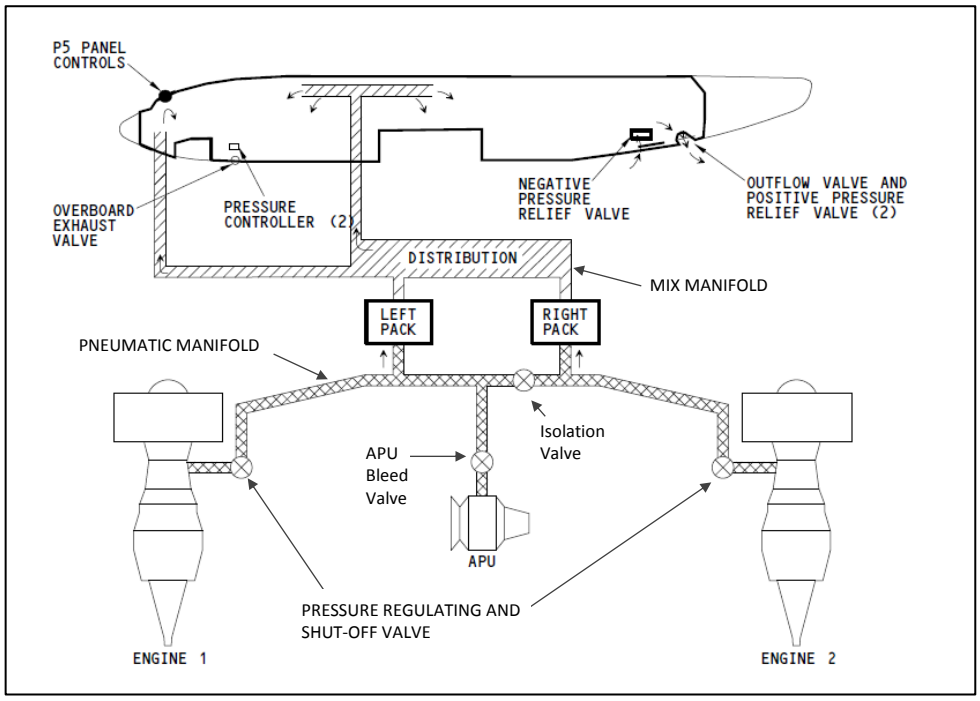
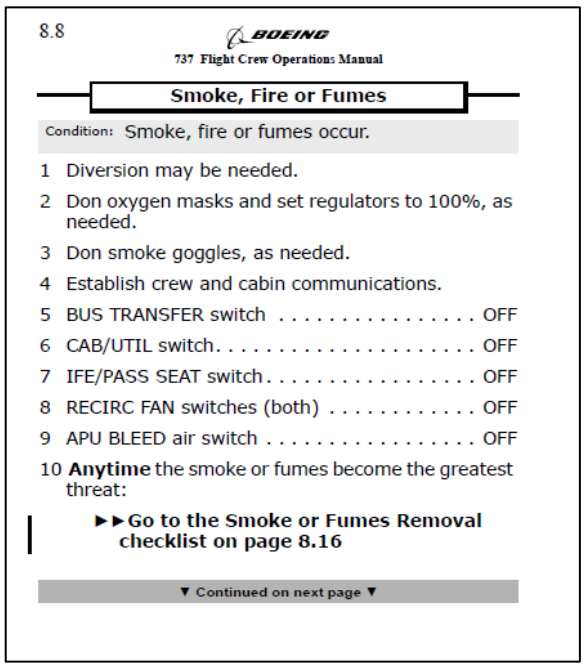


Figure No. 1: Schematic Diagram of Air Conditioning System
(Adapted from *Boeing 737-600/700/800/ 900 Aircraft Maintenance Manual*)

1.4.3 Quick Reference Handbook

Section 8.8 of the Boeing 737-8AS QRH (part of the Flight Crew Operating Manual), dated 29 April 2014, describes the actions to follow in the event of '*Smoke, Fire or Fumes*'. The first page of this Section is reproduced in **Figure No. 2** below. Item No. 2 of this checklist advises Flight Crew to "*Don oxygen masks and set regulators to 100%, as needed*".



8.8

BOEING
737 Flight Crew Operations Manual

Smoke, Fire or Fumes

Condition: Smoke, fire or fumes occur.

1 Diversion may be needed.
2 Don oxygen masks and set regulators to 100%, as needed.
3 Don smoke goggles, as needed.
4 Establish crew and cabin communications.
5 BUS TRANSFER switch . . . . . OFF
6 CAB/UTIL switch. . . . . OFF
7 IFE/PASS SEAT switch. . . . . OFF
8 RECIRC FAN switches (both) . . . . . OFF
9 APU BLEED air switch . . . . . OFF
10 **Anytime** the smoke or fumes become the greatest threat:

►►**Go to the Smoke or Fumes Removal checklist on page 8.16**

▼ Continued on next page ▼

Figure No. 2: Quick Reference Handbook checklist for Smoke, Fire or Fumes

1.5 Flight Crew Reports and Maintenance History

1.5.1 Technical Log Book Entries and Maintenance Action Prior to Subject Event

The APU was replaced on 1 September 2014 due to "*hot section*[8] *distress*". Later on the same day the following defect was entered in the aircraft technical log book: "*After landing […] APU started with packs in AUTO and bleed in ON, electrical smell developed immediately alerting the cabin crew*". Maintenance personnel inspected and tested the APU. No defects or signs of burning were noted. However, they declared the APU to be inoperative and entered the defect in the Hold Item List (HIL)[9] with reference to the Minimum Equipment List (MEL).

On the night of 1 September 2014, Maintenance personnel carried out troubleshooting on the APU in relation to the previous defect regarding the reported cabin smell. The APU air inlet area and the APU compartment cooling air inlet were found to be clean. The APU was operated for 30 minutes with both air-conditioning packs selected ON and it was reported that there were no fumes. However, a "*different smell*" was noticed which was described as "*not strong*". Maintenance personnel deemed it to be associated with the recent APU replacement and declared the APU to be serviceable before releasing the aircraft for service with a request for flight crews to monitor for further issues.

On 3 September 2014, a technical log book entry was made by a flight crew member stating that a "*strong smell of oil (like engine oil)"* was noticed in the flight deck during the descent. It was noted that "*nothing* [was] *reported in the cabin*". The aircraft was withdrawn from service for maintenance troubleshooting. The recorded maintenance action stated that the Fault Isolation Manual (FIM) was followed and a borescope[10] inspection of the number one engine was performed. It was reported that there was no "*wetting evident*". An engine run was conducted, with no smell apparent. The cabin air recirculation filters were also replaced.

Over the next few days, further troubleshooting tasks were requested by the Operator's Engineering department, which included inspections for oil contamination of the APU, the APU oil cooler, and the APU bleed and surge valves and associated ducts. A check for fumes in the aircraft cockpit and cabin with the aircraft pressurised using the APU as the bleed source was also requested. No findings were noted.

On 9 September 2014, a flight crew member made an entry in the technical log book in relation to a "s*erious obnoxious smell"* in the flight deck after engine start and during the descent. The associated maintenance action recorded that: "*On selection of L/H pack to auto using APU as bleed source, slight smell of oil fumes noted with very fine mist evident in flight deck only. Unable to reproduce smell on any further attempts. Cabin pressurised* […]. *Nil findings. #1 and #2 eng idle runs c/out independently using both packs and single pack only. Nil findings* […]*".* Because of the history of smells since the APU was replaced, Maintenance personnel declared the APU to be inoperative with reference to the MEL.

[8] **Hot-section:** The area of a gas turbine engine downstream of the fuel nozzles.
[9] **Hold Item List (HIL):** A list of deferred defects, permitted in accordance with the aircraft's MEL.
[10] **Borescope:** An instrument used for conducting visual inspections of inaccessible areas, such as the internal components of an engine.

Additional troubleshooting tasks were performed at the request of the Operator's Engineering department and it was noted that there was evidence of oil on the "*clamps attaching duct between bleed valve and A/C* [aircraft]". The duct was removed and an inspection was performed on the bleed valve and on the duct running forward, with nil findings.

Following one further flight on 10 September 2014, a technical log book entry was made by a flight crew member describing a "*slight smell on engine #1 start*" which was noticed again during the descent phase of flight. It was also reported that *"eyes and throat* [were] *affected*". Maintenance inspections were performed in consultation with the Operator's Engineering department and it was observed that there was an oil leak evident at the APU compressor. It was noted that the APU remained inoperative and was to be replaced. It was also recorded that *"high power runs C/O* [carried out] *with slight musty smell on start-up and idle power* […]*".*

Later on the same date, following three further flights, another flight crew member made the following technical log book entry: "*strong smell like burned oil during take-off and descent* […]". The APU was replaced that night (10 September 2014) and the aircraft was returned to service the next day. A work order raised by the Engineering department on 10 September 2014, which requested that an "*oil contamination removal*" task be performed on the air conditioning and pneumatic systems after the APU was replaced, was closed with reference to the APU replacement. The performance of the oil contamination removal tasks was not recorded.

On the night of 11 September 2014, six flights after the APU was replaced, the following maintenance action was recorded in the aircraft technical log book: "*APU bleed duct inspected – found mild oil in joints. Same cleaned. ACM* [Air Cycle Machine] *and water separator ducts insp. No fault found. Recirc filters insp. Found clean. # 1 pack func*[tion] *check carried out – ops normal, no smell apparent".* Maintenance personnel noted that the tasks were carried out due to a *"history of oil smell in the cockpit*". Additional inspections of the APU and engine bleed ducts and of the hydraulic reservoir pressurisation system were also performed that night at the request of the Engineering department, as were engine borescopes and inspections for oil deposits behind the engine fan blades. No adverse findings were noted.

On 12 September 2014, following two further flights, a flight crew member made the following technical log book entry:

> *During gnd ops with APU running, and even after APU off, eng running during taxi, t/o* [take-off], *crz* [cruise], *slight cheesy smell, same as explained on prev. occasions in this tech log. During final descent, strong heavy cheesy smell, first in f/d* [Flight Deck] *only, then reported in cabin by all 4 cabin crews. After landing, crews reported of slight headache and layer on tongue. Maintrol* [Maintenance Control] *contacted, who told us to check on return flight if agreed. During return flight, crew informed us of disorientation, which disappeared. No smell on ground in* […] *or during crz. During descent into* […] *passing FL150, idle thrust, smell returned, but much lighter*.

Following this technical log book entry, the aircraft was withdrawn from service by the Operator, pending further maintenance troubleshooting.

The Operator informed the Aircraft Manufacturer of the reports of smells and described the maintenance action that had been carried out to date. The Manufacturer was advised that it was suspected that the oil smells were as a result of residual oil contamination caused by the APU, which had been installed on 1 September 2014 and replaced on the night of 10 September 2014. The Manufacturer concurred with the actions taken to date and recommended that an additional FIM task, "*smoke or fumes in the cabin, source unknown*" be carried out. It was reported to the Manufacturer that during the subsequent engine runs, the odour was still evident at idle power. It was noted that it dissipated during high power settings but returned at low power and was only present when the number one engine was operated. The Manufacturer recommended additional tasks, including inspections of the engines for oil contamination. Following borescope inspections performed with the assistance of the Engine Manufacturer, it was reported that oil deposits were found on the number one engine low pressure compressor "*outflow stator vanes*", with "*slight discolouring*" on the blades of the high pressure compressor, third stage. This finding resulted in the replacement of the number one engine. In addition, the L/H and R/H heat exchangers were cleaned and several air conditioning components were replaced, including the flight deck muffler, the condensers and the reheaters. An "*oil contamination removal from air conditioning and pneumatic systems*" task was also carried out. Engine runs were performed and no smells were observed.

The aircraft was returned to service on 16 September 2014 and operated six flights with no technical log book entries being made relating to unusual smells.

Two flights were operated on 17 September 2014. Following the second flight, a technical log book entry was made regarding a "c*heesy smell"* in the descent when the thrust levers were at idle.

Also, on 17 September 2014, the Operator's Engineering department requested the accomplishment of several maintenance inspections due to "*repeat reports of smell in cockpit*". The tasks requested were similar to those carried out previously and included inspections of the fuselage near the APU inlet door and of the inside of the APU inlet duct for evidence of fluid ingress. Inspections were also requested of the APU compressor inlet, the bleed valves and the bleed ducts for evidence of wet oil. An inspection of the engine bleed ducts at the engines and at the inlets to the air conditioning packs was also requested as was an inspection of the hydraulic reservoir pressurisation system. Further requested inspections included visual and borescope inspections of both engines for oil contamination. In order to attempt to isolate the source of the smell, an engine run with a similar profile to the last flight was also requested. A review of the engine and APU oil consumption was also carried out and no excessive uplifts were noted. Furthermore, no hydraulic uplifts were noted. No adverse findings were reported and these maintenance tasks were referred to in the action taken section of the technical log book associated with the entry for the "*cheesy smell*".

Five flights were operated on 18 September. The subject event occurred on the fifth flight. The Commander's technical log book entry describing the event stated that "*chemical-type fumes* [were] *observed in the flight deck*" and that "*throat and nasal passage very irritated*". The APU was not running at the time of the event.

1.5.2 Air Safety Reports

As part of the Operator's Safety Management System, Air Safety Reports (ASRs) were raised by flight crews for several of the flights on which unusual smells were noticed.

1.5.3 Maintenance Action Taken following Subject Event

Following the incident, numerous maintenance actions were performed at the request of the Operator's Engineering department and with the assistance of the Aircraft Manufacturer. The APU bleed and surge valves were removed to permit inspections of the bleed air ducts. No contamination was found. The bleed air check valve was also inspected and no contamination was found. Borescope inspections were performed on both engines. A scavenge tube on the number one engine was found to be leaking oil and was replaced. This scavenge tube is located in the turbine section of the engine and therefore a leak in this tube could not adversely affect the air conditioning system.

Possible oil streaking was found on the number two engine at the stage one guide vanes of the high pressure compressor. The stage two blades exhibited signs of wetting on all blades with discolouration noted on the stage three casing. This resulted in the number two engine being replaced.

Borescope inspections were performed on the ducting at the number one and number two engine pylon bleed valves and at the L/H and R/H wing leading edge ducting for evidence of oil contamination and none was found.

The following components were replaced:

- The hydraulic air charging manifold and hydraulic quantity transmitters
- The number one engine PRSOV
- Both engine pre-coolers
- Both ACMs
- The L/H and R/H water separators
- The L/H and R/H condensers
- The primary and secondary air conditioning pack heat exchangers on the L/H an R/H sides
- The recirculation filters
- The bleed air isolation valve
- The flight deck muffler

An oil contamination removal task was performed and inspections were carried out to verify that contamination was removed.

The air conditioning ducting from the heat exchanger to the mix manifold and from the condenser to the flight deck muffler was inspected on the left hand and right hand systems, with no evidence of oil contamination found. The three-zone trim air valve and the temperature control valves were inspected and no oil contamination was found.

Engine runs were carried out at various power settings matching the last flight profile and at various air conditioning settings with no smells noted. The cold air outlets on both air conditioning packs were inspected for oil contamination following the engine runs, with no contamination noted.

The aircraft was operated on a positioning flight on 24 September, following which it was reported that there were "*nil fumes/smells evident in cabin and flight deck through all phases of flight. Verbal report from flight crew concurs*". It was returned to service on 25 September 2014. At the time of writing, no further reports of smells or fumes on the aircraft have been reported since the subject event.

1.6 Actions Taken by the Operator

1.6.1 Fume/Smoke Event Checklist

Subsequent to the event, the Operator developed a checklist to assist Maintenance Control in effectively managing the troubleshooting of reports of fumes/smells. The checklist includes guidance regarding which maintenance management personnel should be informed following an initial report of fumes/smells and the subsequent action to take if further reports are received, including moving the aircraft to a main base "*for further work/monitoring*".

1.6.2 Air Safety Reports and Technical Log Book Entries

Following the Operator's review of the ASRs raised in relation to unusual smells on the aircraft, it was noticed that a technical log book entry had not been made for the event that occurred following the first flight on 12 September 2014, as described in **Section 1.5.1** above. Subsequent to this, the Operator's Safety Services Office launched a communication and promotion campaign in association with the Flight Operations and Engineering departments, highlighting the importance of clear communication with Maintenance Control and reminding pilots of their responsibilities to note all defects in the technical log book. The campaign included briefings with flight crews, updated training programs and internal magazine and bulletin articles.

1.7 Workshop Reports

1.7.1 Number One Engine

During on-going troubleshooting for reports of unusual smells in the flight deck, a borescope inspection carried out with the assistance of the Engine Manufacturer on 14 September 2014 revealed deposits of oil on the low pressure compressor outflow stator vanes and "*slight discolouring*" on the blades of the high pressure compressor third stage. As a consequence, the number one engine was replaced.

The engine was sent to an approved repair and overhaul facility where it was observed that the "*engine showed some visual signs of oil leakage on the HPC* [high pressure compressor] *and the bearing number three aft seal*". It was stated that oil consumption was reported to be normal. The engine was disassembled and it was noted in the associated shop report that the number one bearing stationary seal was found with "*out of limit measurements*".

The report also notes that "*the removal reason might be plausible, however, it could not be confirmed as a removal reason during this shop visit as* [the repair organisation] *considers the findings as normal wear and tear*", and that *"oil leakage might have been present, but not in an extent that it would cause significant oil smell in cabin complaints".*

1.7.2 Number Two Engine

The number two engine was inspected as part of the maintenance action carried out following the subject event. Oil was found on the stage one guide vanes and stage two blades of the high pressure compressor, with discolouration noted on the stage three casing. The engine was replaced and was sent to an approved overhaul/repair facility. The findings identified on receipt were that the engine showed some signs of oil leakage on the high pressure compressor, the bearing number one stationary seal and the bearing number three aft seal, and that the bearing number one stationary seal had "*out of limit measurements*". It was noted that oil consumption was within Aircraft Maintenance Manual (AMM) limits and that the findings were considered to be "*normal wear and tear*". As for the number one engine, it was also stated that "*oil leakage might have been present, but not in an extent that it would cause significant oil smell in cabin complaints".*

1.7.3 Auxiliary Power Unit (APU)

The APU that had been installed on the aircraft on 1 September 2014 was subsequently replaced on the night of 10 September 2014 as part of on-going troubleshooting for reports of oil-like smells on the flight deck. The APU was sent to an approved overhaul and repair facility, where it was noted that "*the outer shell of the load compressor housing and the bleed air ducts were found to be covered by traces of oil*". Test runs were performed in the repair facility's test cell and fresh traces of oil were observed in the bleed air system.

The APU was disassembled. The load compressor seal was found to be in "*fair condition*" and there was no indication that oil had by-passed the seal. Nevertheless, oil traces were noticed on the back face of the compressor impeller. A detailed inspection of the load compressor housing revealed that a previous workshop repair of the bearing carrier seat area had been unsuccessful and had "*allowed oil to bypass the mating surface of the liner and load compressor housing*".

2. ANALYSIS

2.1 General

The Flight Crew reviewed the technical log book history in detail during the flight prior to the incident flight and became aware of the numerous reports of fumes in the flight deck occurring on the subject aircraft in the descent phase of flight. Consequently, they reviewed the actions that would be required if fumes were noticed while they were operating the aircraft. The No. 1 Cabin Crew Member was also briefed in this regard. As a result of their prior review, the Flight Crew was prepared when the Commander noticed an "*unusual smell*" on the subsequent flight (the incident flight). Following a brief discussion, both Flight Crew Members donned their oxygen masks in accordance with the QRH checklist for '*Smoke, Fire or Fumes'* and subsequently performed further items from the QRH checklist during the descent.

The FO advised the Commander that he did not notice the smell. Therefore, the Investigation considers that the smell is unlikely to have been strong. Furthermore, the Cabin Crew did not report any unusual smells or fumes in the aircraft cabin. Nevertheless, the actions of the Flight Crew limited their exposure to any fumes that may have been present and hence minimised the possibility of any adverse consequences. A Mayday was declared and ATC facilitated an expeditious approach to EGSS, where a normal landing was performed.

Subsequent medical tests on the Commander carried out on the day following the event revealed "*no evidence of any medical effects*". However, the Commander reported that due to headaches and throat irritations, he did not return to flying duties until 2 October 2014, almost two weeks later. The FO's medical tests also resulted in no adverse findings. As no fumes or unusual smells were reported in the Cabin during the event flight, the Cabin Crew did not attend a doctor.

2.2 Cause of Fumes/Unusual Smells

Following the incident flight, extensive maintenance action was performed in consultation with the Operator's Engineering department and the Aircraft Manufacturer, which included replacing multiple air conditioning system components. The number two engine was replaced due to evidence of oil in the high pressure compressor (the number one engine had been replaced previously). An oil contamination removal task was performed on the air conditioning system and extensive engine runs were carried out to verify that there were no smells or fumes. The aircraft was returned to service on 25 September 2014. No further reports of smells or fumes were made.

Both engines and the APU were sent to Maintenance Repair Organisations for repair/overhaul. The workshop reports for the engines noted some evidence of oil in the high pressure compressors of both engines. It was noted that the engines had *"normal wear and tear",* with oil consumption within normal limits and that the findings would not cause "*significant oil smell in cabin complaints*".

The workshop report for the APU noted that "*the outer shell of the load compressor housing and the bleed air ducts were found to be covered by traces of oil*" which was attributed to an unsuccessful workshop repair, which had been previously performed on a bearing carrier seat area. This APU had been installed on 1 September 2014 and following its installation, smells on board the aircraft began to be reported. It is likely that the oil leak, identified in the workshop report, contaminated the air-conditioning system following its installation until the APU was declared unserviceable by maintenance personnel on 9 September 2014. This APU was replaced on the night of 10 September. However, it is likely that the now-contaminated air conditioning system continued to cause unusual smells in the aircraft. Considering the numerous inspections performed by maintenance personnel, during which no contamination was found, it is possible that the nature of the contamination was such that it was not readily visible and was therefore difficult to detect.

APU bleed air enters the pneumatic manifold at a point to the left of the bleed isolation valve. Therefore, the flow is biased towards the left pack, which supplies conditioned air to the cockpit. This may have resulted in the left hand air conditioning system being more affected by contamination than the right hand system and may explain why the majority of the reports were for unusual smells in the cockpit and not the aircraft cabin.

2.3 Replacement of the Number One Engine

Following a report of a smell in the aircraft on 12 September 2014, the Operator requested assistance from the Aircraft Manufacturer. The Operator advised the Manufacturer that it was suspected that the unusual smells were as a result of residual oil contamination caused by the APU which had been installed on 1 September 2014.

Following further inspections performed in consultation with the Manufacturer, oil deposits were found on the number one engine low pressure compressor outflow stator vanes, with "*slight discolouring*" on the blades of the high pressure compressor third stage. It is likely that at the time, this was believed to have been the cause of the unusual smells. As a result, the engine was replaced, as were a number of air conditioning components. In addition, an "*oil contamination removal from air conditioning and pneumatic systems*" task was performed.

2.4 Maintenance Action following Reports of Fumes/Smells

A work order raised by the Engineering department on 10 September 2014, which requested that an "*oil contamination removal*" task be performed on the air conditioning and pneumatic systems after the APU was replaced, was closed with reference to the APU replacement. The APU was replaced on the night of 10 September 2014. However, the performance of the oil contamination removal tasks was not recorded at this time.

On 12 September 2014, eight flights after the APU replacement, a flight crew member reported to Maintenance Control, following a flight, that a smell was still present on the aircraft. No technical log book entry was made and no maintenance action was carried out. Following the return flight, the flight crew noted in the technical log book that on the earlier flight a "*strong heavy cheesy smell*" was present, and that the Cabin Crew reported a "*slight headache and layer on the tongue*". Following this entry, the Operator withdrew the aircraft from service and the Aircraft Manufacturer was requested to provide technical assistance.

Notwithstanding the instances outlined above, extensive troubleshooting and maintenance actions were carried out on the aircraft following the reports of unusual smells, from the time that the first report was made until the incident occurred. In addition, assistance was requested from the Aircraft Manufacturer when reports continued to be raised. Furthermore, following the report of a "*cheesy smell"* on 17 September 2014, the day before the subject event, several maintenance tasks were performed. These included engine borescope inspections and the performance of an engine run with a similar profile to the last flight. No adverse findings were reported and the aircraft was released to service. This highlights the difficulty in positively identifying the cause of such reports.

Regarding crew reports, it is essential that all occurrences of unusual smells or fumes noticed during aircraft operation are reported by flight crews in the aircraft's technical log book. Subsequent to the event the Operator launched a communication and promotion campaign in association with the Flight Operations and Engineering departments, highlighting the importance of clear communication with Maintenance Control and reminding pilots of their responsibilities to note all defects in the technical log book. In addition, the Operator developed a checklist to assist with more effectively managing the troubleshooting of reports of smells or fumes. Consequently, no Safety Recommendations are made in this regard.

3. CONCLUSIONS

(a) Findings

1. The aircraft was operating on a valid Airworthiness Review Certificate.

2. Reports of unusual smells on the aircraft were raised by flight crews following the replacement of the Auxiliary Power Unit on 1 September 2014.

3. Extensive maintenance actions were performed following the majority of reports of unusual smells. However, the actions were unsuccessful in that reports of unusual smells continued to be raised.

4. Maintenance personnel declared the Auxiliary Power Unit to be unserviceable/inoperative on 9 September 2014 with reference to the Minimum Equipment List.

5. Reports of unusual smells on the aircraft continued to be raised after the Auxiliary Power Unit was declared inoperative.

6. The Auxiliary Power Unit was replaced again on the night of 10 September 2014. However, reports of unusual smells on the aircraft continued to be raised.

7. An oil contamination removal task was called up by the Operator's Engineering department, to be completed following the Auxiliary Power Unit replacement. There is no record that this task was carried out before the aircraft was returned to service on 11 September 2014.

8. No technical log book entry was made and no maintenance action was recorded following a report on 12 September 2014 of an unusual smell until after the subsequent flight. Following this flight, the number one engine was replaced, due to oil deposits on the number one engine low pressure compressor outflow stator vanes and slight discolouring on the blades of the high pressure compressor, third stage.

9. A further report of a smell was raised following the replacement of the number one engine. Following this report, extensive troubleshooting was carried out, which included engine borescope inspections and the performance of an engine run with a similar profile to the last flight, with no adverse findings noted. The incident flight occurred the following day.

10. Following the subject event, extensive maintenance action was performed, including the replacement of the number two engine, due to evidence of oil/discolouration in the high pressure compressor.

11. Workshop reports for each of the removed engines discounted the findings regarding the engines as a cause of oil smells in the aircraft.

12. The workshop report for the Auxiliary Power Unit that was fitted on 1 September 2014 and removed on the night of 10 September 2014 noted that a previous workshop repair of a bearing carrier seat area had been unsuccessful. It resulted in an internal oil leak, whereby oil was allowed to bypass the mating surfaces of the liner and load compressor housing.

13. It is likely that the oil leak within the Auxiliary Power Unit installed on 1 September 2014 and removed on the night of 10 September 2014 caused the aircraft's air conditioning system to be contaminated by oil.

14. Subsequent to the event, the Operator developed a checklist to assist maintenance personnel in troubleshooting smoke and fume events. In addition, a communication and promotion campaign in association with the Flight Operations and Engineering departments was launched highlighting the importance of clear communication with Maintenance Control and reminding pilots of their responsibilities to note all defects in the technical log book.

(b) Probable Cause

Residual contamination in the air conditioning system, leading to fumes/smells in the aircraft.

(c) Contributory Cause(s)

An internal oil leak in a previously installed Auxiliary Power Unit, due to an unsuccessful workshop repair.

4. SAFETY RECOMMENDATIONS

This Investigation does not sustain any Safety Recommendations.

- END -

In accordance with Annex 13 to the Convention on International Civil Aviation, Regulation (EU) No. 996/2010, and Statutory Instrument No. 460 of 2009, Air Navigation (Notification and Investigation of Accidents, Serious Incidents and Incidents) Regulation, 2009, the sole purpose of this investigation is to prevent aviation accidents and serious incidents. It is not the purpose of any such investigation and the associated investigation report to apportion blame or liability.

A safety recommendation shall in no case create a presumption of blame or liability for an occurrence.

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