Air Accident Investigation Unit Ireland

SYNOPTIC REPORT

Serious Incident
Airbus A320-214, EI-DVJ
Dublin, Ireland

3 October 2015

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 cause(s).

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.

Extracts from this Report may be published providing that the source is acknowledged, the material is accurately reproduced and that it is not used in a derogatory or misleading context.

[1] **Annex 13**: International Civil Aviation Organization, Annex 13 to the Convention on International Civil Aviation, Air 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 3 October 2015, 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:	Airbus A320-214, EI-DVJ
Number and Type of Engines:	2 x CFM 56-5B4/3
Aircraft Serial Number:	3857
Year of Manufacture:	2009
Date / Time (UTC[4]):	3 October 2015 @ 06.40 hrs
Location:	After take-off from Dublin Airport, Ireland
Type of Operation:	Commercial Air Transport
Persons on Board:	Crew - 6 Passengers - 148
Injuries:	Pilot - Nil Passengers - Nil
Nature of Damage:	None
Commander's Licence:	Airline Transport Pilot Licence (ATPL), Aeroplanes (A), issued by the Irish Aviation Authority (IAA)
Commander's Details:	Male, aged 40 years
Commander's Flying Experience:	10,523 hours, of which 6,691 were on type
Notification Source:	Duty Manager, Dublin Airport Authority (DAA)
Information Source:	AAIU Report Form submitted by the Pilot, AAIU Field Investigation, Operator's Investigation Report

[4] **UTC**: Co-ordinated Universal Time. All times in this report are UTC (local time minus one hour on the date of the occurrence).

SYNOPSIS

Immediately after take-off from Dublin (EIDW), on an early morning scheduled passenger flight to Munich, Germany (EDDM), the Flight Crew detected an unusual odour in the cockpit. A short time later, the Cabin Crew reported that there were fumes in the aircraft cabin. Following an assessment of the situation, the Flight Crew declared a PAN (state of urgency) to Air Traffic Control (ATC) and donned their oxygen masks. The aircraft returned to EIDW, where a normal landing and taxi to stand were performed. The passengers disembarked using an air bridge. The fumes were subsequently attributed to an incorrectly performed engine wash procedure, which was carried out by maintenance personnel the night before the occurrence flight. No injuries were reported to the Investigation.

1. FACTUAL INFORMATION

1.1 History of Flight

Immediately after take-off from EIDW, at approximately 06.40 hrs, the Flight Crew detected a "*strange smell*" in the aircraft cockpit. This was followed by a call from the Senior Cabin Crew Member (SCCM) to advise that there was an "*extremely bad fumy smell in the cabin straight after take-off*". There were no cockpit warnings or indications of a malfunction. The Commander, who was the Pilot Flying (PF), switched the pack flow (air conditioning system) to HI (high). However, the smell was still apparent in the cockpit. He spoke again with the SCCM, who informed him that there was some improvement in the cabin. The Commander advised the SCCM that there had been some maintenance performed on the aircraft and that the smell may be connected to that, or to a previous de-icing process performed on the aircraft. He confirmed that the SCCM was feeling okay and asked her to check if the Cabin Crew Members (CCMs) at the rear of the aircraft had noticed anything. She said she would report back. The Flight Crew noticed a reduction in the intensity of the smell at this time.

A short time later, the SCCM reported back to the Commander, stating that the CCMs at the rear of the aircraft had noticed a "*smoke-like effect*" in the cabin after take-off, which had since cleared. The SCCM said a smell was apparent in the rear galleys, but that it had reduced in intensity. The Commander told the SCCM that he could no longer smell anything unusual in the cockpit, but that the Co-Pilot, who was the Pilot Monitoring (PM), could. The Commander advised the SCCM that because the smell was still present, he would "*go back into Dublin*". The SCCM asked if she could carry out a further inspection of the passenger cabin before the decision to return to Dublin was made. At this point, the Flight Crew informed ATC of a "*slight problem here in the cabin*" and requested to enter a holding pattern. Following the SCCM's re-inspection of the Cabin, she informed the Commander that the smell was still noticeable, but that it had "*dissipated*". The Commander, having already discussed the possibility with the Co-Pilot, informed the SCCM that the aircraft would return to Dublin. A NITS[5] briefing was given to the SCCM for the return to EIDW, which was expected to take approximately 10 minutes. The SCCM was advised that a normal landing was planned.

[5] **NITS Briefing**: An emergency briefing given by the Flight Crew to the Cabin Crew. N: Nature of the situation, I: Intentions of the Commander, T: Time remaining to landing, S: Special Instructions, if any.

The Commander made a PA[6] to the passengers, advising them of the situation. At this point, he noticed that the smell was becoming worse and instructed the Co-Pilot to declare a PAN[7] to ATC, reporting that "*we have some fumes coming through into the cockpit*". Following the receipt of the PAN declaration, ATC granted an immediate descent and notified the Airport Fire Services (AFS) and the Operator[8]. The Flight Crew donned their oxygen masks and carried out the initial items from the '*SMOKE/FUMES/AVNCS SMOKE*' checklist in the Quick Reference Handbook (QRH), which includes the requirement to use the crew oxygen masks if necessary. The Commander advised the SCCM that both he and the Co-Pilot had donned their oxygen masks as a precaution and confirmed again with the SCCM that all was okay in the cabin.

A normal landing was performed at EIDW at approximately 07.02 hrs. An expeditious taxi had been requested by the Flight Crew when the aircraft was on the approach and this was facilitated by ATC, with the AFS providing an escort. As the aircraft taxied towards the parking stand, the Flight Crew made radio contact with the Operator's Station Controller, to request the presence of ground staff to assist on arrival. This request was acknowledged. When the aircraft was on the parking stand, approximately one and a half minutes later, at approximately 07.08 hrs, the Flight Crew noticed that there was no one at the air bridge. At the same time, the SCCM made contact with the Flight Crew and advised of the need to "*get the* [cabin] *doors open straight away, to get some fresh air*". The Commander informed her that they were awaiting the air bridge. The Flight Crew then made several further requests to the Operator's Station Controller for the air bridge, one of which highlighted the presence of fumes on board. The SCCM contacted the Flight Crew again to ask if the door could be opened a little, advising that it was "*very fumy*".

The positioning of the air bridge at the aircraft[9] commenced a short time later, at around 07.11 hrs, approximately three minutes after arrival on stand. Once the air bridge was in position, the forward passenger door was opened and the passengers disembarked the aircraft. The Operator reported that the smell/fumes in the cabin were such "*that by disembarkation, many passengers had* [their] *mouths covered with items of clothing and handkerchiefs*".

1.2 Injuries to Persons

No injuries were reported to the Investigation.

1.3 Personnel Information

1.3.1 Aircraft Commander

Personal Details:	Male, aged 40 years
Licence:	ATPL issued by the IAA
Total all Types:	10,523 hours
Total on Type:	6,691 hours

[6] **PA:** Public Address.
[7] **PAN:** A call to ATC to indicate a state of urgency.
[8] **Operator:** The Airline.
[9] In this case, the Operator was responsible for the positioning of the air bridge at the aircraft.

1.3.2 Co-Pilot

Personal Details:	Female, aged 27 years
Licence:	ATPL issued by the IAA
Total all Types:	2,067 hours
Total on Type:	1,771 hours

1.3.3 Medical Reports

The Operator informed the Investigation that following the occurrence, medical examination of the Flight Crew and Cabin Crew Members, which included blood tests and lung function tests, resulted in no adverse findings. The Operator also advised that there were no subsequent reports of associated illness from any of the Crew Members involved or from any of the passengers.

1.4 Aircraft Information

1.4.1 General

The aircraft, an Airbus A320-214, was manufactured in 2009. Its Certificate of Airworthiness (C of A) was issued by the IAA on 3 April 2009. The Airworthiness Review Certificate (ARC) in force at the time of the occurrence was issued on 3 April 2015 and was valid until 2 April 2016. The aircraft had operated for a total time of 19,630 hours from the date of manufacture until the occurrence date.

There is no integral air stairs fitted to the aircraft; an air bridge or mobile passengers steps is required for embarkation/disembarkation.

1.4.2 Pneumatic and Air Conditioning Systems

1.4.2.1 Pneumatic System

The aircraft's pneumatic system (**Figure No. 1**) utilises bleed air from the engines and/or the Auxiliary Power Unit (APU).

Engine bleed air is extracted from the fifth stage of each engine's high pressure compressor, through an Intermediate Pressure (IP) Bleed Check Valve, or from the ninth (final) stage, through a High Pressure (HP) Bleed Valve, depending on the engine speed/power settings.

When engine power is low, bleed pressure from the fifth stage is low. Therefore, bleed air is supplied from the ninth stage. According to the Engine Manufacturer, the temperature of this air is approximately 425^{o} Celsius (C). When engine power is high, the HP Bleed Valve closes and bleed air is supplied from the fifth stage. The temperature of this air is 370-480^{o} C. The temperature of the bleed air is then reduced to approximately 200^{o} C by pre-coolers fitted to the engine pylons.

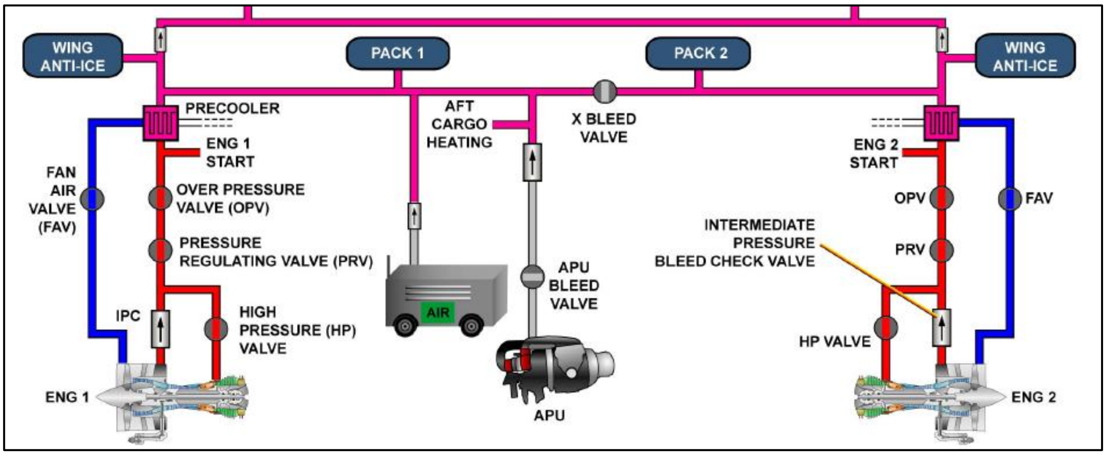

Figure No. 1: Pneumatic system schematic (*Airbus A320 Technical Training Manual*)

1.4.2.2 Air Conditioning System

As shown in **Figure No. 2** below, two Flow Control Valves (FCVs) connect the pneumatic system to two air conditioning packs which cool and dehumidify the air. The cooled air is supplied to a mixer unit, where it is mixed with air returning from the aircraft cabin (recirculated air). Depending on the temperature selected by the Flight Crew, the trim air valves permit unconditioned hot air to be mixed with the air from the mixer unit. This air is then supplied to the aircraft cockpit and cabin.

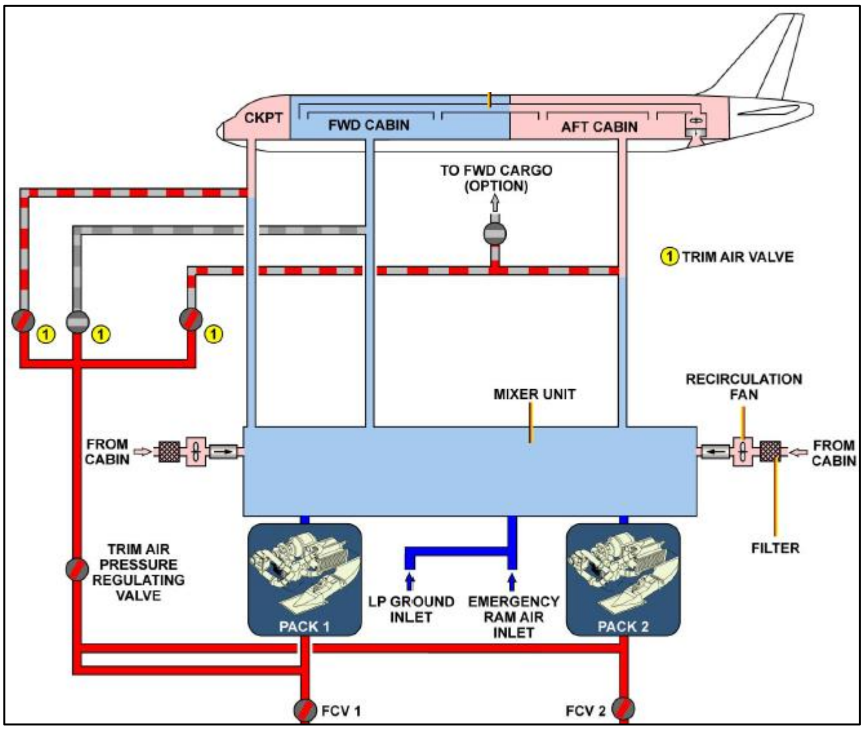

Figure No. 2: Air conditioning system schematic (*Airbus A320 Technical Training Manual*)

The recirculated air is filtered by High Efficiency Particulate Arresting (HEPA) filters, before it enters the mixer unit. The specification of the HEPA filters installed requires a 99.97% removal efficiency for a particle size 0.3 microns[10] (DOP test[11]). The Filter Manufacturer's published information notes that HEPA filters are designed to remove particulate, not gaseous contamination/odours, but that aerosolised droplets may be adsorbed[12] by the filters. The information also states that the HEPA filters installed have a microbial removal efficiency of greater than 99.999% for bacteria and viruses.

According to the Aircraft Manufacturer, approximately 1% of core engine airflow is extracted by the bleed system. The air supplied by the air conditioning system to the aircraft cabin and cockpit comprises approximately of 60% from the air conditioning packs, with the remaining 40% being supplied through the recirculation system. The change rate (renewal rate) of the air in the cockpit and cabin is approximately 36 times per hour.

1.5 Engine Compressor Wash

1.5.1 Background

The compressors of aircraft gas turbine engines compress ambient air during engine operation. This air may contain a variety of substances such as dust, sand and salt, which can be deposited on the compressor blades and stator vanes, adversely affecting compressor performance. This can lead to reduced engine efficiency, causing the Exhaust Gas Temperature (EGT) to reach values closer to the maximum allowed during take-off power settings—giving a reduction in the so-called EGT margin and a corresponding increase in fuel consumption. To remove such deposits and counteract these effects, compressor washes are regularly performed by maintenance personnel, using an engine wash rig, which utilises pure water and/or a special detergent. The Operator schedules the completion of this non-mandatory task every 1,500 flight hours.

1.5.2 Engine Wash Rig used before Occurrence Flight

A compressor wash was carried out on both engines on the aircraft while it was undergoing overnight maintenance on the night before the occurrence flight.

The engine wash rig used, which is fitted with two 115 litre (25 imperial gallons) stainless steel fluid tanks, is shown in **Photo No. 1.** During operation, the water/detergent added to the tanks is pressurised by two rechargeable on-board nitrogen cylinders. Once pressurised, the fluid can be directed through lances, which dispense water/detergent into the engine compressors. Operating instructions are included, in the form of placards affixed to the rig and an attached booklet.

[10] **Micron:** One millionth of a metre i.e. one thousandth of a millimetre.
[11] **Dispersed Oil Particulate (DOP) test:** A technique for measuring the fine particle arresting efficiency of an air or gas cleaning system or device. The DOP test consists of challenging the filter with an aerosol mist of oil droplets, with a mean size of 0.3 microns.
[12] **Adsorbed:** Holding molecules of a gas or liquid or solute as a thin film on the outside surface or on the internal surfaces within a material.

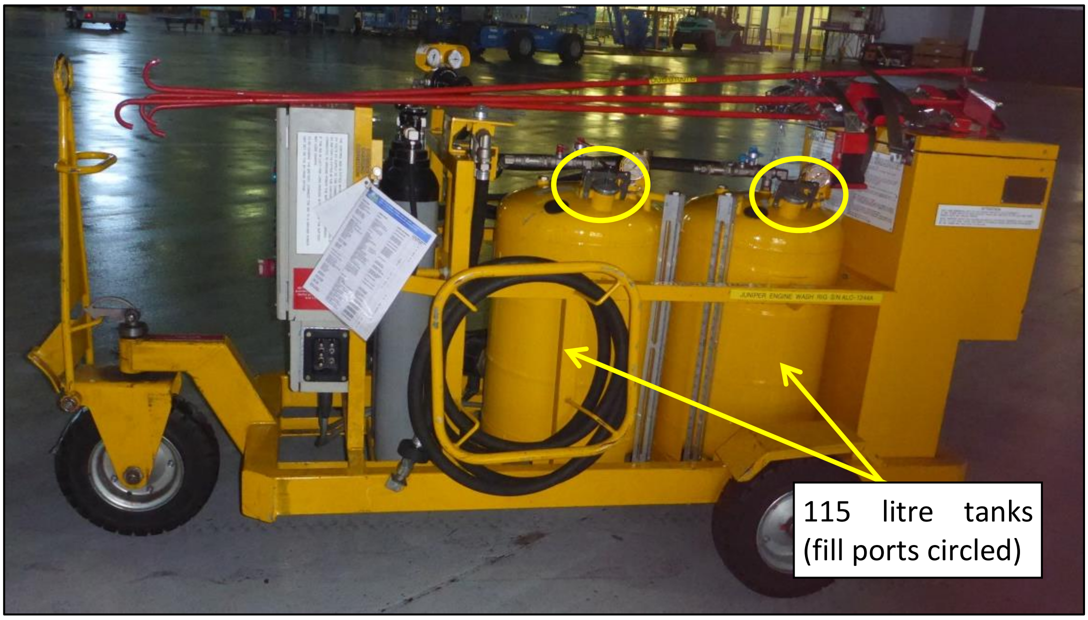

Photo No. 1: Engine wash rig used before occurrence flight

1.5.3 Aircraft Maintenance Manual Engine Wash Procedures

1.5.3.1 General

The Aircraft Maintenance Manual (AMM) task used by maintenance personnel was 72-00-00-100-026-A: '*Washing of the Engine Gas Path with pure water*' (revision date 1 August 2015). The following caution was included at the beginning of the AMM task:

> *IF CLEANING AGENT IS USED, PROPER AIRCRAFT MAINTENANCE CONFIGURATION, ENGINE RINSING AND POST ENGINE WASH TEST MUST BE COMPLETED TO PREVENT THE POSSIBILITY OF FUMES IN THE CABIN WHEN AIRCRAFT RESUMES REVENUE FLIGHT OPERATION.*

The AMM task stated that for EGT margin recovery, it was recommended to perform the engine gas path water wash with pure water only.

A subtask[13] described how the engines should be prepared for washing (before this subtask can be completed the engines' fan cowl doors must be opened). The subtask requires various pressure sensing pipes to be disconnected at the Electronic Control Units of the engines. The open pipes and ports must be then covered with protective blanks. The servo pressure lines at the nacelle anti-ice valves must also be disconnected, but not blanked.

[13] AMM Subtask 72-00-00-110-057-A

At the time, the subtask also included the following caution regarding corrosion inhibitor (described as a corrosion preventative additive/product/oil):

> *CORROSION PREVENTATIVE ADDITIVE SHOULD BE USED. HOWEVER, IF NONE OF THE CORROSION PREVENTATIVE PRODUCTS SPECIFIED (REFER TO CHAPTER B CONSUMABLE MATERIALS) IS AVAILABLE, THE ENGINE MUST RESUME REVENUE SERVICE OPERATION WITHIN 24 HOURS FOLLOWING THE POST ENGINE WASH TEST.*

The next section of the subtask stated:

> (7) *Servicing of the oil tank*
>
> *<u>CAUTION:</u> IF THE OIL TANK IS FULL, DRAIN ONE QUART (ONE LITER) OF OIL PRIOR TO ADD* [sic] *CORROSION PREVENTATIVE PRODUCT. THE OIL TANK MUST NOT BE TOPPED UP BEYOND THE WINDOW MARK.*
>
> *(a) Service the oil tank with one quart (one liter) of lubrication system corrosion preventative oil… or corrosion preventative additive… (Ref AMM TASK 12-13-79-610-002).*

1.5.3.2 Post Engine Wash Test

9 Following the performance of the engine wash procedure, the reconnection of all previously disconnected pipes and the closing of the engines' fan cowl doors, a '*Post Engine Wash Test*', must be performed, which is described in a further subtask[14]. The stated purpose of this test is "*to ensure that the bleed system is free from contaminant*", which the subtask notes, has the potential to cause "*smoke/smell in the cabin*".

The procedure instructs personnel to start the engine within two hours (or 30 minutes in icing conditions) to "*purge the lube/sump system of any water ingestion"*[15]. The procedure requires that the relevant engine should be run at idle for five minutes, before operating the ENG BLEED system and the ANTI ICE/WING system. The stated aim of this part of the procedure is to "*purge water potentially trapped in High Pressure (HP) bleed ducts and HP engine chambers*".

The engine should then be run at idle for a further five minutes, before increasing the engine thrust to "*at least 60 percent Fan (N1) for 10 minutes*". Maintenance personnel are then instructed to press the ANTI ICE/WING switch twice, which operates the wing anti ice system again. The stated aim of this part of the procedure is to "*purge water potentially trapped in IP bleed ducts and IP engine bleed chambers*".

[14] AMM Subtask 72-00-00-620-063-A
[15] During an engine wash, there is potential for moisture to enter the lubrication system through the bearing air/oil seals.

The engine should then be returned to idle for a further five minutes before switching on the air conditioning packs and checking for "*anti-freeze mixture odour/smoke in the cabin*" (the AMM requires an anti-freeze mixture to be used in the engine wash rig tanks if temperatures are below 5° C[16]). An anti-freeze mixture was not used in this case, nor was it required to be.

1.5.3.3 Alternative Post Engine Wash Test

An alternative post engine wash test[17], which is only applicable if the engine wash is performed with pure water, is permitted by the AMM, provided that the "*water wash crank procedure*" was not used and that the outside air temperature is not less than 5°C. The "*water wash crank procedure*" is an automatically-controlled engine cranking method, selected from the cockpit through the Multi-Function Control and Display Unit (MCDU). The availability of the water wash crank procedure depends upon the engine software version installed and was not used during the engine wash performed on EI-DVJ. Therefore, the alternative post engine wash test was permitted. The purpose of the alternative post engine wash test, as stated in the AMM, is the same as that stated for the normal procedure – "*to ensure that the bleed system is free from contamination*". It includes similar checks to those outlined above for the normal post engine wash test, but with the engines operating at idle power only.

The Aircraft Manufacturer was requested to comment on the efficacy of the alternative post engine wash test in detecting contamination. The Manufacturer reiterated that the alternative post engine wash test would only be applicable if the engine was washed with pure water and stated that, if the engine wash was performed with a cleaning agent, the AMM requires the engine to be rinsed with water, followed by engine runs at 60% N1.

1.6 Maintenance Personnel

1.6.1 Introduction

Two maintenance personnel, referred to in this Report as Engineer[18] A and Engineer B, performed the engine wash task on both engines on the aircraft while it was undergoing overnight maintenance on the night before the occurrence flight.

The Engineers work a shift pattern consisting of two 12 hour day shifts, followed by two 12 hour night shifts, which is then followed by four days off. Both Engineers commenced duty at 18.00 hrs on 2 October 2015, for the first of their two 12 hour night shifts, having finished the second of two 12 hour day shifts at 18.00 hrs the day before. The Engineers reported that they felt well rested before the commencement of their shift.

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[16] Meteorological records indicate that the temperature at Dublin Airport was above 5° C on the night of 3 October 2015.
[17] AMM Subtask 72-00-00-620-070-A: Alternative procedure - Post Engine Wash Test.
[18] **Engineer:** Aircraft Maintenance Technicians are referred to by the Operator as "Engineers".

Neither of the Engineers was a supervisor. However, Engineer A held EASA Part 145[19] maintenance approvals on the aircraft type under the Operator's personnel approval system. The Operator's IAA-approved Maintenance Management Organisation Exposition (MMOE) permits non-certifying personnel to work unsupervised, provided work performed is "*verified and certified by a person holding the appropriate certification authorisation privileges*".

1.6.2 Interviews and Statements

Statements from both Engineers were provided to the Investigation. Subsequently, the Investigation interviewed the Engineers. The Engineers reported that at the commencement of their shift, they were tasked with carrying out the engine washes on the aircraft. They said that they reviewed the workorders in the aircraft maintenance computer system and that they printed and read the relevant section of the AMM. Engineer B said they read the AMM together and that he also had a "*look through it separately*". The Engineers understood from the AMM that a corrosion inhibitor was to be used if available, but that it was not necessary if the aircraft was being returned to service within a 24 hour period. They said it was decided to use it to cover any unforeseen event that could prevent the aircraft from flying within the 24 hour period. Engineer A ordered two cans of corrosion inhibitor from stores, each containing eight US fluid ounces[20] of inhibitor.

The Engineers stated that although Engineer A had performed the task in the past, they decided that Engineer B would "*man the rig*" as he had performed the task "*a couple of times before*". He had never used corrosion inhibitor before; however, he said that he read in the AMM that the corrosion inhibitor was to be added to the oil tanks of each engine.

The aircraft was towed to the maintenance hangar to facilitate the engine wash task. Engineer A collected the cans of corrosion inhibitor from stores, and placed them on the engine wash rig. The rig, with the cans on top of it, was positioned adjacent to the aircraft in the hangar.

Engineer B assisted Engineer A in opening the fan cowl doors of the engines, disconnecting the air pressure pipes as required, and obtaining and fitting the necessary blanks. Engineer B also had to "*re-familiarise*" himself with the engine wash rig, by reading the instruction placards on the rig and the attached instruction booklet, which detailed how to connect the lances of the rig to the engine and how to adjust the pre-charge pressures of the tanks and the rate of fluid flow. Before pressurising the rig for use, with the cans of corrosion inhibitor sitting on top of the wash rig and "*tank*" in his mind, he checked with Engineer A as to where the inhibitor was to be added: "*I said one in each tank* [meaning, at this stage, the wash rig tanks], *and he said yeah, one in each tank* [meaning the engine oil tanks]". Engineer B poured one can of inhibitor into each of the two water-filled tanks of the wash rig (**Photo No. 1**). Engineer A was carrying out other preparatory tasks on the aircraft/engines at this time and did not see the corrosion inhibitor being added to the wash rig. He said he was of the understanding that the corrosion inhibitor had been added to the engine oil tanks.

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[19] **European Aviation Safety Agency (EASA) Part 145:** (Regulation (EU) No 1321/2014) on the continuing airworthiness of aircraft and aeronautical products, parts and appliances, and on the approval of organisations and personnel involved in these tasks.

[20] **US Fluid Ounce:** A unit of fluid quantity used in aviation. 1 US Fluid Ounce = 29.6 Millilitres. 8 US Fluid Ounces = 236.6 Millilitres. 32 Fluid Ounces = 1 US Quart.

Engineer B stated that the subsequent wash process used almost all of the contents from each of the wash rig's two tanks, with one tank being used for each engine. The Engineers said that following the wash procedure, engine runs were carried out as per the AMM. The alternative post engine wash procedure was used (AMM Subtask 72-00-00-620-070-A), which permits the engines to be operated at idle power only. It was reported that both Engineers were in the cockpit during the engine run and that there was no evidence of unusual smells.

Following the engine run, which was estimated to have taken around 25 minutes to half an hour to complete, the Engineers inspected the aircraft cabin for unusual smells and none were noticed. The Engineers estimated that the entire engine wash process took approximately four hours and reported that there was no element of time pressure.

Engineer B said that the following day he became aware of media reports relating to an in-flight turn back due to fumes. When he discovered that the aircraft involved was the one the engine wash had been performed on, he contacted Engineer A and advised him that he thought that it may have been caused by the "*water/inhibitor mix that hadn't burnt off or got trapped in the bleed system*". It was then that Engineer A realised that the inhibitor had been placed in the wash rig tanks and not the oil tanks of the engines. Engineer A immediately notified the Technical Shift Supervisor and advised him what had happened and requested him to remove the engine wash rig from service.

1.7 Training

Annex II, Part 145.A.30 (e), of Regulation (EU) No 1321/2014 regarding organisations involved in the continuing airworthiness of aircraft, states the following:

> *The organisation shall establish and control the competence of personnel involved in any maintenance, management and/or quality audits in accordance with a procedure and to a standard agreed by the competent authority* [the IAA]. *In addition to the necessary expertise related to the job function, competence must include an understanding of the application of human factors and human performance issues appropriate to that person's function in the organisation.*
>
> *'Human factors' means principles which apply to aeronautical design, certification, training, operations and maintenance and which seek safe interface between the human and other system components by proper consideration of human performance. 'Human performance' means human capabilities and limitations which have an impact on the safety and efficiency of aeronautical operations.*

Associated with these requirements, the Operator's maintenance personnel receive Company Procedure/Continuation and Human Factors training every two years. Engineer A received his Company Procedure/Continuation training on 3 November 2014 and his Human Factors training on 4 November 2014. Engineer B received these training courses on 4/5 March 2014.

The Operator's Human Factors training course syllabus referred to the factors affecting human performance (the "*Dirty Dozen*"[21]), including "*communication*", "*lack of knowledge*" and "*lack of awareness*" and "*the safety nets to combat them*". Safety Occurrences that have occurred within the airline are discussed during both the Human Factors training course and the Company Procedure/Continuation training course.

The Operator did not have an engine wash training program in place at the time of the occurrence and therefore neither Engineer had received training in engine wash procedures.

1.8 Actions Taken by the Operator

1.8.1 Maintenance Action

The Operator reported that the Engine Manufacturer was informed following the occurrence. In consultation with the Engine Manufacturer, a water wash with an added cleaning agent was performed on both engines, followed by a wash with pure water. A decontamination of the aircraft's air conditioning system was carried out. An inspection for oil wetting of the forward sump pressurisation tube on both engines was performed, as was an inspection of the engine bleed ducts. No adverse findings were noted.

The air conditioning recirculation filters and the avionic equipment cooling air filter were replaced. In addition, repetitive visual inspections of the engines and the master chip detectors were scheduled to be performed every 50 to 75 flight hours, for a total of three inspections. These inspections were performed and no adverse findings were reported.

1.8.2 Technical Notice

Subsequent to the event, the Operator published a Technical Notice (TN), entitled '*CFM56-5B Engine Water Wash Procedure (Revised)*' (Document No. 607, 19 November 2015).

The TN states that "*the latest revision of the Aircraft Maintenance Manual (Revision Number 71, dated November 1st 2015) has revised the engine water wash procedure TASK 72-00-00-100-026-A*", to include the following note:

> *The engine must resume service operation within 24 hours following this Post Wash Test. If not, a dry-out and re-lubrication procedure must be performed (Ref AMM TASK 72-00-00-100-007).*

The following is also stated in the TN:

> *The option to use corrosion preventative oil has been removed from the AMM. As a result, we have restricted access to all corrosion preventive oil in* [the Aircraft Maintenance Computer System] *stock, to ensure the previous method cannot be carried out inadvertently.*

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[21] **Dirty Dozen:** This commonly used Human Factors term refers to twelve of the most common human error conditions that can act as precursors to accidents or incidents.

1.8.3 Technical Training

Following an internal investigation into the occurrence, the Operator developed an on-line engine wash training program for maintenance engineers. In addition, the event has been included for discussion in subsequent Human Factors training courses.

1.9 Corrosion Inhibitor

1.9.1 General

Numerous country-specific Safety Data Sheets are published by the Manufacturer of the corrosion inhibitor, which is a synthetic oil-based fluid. Regarding inhalation, the UK-specific Safety Data Sheet notes "*overexposure to the inhalation of airborne droplets or aerosols may cause irritation of the respiratory tract*". The flash point quoted is 218^{o} C.

The inhibitor Manufacturer stated that the product is insoluble in water and, as such, the engine washing procedure may have resulted in the corrosion inhibitor leaving a residual coating on the engine compressors. The Manufacturer was asked to comment on the potential hazardous effects as a result of the occurrence. In response, the Manufacturer noted that "*the conditions, circumstances and thermodynamics in this scenario are complex*" and could not be fully understood due to the number of variables involved and the fact that the corrosion inhibitor was used incorrectly.

1.9.2 Engine Manufacturer's Publication

An article on the use of corrosion inhibitor during engine water washing was included in a publication issued by the Engine Manufacturer in April 2015, entitled '*CFM Fleet Highlites*'. The article identified a link between the systematic use of the corrosion inhibitor type used in the subject event, and reduced engine bearing life. The article states that the post wash engine run, as currently defined in the AMM "*has been found to be effective in reducing water concentrations in the oil to that of pre-wash levels. As such, an oil corrosion inhibiting additive is not necessary*". It is also stated that the AMM water wash procedure "*is being updated in order to remove oil additives …, and … as a precaution, at the next revision*" and that "*these updates will also be incorporated into the next AMM water wash procedures for all CFM56 engine programs*".

As noted in **Section 1.8.2**, the option to use corrosion inhibitor has since been removed from the AMM.

1.10 Positioning of the Air Bridge

According to the Airport Authority, the aircraft parking stand to be used was allocated approximately five minutes before the returning aircraft landed. However, the Operator reported that the aircraft landed sooner than they initially expected and that this, in conjunction with the distance of the parking stand allocated from the boarding staff station, where the ground staff members were located, led to a delay in ground staff reaching the parking stand. This resulted in the air bridge not being positioned at the aircraft until approximately three minutes after arrival at the parking stand, with a consequent delay in the opening of the passenger door.

During the course of the Investigation, the Operator advised that subsequent to the event they reviewed the delayed positioning of the air bridge and considered recommending to the Airport Authority that the possibility of providing a dedicated stand for cases where rapid disembarkation is required, with associated procedures for ground staff, should be examined.

However, the Operator deemed that due to the unpredictability of these events and their rarity, such a procedure would not be practical. The Operator also advised that a planned upgrade to the Flight Information Display System (FIDS) at EIDW would result in more accurate aircraft arrival time information being available to ground personnel.

The Investigation's Draft Report included a proposed Safety Recommendation to the Operator recommending that it conducts a review of the procedures it uses for ensuring the timely provisioning of disembarkation equipment (air bridges or mobile passenger steps) for aircraft returning due to fumes or other situations where a prompt disembarkation would be desirable. In response, the Operator informed the Investigation that its Operations Control communications protocol for significant events has been amended, to ensure that appropriate staff are assembled at the allocated gate in a timely manner, and if necessary, to arrange for passenger steps to be deployed to a remote parking stand if no air bridge-equipped stand is available at the estimated time of arrival. The Operator also advised that it is in the process of implementing a new Ground Control Centre at EIDW, which will "*greatly enhance the efficacy of communications and response at Dublin Airport to any non-normal return*".

2. ANALYSIS

2.1 General

On the aircraft's first flight on the day of the occurrence, fumes became apparent in the cockpit and cabin immediately after take-off. Following the Flight Crew's assessment of the situation during the climb, and in consultation with the SCCM, the Commander made the prudent decision to return to EIDW. A PAN was declared and ATC facilitated the return. The Flight Crew donned their oxygen masks in accordance with the QRH, which limited their exposure to the fumes and minimised the possibility of any adverse consequences, and a normal landing was performed at EIDW.

A scheduled engine wash was performed on the aircraft when it was undergoing maintenance on the night before the occurrence. Prior to the engine wash being carried out, one can, containing eight US fluid ounces (236.6 millilitres) of corrosion inhibitor, was erroneously added to each of the 115 litre water tanks of the engine wash rig. This likely resulted in the inhibitor, which is insoluble in water, being deposited within the compressor sections of each engine during the engine wash procedure. The design of the aircraft's engine bleed air and air conditioning systems is such that any contamination of this nature in the compressor sections of the engines, APU or associated bleed ducting can lead to fumes or unusual odours entering the aircraft cockpit and cabin.

2.2 Aircraft Fumes

2.2.1 General

The Engineers who performed the engine wash task reported that following the wash, they carried out a post wash test in accordance with the AMM and that no fumes were noticed in the aircraft cockpit or cabin. The test performed was the '*Alternative procedure - Post Engine Wash Test*', which permits the engines to be operated at idle power only.

During this test, bleed air would have been supplied through each engine's High Pressure (HP) bleed valve, by the ninth stage of each engine's high pressure compressor, which is the final stage of compression. However, as no fumes were noticed during the engine run, which was reported to have lasted for approximately half an hour, it is unlikely that there was any corrosion inhibitor trapped in the HP bleed ducts and HP engine chambers. Because only 1% of the core engine air is extracted by the bleed system, it is likely that the majority of any corrosion inhibitor residue remaining on the compressor blades and stator following the engine wash, passed through the engine during the idle run, without entering the HP bleed system.

Fumes only became apparent after take-off, when the engine power setting was such that bleed air would have been supplied by the fifth (Intermediate Pressure - IP) stage through the IP bleed check valve of each engine. Only then would any corrosion inhibitor trapped in the IP engine bleed chambers or the associated bleed ducting be purged. Pressurised air in the engines' high pressure compressors reaches temperatures in excess of 400^{o} C. The corrosion inhibitor's flash point is 218^{o} C and the quickly clearing "*smoke-like effect*" observed in the cabin after take-off, could have been due to vaporisation or heating of the remaining fluid, with the persisting fumes likely resulting from the now-contaminated air conditioning system.

2.2.2 Efficacy of the Alternative Procedure Post Engine Wash Test

According to the AMM, the purpose of the '*Alternative procedure - Post Engine Wash Test*' is to "*ensure that the bleed system is free from contamination*". This test permits the engines to be operated at idle power following an engine wash using pure water, which was not the case in this event. It would not be effective in ensuring that the bleed system was free from contamination; ordinarily, when a wash is performed with anything other than pure water, the AMM requires engine runs to be performed at higher power settings (60% N1).

2.2.3 Cabin Air Quality

The air in the aircraft cabin and cockpit is changed (renewed) at a rate of approximately 36 times per hour. Notwithstanding reports that fumes were still present in the aircraft cabin when the aircraft arrived at the parking stand, the combination of a finite amount of contaminant and the rate of cabin air renewal may explain the general reduction in the intensity of the fumes reported as the event progressed. In addition, 40% of the air in aircraft cockpit and cabin is recirculated through the HEPA recirculation filters, which although not designed to remove odours, would also likely result in a general improvement in the overall cabin air quality.

Regarding potential hazardous effects, the corrosion inhibitor Manufacturer noted that the conditions, circumstances and thermodynamics in this scenario were complex and could not be fully understood due to the number of variables involved and the fact that the corrosion inhibitor was used incorrectly. Post-event medical examination of the Flight Crew resulted in no adverse findings. The Flight Crew Members donned their oxygen masks and therefore were no longer breathing air from the air conditioning system. However, the Cabin Crew Members, similar to the passengers, were breathing cabin air throughout the event. Subsequent medical tests on the Cabin Crew Members also resulted in no adverse findings and, at the time of writing, there have been no reports of associated illness from any of the Crew Members involved or from the passengers.

Before the aircraft was returned to service, the Operator, in consultation with the Engine Manufacturer, performed an engine cleaning procedure using a detergent followed by a wash with pure water. In addition, engine inspections and an air-conditioning system de-contamination procedure were also performed.

2.3 Human Factors

The Maintenance Engineers involved in the engine wash task said that they read the associated AMM procedure, which at the time, included a requirement to use corrosion inhibitor if the aircraft was not resuming revenue service within 24 hours of the wash process. The Engineers decided to use the corrosion inhibitor to cover any unforeseen event that would prevent the aircraft flying within the 24 hour period.

When the aircraft was in the maintenance hangar, Engineer B assisted Engineer A in preparing the engines for washing, which involved disconnecting and blanking several air pressure pipes. Regarding the corrosion inhibitor, Engineer B said he had read in the AMM that it was to be added to the oil tanks of the engine. However, although he had performed the engine wash in the past, he had never used the corrosion inhibitor and before using the engine wash rig, which is fitted with two fluid tanks, he needed to re-familiarise himself with its operation by reading the instructional placards and booklet affixed to the rig.

While trying to assimilate this information and with "*tank*" in his mind and the visual cue of the cans of inhibitor on top of the engine wash rig, he sought clarification from Engineer A as to where the cans were to be added, asking "*one in each tank?*", meaning at this stage, the wash rig tanks. Engineer A replied, saying "*yeah, one in each tank*", meaning the engine oil tanks. This was interpreted by Engineer B as confirmation that he was to add the inhibitor to the wash rig tanks. From an engineering perspective, the addition of corrosion inhibitor into the wash rig tanks would not seem unreasonable; for example, the AMM requires anti-freeze to be added to the wash rig tanks if temperatures are below 5^{o} C. Engineer A was performing other tasks on the aircraft in preparation for the engine wash and did not see the inhibitor being added, but believed that the corrosion inhibitor had been added to the engine oil tanks as required.

The Engineers advised that they felt well rested at the commencement of their shift, which is when the engine wash task was commenced. Therefore, fatigue was unlikely to have been a factor in the error. However, neither Engineer had received training in engine wash procedures at the time of the occurrence. Whilst the Investigation acknowledges that it would not be practical for engineers to receive training for each and every maintenance task, the engine wash task requires the use of specialised equipment with detailed operating instructions and consequently, the Investigation considers that specific task training would have been appropriate. Such training would have reduced the likelihood of an error occurring. The Investigation notes that subsequent to the event, the Operator developed an engine wash training programme for maintenance engineers. Therefore, no Safety Recommendation is made in this regard.

Both Engineers had received their required Company Procedure/Continuation and Human Factors training courses. The Human Factors course included information on the factors affecting human performance, including "*communication*", "*lack of knowledge"* and "*lack of awareness*" and the "*safety nets to combat them*". The Operator's Human Factor training course will now refer to this occurrence and therefore no Safety Recommendation is made in this regard.

2.4 Positioning of the Air Bridge

When the decision to return to Dublin was made by the Flight Crew, a PAN was declared to ATC, advising that there were fumes in the cockpit. The Flight Crew was busy coordinating the short return flight and did not inform the Operator until the aircraft was taxiing towards its parking stand. However, immediately after the aircraft made the PAN call, ATC informed the Operator of the aircraft's return. Therefore, the Operator was aware that the aircraft was returning to EIDW.

Upon arrival at the parking stand, which had been allocated by the Airport Authority approximately five minutes before the aircraft landed, the SCCM expressed the understandable need to the Flight Crew to "*get the* [cabin] *doors open straight away, to get some fresh air*" followed by a further request for permission to open the passenger door a little, due to the fumes. However, to prevent the possibility of injury, cabin doors are normally not opened until an air bridge or mobile passenger steps is positioned at the aircraft.

The Investigation notes that the aircraft arrived at the parking stand approximately six minutes after landing, and approximately 11 minutes from when the parking stand was allocated. A further three minutes approximately elapsed before movement of the air bridge was commenced. The Investigation therefore considers that sufficient time was available to ensure the prompt positioning of an air bridge or mobile passenger steps, which due to the presence of fumes on board the aircraft, would have been appropriate. The Investigation acknowledges the Operator's review of this aspect, the remedial actions taken and the further actions proposed for enhancing the efficacy of their response to aircraft returning due to fumes or other situations where a prompt disembarkation would be desirable. Consequently, no Safety Recommendation is made in this regard.

3. CONCLUSIONS

(a) Findings

1. The airworthiness certification for the aircraft was valid.

2. A scheduled engine wash procedure was performed on the aircraft during overnight maintenance.

3. The AMM engine wash procedure required corrosion inhibitor to be added to the aircraft engines' oil tanks, but this step could be omitted if the aircraft was returning to service within 24 hours.

4. In preparation for the wash procedure, one eight US fluid ounce (236.6 millilitres) can of corrosion inhibitor was erroneously added to each of two 115 litre water-filled engine wash rig tanks.

5. Almost all of the 115 litres of fluid (water/corrosion inhibitor) in each tank was used during the wash process performed on the engines.

6. The Operator did not have an engine wash training program in place prior to the occurrence and therefore neither Engineer had received training in engine wash procedures.

7. No fumes or smells were noticed during the alternative post engine wash test, which permitted the engines to be operated at idle power only.

8. Shortly after take-off on the aircraft's first flight following the engine wash procedure, the Flight Crew detected an unusual smell in the cockpit. At the same time, the Cabin Crew noticed fumes and smoke in the aircraft cabin.

9. The Flight Crew donned their oxygen masks and declared a PAN to ATC, who facilitated a return to EIDW.

10. A normal landing was performed at EIDW and an expeditious taxi to the parking stand under escort of the AFS was carried out.

11. The positioning of the air bridge at the aircraft was not immediate and resulted in a delayed opening of the cabin doors.

12. Medical tests on the Flight Crew and Cabin Crew resulted in no adverse findings. At the time of writing, there have been no subsequent reports of associated illness from any of the Crew Members involved or from the passengers.

13. Subsequent to the occurrence, the Operator developed an engine wash training programme.

14. The requirement for corrosion Inhibitor to be added to the engine oil tanks prior to the performance of an engine water wash has been removed from the AMM.

(b) Probable Cause

The presence of corrosion inhibitor in the Intermediate Pressure (IP) bleed ducts and IP engine bleed ducts following an engine wash procedure, leading to contamination of the air conditioning system.

(c) Contributory Factors

1. Corrosion inhibitor was erroneously added to the water tanks of the engine wash rig.

2. The Operator did not have an engine wash training program in place prior to the occurrence and therefore neither Engineer had received training in engine wash procedures.

3. The alternative post engine wash test did not result in any adverse findings; this test was only applicable if the engines were washed with pure water.

4. SAFETY RECOMMENDATIONS

As a result of the remedial actions taken by the Operator and the further actions proposed, 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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