SERIOUS INCIDENT

Aircraft Type and Registration:	Airbus A320-232, G-EUYB
No & Type of Engines:	2 International Aero Engine V2527-A5 turbofan engines
Year of Manufacture:	2008 (Serial no: 3703)
Date & Time (UTC):	23 September 2019 at 0710 hrs
Location:	On approach London Heathrow Airport
Type of Flight:	Commercial Air Transport (Passenger)
Persons on Board:	Crew - 6 Passengers - 139
Injuries:	Crew - 2 (Minor) Passengers - None
Nature of Damage:	None
Commander's Licence:	Airline Transport Pilot's Licence
Commander's Age:	43 years
Commander's Flying Experience:	12,700 hours (of which 6,000 were on type) Last 90 days - 150 hours Last 28 days - 52 hours
Information Source:	AAIB Field Investigation

Synopsis

During approach to London Heathrow Airport the flight crew detected strong acrid fumes on the flight deck. They both donned oxygen masks and continued to land at Heathrow. After shutting down on a taxiway and removing their masks, the co-pilot became incapacitated and the commander felt unwell; both pilots were taken to hospital but released later that day.

Investigations carried out by the AAIB and the operator did not identify the source of the fumes.

Numerous other similar fume events have been reported to the AAIB and the CAA. This report reviews five other similar events which occurred with the same operator on the same aircraft type. It was not possible to identify the cause of these events, but, several common features have been identified.

The operator and aircraft manufacturer have taken action to try to reduce the number of events, which includes; the development of detailed maintenance procedures to identify the source of fumes, changes to flight crew operating procedures and the evaluation of modifications to enhance cabin air recirculation filtration systems.

History of the flight

On the day prior to the incident, the flight crew operated three flights together in a different aircraft. The first two sectors were return flights from Heathrow to Paris Charles de Gaulle Airport, the third sector was from Heathrow to Zurich Airport. The crew arrived in Zurich at approximately 1330 hrs and spent the night in the crew hotel.

Both flight crew had previously been involved in separate fume events on the same aircraft type. They reported that they had discussed these events during the evening.

G-EUYB was flown, by a different crew, from Heathrow to Zurich on the day prior to the incident. The aircraft landed at 2043 hrs and was parked at Zurich overnight. There were no deferred defects with the aircraft. It rained overnight and the temperature was approximately 13°C.

The incident crew reported for the return sector to Heathrow at 0345 hrs for a scheduled departure at 0510 hrs. Both flight crew reported that they were well rested. The initial departure from Zurich was uneventful. It was still raining during the departure and the aircraft entered cloud at approximately 1,000 ft agl and remained in cloud for the majority of the climb. Shortly after passing through FL100 the flight crew detected a slight odour on the flight deck. The commander initially thought the smell was coming from the galley ovens. The co-pilot described it as a “sweaty socks” smell; he reported that he had smelt similar smells on this type of aircraft before, but this was stronger than he had previously experienced. The commander was concerned that they were preconditioned to detect fumes because of their previous experience of fume events and their discussion the evening before. He proposed they waited 30 seconds prior to taking any action to see if the smell dissipated. After 30 seconds the smell had gone. The crew discussed further options and agreed to continue the flight.

The flight crew’s previous experience suggested that if the smell was going to reoccur it was most likely to occur when thrust was reduced for descent so, during the cruise, they discussed their actions if the smell returned and reviewed the SMOKE / FUMES / AVNCS SMOKE checklist. They briefed for the co-pilot to fly the descent and approach for the commander’s landing.

The initial descent into Heathrow was uneventful. There were clear skies throughout the descent. The aircraft held briefly at BIGGIN HILL and was then radar vectored for an ILS approach to Runway 27L. As the aircraft intercepted the localiser ATC requested the aircraft to reduce speed to 160 kt. The aircraft was slightly above the glideslope so the co-pilot used speed brake to intercept the glideslope from above and decelerate.

Having intercepted the ILS, as the aircraft passed through 4,000 ft both flight crew detected a sudden, very strong smell. The commander described it as a “manure smell”; “like a field which had just been muck spread”. He described the smell instantly “hitting him” in the back of the throat. There was no smoke and no obvious source of the smell. The co-pilot described it as a “strong sweaty socks” smell. He reported feeling itchy skin around his eyes and a scratchy throat. The commander took control and instructed the co-pilot to put on his

oxygen mask. Once the co-pilot was on oxygen and communication was re-established the co-pilot took control whilst the commander donned his oxygen mask.

The commander requested an early hand-over from the approach controller to the tower controller, which was granted. He then made a PAN call to Heathrow Tower; he reported that they had fumes on the flight deck and required a priority landing. The flight crew then selected the landing gear down and landing flap then decelerated to the final approach speed. ATC advised the two aircraft ahead of G-EUYB and one behind to expect a go-around and then instructed them to go-around in sequence. The flight crew discussed options and agreed the safest course of action was to continue the approach. The aircraft was stable at 1,000 ft agl. The commander elected to use Autoland. He advised ATC that they would vacate onto the parallel taxiway where they would require an inspection from the emergency services. The aircraft landed at 0644 hrs, vacated the runway at N6 and stopped on Taxiway A.

Once the aircraft had stopped the commander asked the co-pilot to complete the after landing procedure and the initial actions of the SMOKE / FUMES / AVNCS SMOKE checklist. The co-pilot made initial contact with 'Fire 1'[1] and advised them that they had fumes on the flight deck and were completing some checklists. The commander made the Alert Call[2] and gave the Senior Cabin Crew Member (SCCM) a NITS[3] briefing via the interphone. The SCCM confirmed there was no smell in the cabin and the passengers were not aware of anything unusual. The commander then spoke to Fire 1 and made an announcement to the passengers to explain what was happening.

The co-pilot removed his oxygen mask briefly to confirm if the fumes were still present. He confirmed the fumes were still present so the flight crew decided to shut down both engines and open the flight deck windows. At this stage the co-pilot started to feel nauseous. The Auxiliary Power Unit (APU) was started for electrical power and the engines were shutdown. The co-pilot then vomited out of the flight deck window. The commander initially planned for the aircraft to be towed to a parking stand but as it became apparent that the co-pilot needed urgent medical attention, he requested steps be brought to the aircraft. The co-pilot went to the aircraft toilet and continued to vomit. The SCCM came on to the flight deck to assist the commander. The SCCM reported that he smelt a "chemical smell", "a clean clinical smell" on the flight deck. He confirmed that there was no smell in the cabin.

The fire service brought access steps to the aircraft. Communication between the fire service and the flight crew was challenging due to the wind noise with the flight deck windows open. The fire service initially thought the co-pilot was trying to exit the aircraft via the flight deck window so positioned the step adjacent to the window. However, after further discussion

Footnote

1 'Fire 1' is the callsign used by the lead fire service vehicle.

2 The Alert Call is a standard PA made by the flight crew to alert the cabin crew to a non-normal situation – 'Will the Senior Cabin Crew Member please report to the flight deck, via the interphone'. The 'via the interphone' is added when the flight crew are on oxygen as it is difficult to communicate if the SCCM comes onto the flight deck.

3 NITS is an acronym used for cabin crew briefings in non-normal situations. It stands for Nature, Intentions, Time and Special Instructions.

the steps were repositioned to Door 1 right. It took the fire service some time to position the steps at the door due to the turning circle of the vehicle, limited space on the taxiway and a concern that the vehicle would become stuck in soft grass at the side of the taxiway. The aircraft door was opened at approximately 0706 hrs and fire crews and paramedics entered the aircraft. The fire crew inspected the aircraft and reported that they could not detect any unusual smells or fumes. A member of the operator's engineering staff also boarded the aircraft after the event and did not detect any fumes or odours.

The co-pilot and commander were assessed by the paramedics and both taken to hospital. The passengers subsequently disembarked via steps onto coaches and were transported to the terminal. None of the passengers or cabin crew reported any ill effects.

The co-pilot and commander were released from hospital later the same day.

Recorded information

Recorded information was available from the FDR, CVR and Digital ACMS recorder (DAR)[4]. Analysis of parameters related to the control of the engine pneumatic bleed and air conditioning system did not identify any anomalous operation during the incident flight.

Weight and balance

The aircraft departed Zurich with 7,000 kg of fuel at a takeoff weight of 65,300 kg. The aircraft weight was approximately 62,000 kg when it landed at Heathrow. There were no dangerous goods loaded on the aircraft.

Flight crew

Both flight crew had previously been involved in separate fume events.

The commander had experienced a similar fumes event to this incident on 21 December 2018 during a flight from Heathrow to Geneva. Fumes were detected on the flight deck during descent into Geneva. After landing the commander required hospital treatment.

The co-pilot was involved in a serious incident during landing at Valencia Airport on the 5 August 2019 which is being investigated by the Spanish State Investigation Authority[5].

Aircraft information

The Airbus A320 is a twin engine, narrow-body passenger aircraft, designed for short to medium haul operations. The aircraft internal layouts are generally similar and consist of the four main areas within the fuselage: the flight deck, the forward galley, the main passenger cabin with moveable curtain divide and the rear galley. The flight deck is divided from the rest of the cabin by a reinforced cockpit door.

Footnote

[4] Digital ACMS Recorder that recorded additional parameters than the FDR.
[5] Available at https://www.mitma.gob.es/organos-colegiados/ciaiac [accessed 30 March 2020].

Air conditioning system

The aircraft is fitted with a fully automatic air conditioning and pressurisation system known as the Environmental Control System (ECS).

It separates the fuselage into three independently controlled zones which are: the flight deck, the forward cabin and the aft cabin. A schematic of the ECS is shown in Figure 1.

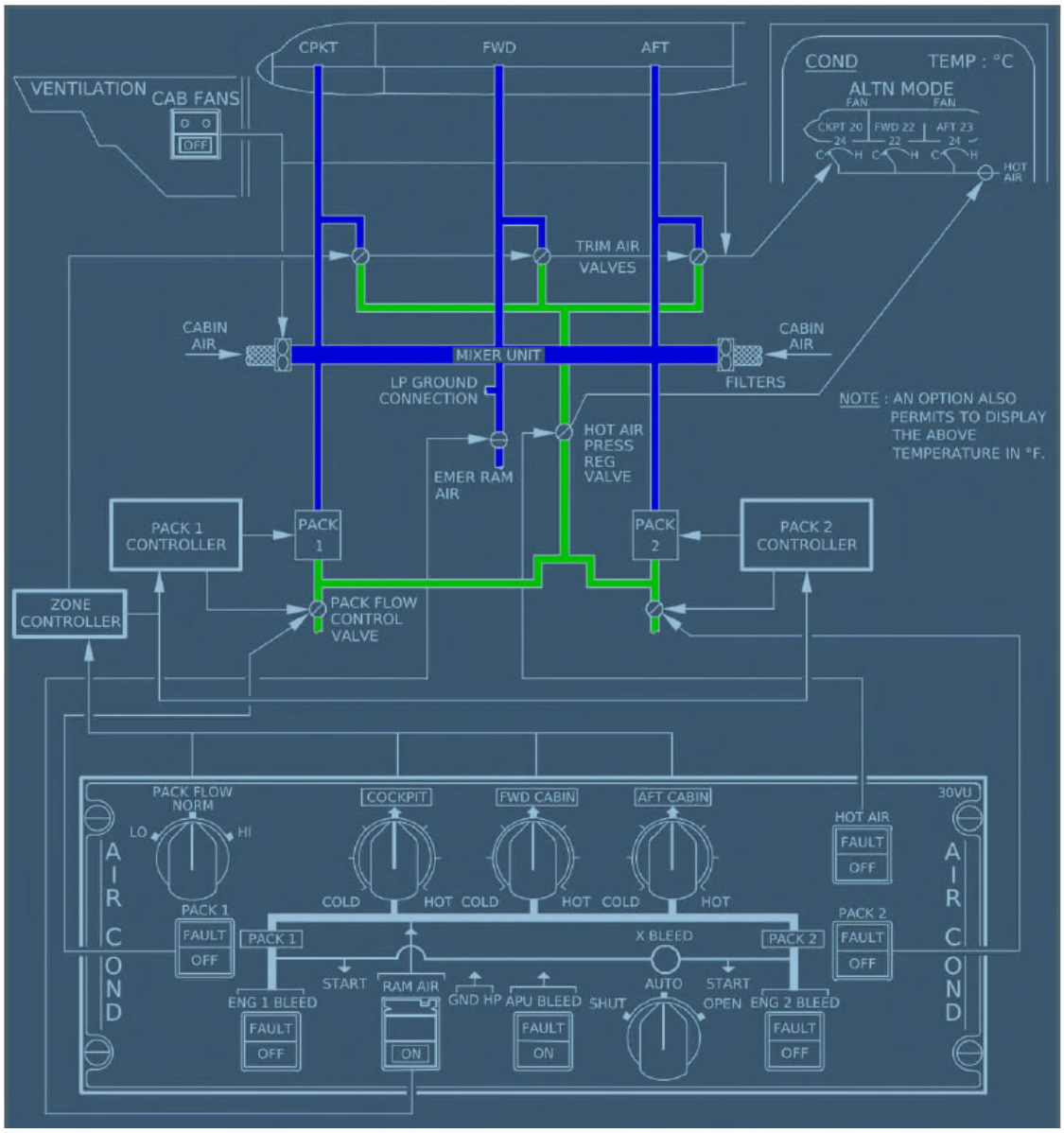

Figure 1
ECS schematic

In normal operations, the left engine supplies bleed air to the left pack[6] and the right engine supplies bleed air to the right pack. When the engines are not running, the APU can supply bleed air to both packs.

The bleed air from the engines or APU passes through electronically controlled heat exchangers, valves and mechanical devices to produce conditioned air. The conditioned air is at a temperature and flow rate that is suitable to enter the mixer unit where it is mixed with the recirculated cabin air prior to distribution to the flight deck and cabin to maintain a comfortable environment. Trim valves allow hot bleed air to mix downstream of the mixer units to optimise temperature regulation. During normal pack operation with the trim air system operative the cockpit is only supplied with air from pack 1 mixed with the recirculated air. The temperature in each zone can be selected and set from the AIR COND panel on the flight deck and can be fine-tuned for each cabin zone through the temperature control panel installed on the Flight Attendant Panel (FAP).

Cabin pressurisation is automatically maintained by the outflow valves which are controlled by the aircraft pressurisation controller.

There is a constant movement of air throughout the aircraft cabin via a system of ducts, louvres and vents. The ECS is designed to produce a slightly higher air flow per occupant on the flight deck.

Auxiliary power unit (APU)

The APU is a self-contained gas turbine engine mounted within the tail section of the fuselage. The APU is normally used on the ground, when the engines are not running, to supply air and electricity. The APU provides power via an accessory gearbox to drive a generator supplying the aircraft electrical systems and a load compressor to produce bleed air for the ECS and other systems. It uses fuel from the aircraft fuel system and is started using the aircraft batteries. It is started from the flight deck and its operation is automatically controlled by an electronic control unit. Once it is running, electrical power and bleed air is manually selected from the flight deck as required. A schematic of the APU is shown at Figure 2.

Footnote

[6] A 'pack' consists of an air cycle machine, heat exchangers and valves which adjust the temperature of the bleed air supplied from the engine or APU to a temperature suitable for the cabin air conditioning.

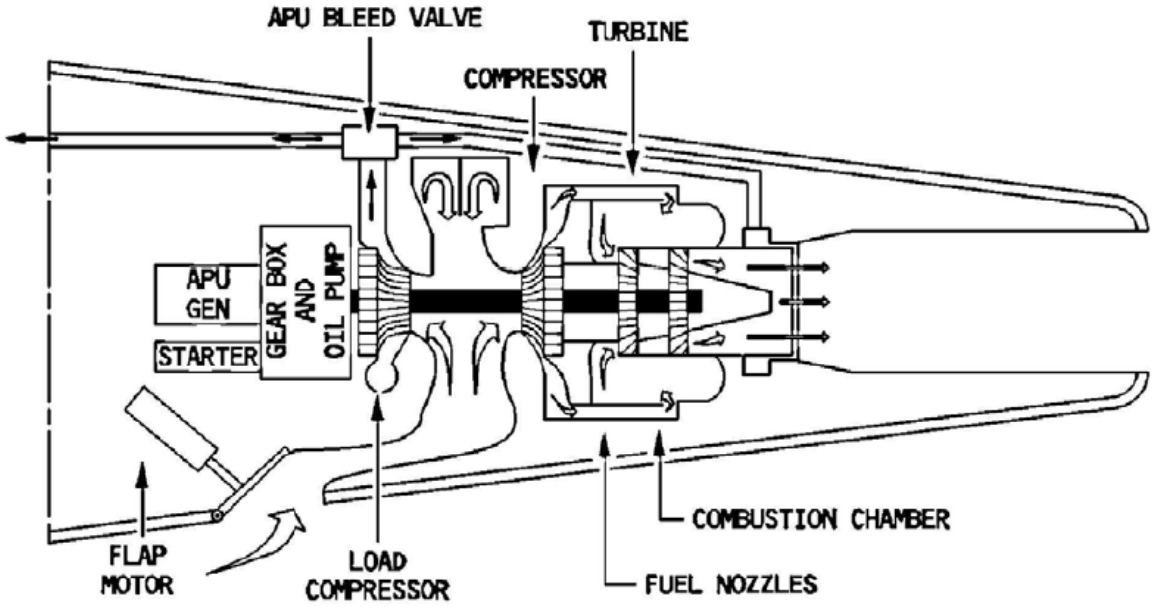

Figure 2
APU schematic

Aircraft examination

After the passengers had disembarked with their hand baggage, the aircraft was towed to a remote stand. Once catering, hold baggage and cargo had been removed the aircraft doors were closed. However, the flight deck side windows were left open.

When the AAIB Inspector boarded the aircraft approximately six hours after the incident, there were no residual abnormal odours or fumes apparent.

With assistance from the operator's engineering staff the aircraft systems were run in various combinations using the battery, the APU and the engines to try to establish the source of the fumes and odour. At various points during the testing, the left, right and forward avionics bays were accessed. There was no abnormal odour or fumes in these bays and there was no evidence of wiring, line replaceable units or avionics equipment cooling system failure. There was also no evidence of excessive dust, moisture or microbiological growth in the bays. Whilst the systems were being operated a handheld air testing device was used but showed no evidence of organic substances within the cockpit atmosphere.

The aircraft was then handed back to the operator to carry out further testing.

Based on the previous experience of fume and odour events the operator had developed a series of post fume event Work Packages (WP). These comprised of a set of conditional inspections that were to be carried out based on the evidence and data available:

- Work package 0 – Inspection in case of localised odour event within the cockpit or cabin. This WP lists a set of steps looking for localised domestic

causes within the cockpit and cabin areas including fluid spillages and residue on surfaces and in ancillary catering equipment. It also draws attention to the possibility of electrical equipment failure sources which requires circuit breakers, light fittings, power sockets and avionic cooling fans to be checked.

- Work package 1 is subdivided into 1A, 1B and 1B Plus and sets out a methodical step by step approach as follows;
    - Work package 1A – Basic exterior visual inspection from the ground. This set of checks focusses on hydraulic, APU and engine fluid levels. It also details a series of visual examinations for signs of fluid leakage on or around the engine fan blades and nose landing gear. In addition, it requires inspections for leakage apparent from the APU bay and on the rear fuselage and lower surfaces, looking specifically for leakage from fairings, overboard drains and panel seals.
    - Work package 1B – Includes all of WP 1A with the addition of access to the APU bay to carry out detailed inspections of the APU and its associated equipment. It also requires an inspection of the rudder yaw damper servo and the cargo door operating switch for signs of hydraulic leakage.
    - Work package 1B Plus – Includes WP 1A and 1B with the addition of comprehensive inspections of the APU bleed system and ECS system components. This requires detailed inspections of the APU and the left and right ECS air conditioning pack components, accessory seals and drains. To enhance detection of leakage and contamination this WP requires most of the inspections to be carried out using black light[7].
- Work package 2 – This set of inspections follow WP 1 where evidence is suggesting the air contamination originates from the APU or engines. It requires internal inspections using borescopes in accordance the Aircraft Maintenance Manual (AMM).
- Work package 3A – This WP requires an ECS check with the APU and engines at idle and is used to confirm the presence or absence of any smells or fumes following nil findings during WP 1A, 1B or 1B Plus.
- Work package 3B – This WP requires an ECS check with the APU and engine bleeds at higher power settings and is designed to isolate an odour when it is suspected to be originating from one of the engines. It is carried out on the ground with both engines and the APU running and the aircraft doors closed. There are various safety notes within this WP. Those onboard the aircraft are restricted to essential personnel only and all should have

Footnote

[7] Black light. An inspection light source producing ultraviolet light in the safe UVA wavelength. This causes traces of many types contaminant to fluoresce and become visible to the naked eye.

access to a portable oxygen bottle and mask. It includes the requirement to allow sufficient time between each engine and ECS configuration test to allow them to clear through prior to each stage in the testing.

- Work package 4 – ECS system decontamination requirements. This WP is carried out when the ECS system is found to have been contaminated and requires the ECS and APU bleed duct to be internally clean in accordance with the appropriate AMMs. It also directs that removed components must be quarantined for incident investigation.

G-EUYB was withdrawn from service and all the work packages were completed. No fumes or abnormal odours manifested themselves during these tests and the aircraft was released to service. However, four further events were reported up to the end of December 2019. In each case no faults could be found during the troubleshooting.

Actions taken by the aircraft manufacturer

The aircraft manufacturer has been collating data from operators relating to past and current fume events and has carried out research to identify the source and identify solutions. In reviewing the data, they observed that the presence of fumes dissipates at higher altitudes.

In many cases their advice, used in conjunction with the steps set out in the various AMMs, have led to a decrease in the number of fume events. However, in some cases the source of the fumes could not be found. As a result, the manufacturer has initiated several work programmes to further alleviate odour and fume events. This includes the introduction of an enhanced ECS filtration system, to be made available as a modification, and providing active support to supplier led investigations into further filter enhancements.

In order to address the issue of fume events the manufacturer has taken the following action:

> Project FRESH has been initiated to investigate and regularly inform operators of fume event arisings.
>
> The manufacturer has published an In-Service Information paper (Ref ISI 21.00.001.139) setting out all the known aspects of fumes and smoke events and includes the details of a filter and sensor product research and development programme.

The operator of G-EUYB, and the other aircraft detailed in this report, has joined this project which provides regular updates to operators from the manufacturer's customer services team. In addition, they have issued an In-Service Information paper to inform all operators of the background information, mitigations available (or ongoing) and best practices to address fume events.

Other similar events

During the investigation into the circumstances surrounding G- EUYB, the operator reported many similar events on their Airbus A320 fleet[8]. Figure 3 shows the number of events reported during 2019 and the start of 2020. Summaries of five of these events, all of which occurred during the latter part of 2019, are included below to show the circumstances, the various outcomes and common factors.

Fume events are not unique to this operator or to the Airbus A320. In the past 12 months the AAIB had received 37 reports of fumes events in Commercial Air Transport aircraft from various operators and aircraft types (including the six events included in this report). In the last five years 107 events have been reported. In the last year the AAIB has published two other reports on fume events (EI-DEO - AAIB Bulletin 2/2020 and G-YMMU – AAIB Bulletin 12/2019).

The CAA mandatory occurrence reporting (MOR) scheme has received 674 reports of smell, smoke or fumes events in the past 12 months and 3,166 in the last five years. In 2019, the operator involved in this event reported 536 smell, smoke or fumes events to the CAA, of these 398 involved the Airbus A320 series aircraft.

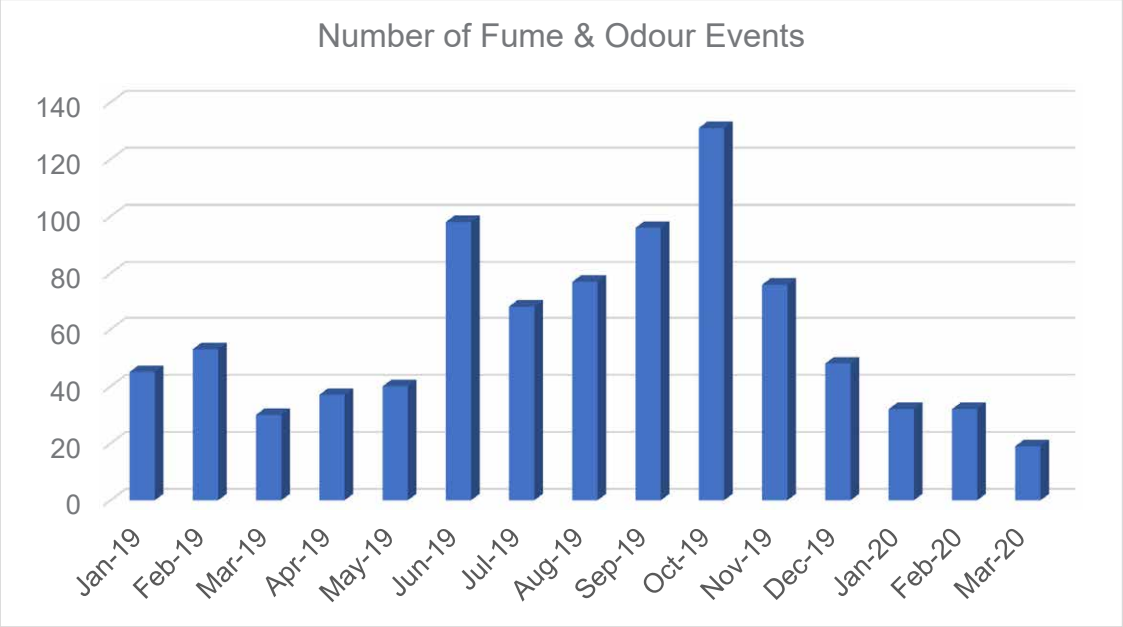

Figure 3

Fume and odour events on the operator's Airbus A320 fleet in 2019 and early 2020

Footnote

[8] Airbus A320 fleet in this report refers to A318/A319/A320 and A321 narrow body aircraft.

Airbus A320-232 G-EUUK

The aircraft had been parked overnight at Copenhagen Airport and was scheduled for a return flight to Heathrow on the morning of 1 October 2019. After completion of boarding the APU was started and run for one minute with its air bleed selected OFF. The air bleed was then selected ON, and after a further minute, the right air conditioning pack was selected ON. Almost immediately a strong odour, described as being like "sweaty socks" became apparent on the flight deck. The left pack was selected ON and a similar odour but to a lesser extent was apparent throughout the cabin. Both packs were selected OFF and the cockpit windows opened to vent the fumes which dissipated in approximately seven minutes. After a 30 minute delay, the aircraft preparations for departure were completed and the aircraft flew without incident until the final approach to Heathrow.

As the aircraft commenced final approach to Runway 27 at Heathrow, at about 5,000 ft, a "sweaty sock" odour was detected throughout the aircraft. The smoke and fumes abnormal and emergency procedures were completed and, within 60 to 90 seconds, the fumes dissipated from the flight deck. Fumes were still apparent in the cabin, so engineering and medical assistance was sought. Some of the cabin crew reported a "fuzzy headed" feeling, tingling throats and nasal congestion. This alleviated in fresh air and medical assistance was not required.

G-EUUK pilots' observation

The pilots of G-EUUK had noted that another fume event had taken place on the previous afternoon during descent into Heathrow and was recorded in the maintenance log. The log showed that the prescribed post event work pack had been completed and the aircraft had been released to service. It then flew to Copenhagen without incident prior to its overnight stop.

Airbus A320-232 G-EUUM

G-EUUM had a fume event on route to Fiumicino Airport (Fiumicino) in Rome. After this event the operator's post smoke and fume events work package had been carried out with no conclusive results. However, during the checks the APU lubricating oil level had been found to be slightly above maximum and so a small amount of oil had been removed to re-establish the correct level. No contamination was found in the APU ducts and passages.

The aircraft was repositioned on a non-revenue flight from Fiumicino to Heathrow. The flight was uneventful until the aircraft was approaching Heathrow. During descent there was some atmospheric electrical activity, but the aircraft did not enter cloud until FL150. The aircraft was in and out of cloud until approximately 1,200 ft aal. Engine anti-ice was used whilst in cloud along with a single use of the igniters[9] once the total air temperature had increased above 10°C.

Footnote

[9] Engine ignition should be on whenever severe turbulence or heavy rain is encountered. Engine ignition is automatically selected on when engine anti-ice is selected on. If engine ignition is required when anti-ice is not being used it must be selected manually.

Whilst heading downwind to Heathrow, the pilots became aware of an unusual odour, described as being like a "mouldy, wet laundry" smell. At this stage in the flight, the pilots were unable to determine whether it was throughout the aircraft or just on the flight deck. The odour remained and the pilots decided to don oxygen masks which they did, albeit with some difficulty due to the air hoses being incorrectly clipped over the nose piece at the front of the mask. They carried out the smoke and fumes abnormal and emergency procedures. A PAN was declared, and the pilots completed a normal approach and landing at Heathrow. The flight crew did not require any medical treatment.

G-EUUM pilots' observations

No passengers were carried, but the air conditioning systems were operated normally during the flight. However, the galley and cabin electrical systems were turned off. As it was a non-revenue flight there were only the two pilots on board and the cockpit door remained latched open.

Despite the fume event the pilots' main concern was that they discovered the oxygen masks incorrectly stowed. The way in which the hoses had been clipped together prevented donning of the mask until they had been undone. In this situation it had a minor effect. However, in a depressurisation event at high altitude, it could potentially be more of a problem.

The operator investigated the incorrectly stowed oxygen mask. There was no record of restowing the masks in the aircraft maintenance log and the maintenance provider in Rome did not have a record of restowing the mask. It could not be determined who restowed the masks. The AMM instructions for restowing the mask contained the following note:

> *'When you put the oxygen mask in its stowage box, the harness upper spacer and the harness lower spacer can become caught on the oronasal cone. To prevent this, you must not put the inflatable harness in the oxygen mask.'*

The following safety action was taken to prevent reoccurrence:

> The operator carried out a fleet-wide check to confirm that oxygen masks were correctly stowed and issued a Quality Alert Bulletin to all engineering staff to remind them of the importance of stowing the masks in accordance with the AMM.

Airbus A319-131 G-EUPG

The aircraft was climbing out from Brussels Airport when an unusual odour became apparent within the flight deck. The SCCM contacted the pilots and advised that a "plasticine" like odour had become apparent in the forward galley area. In addition, the SCCM reported that the cabin staff in the rear galley area were beginning to experience headaches and dry throats. The initial actions of the smoke and fumes abnormal and emergency procedures were carried out and the fumes began to dissipate.

The aircraft continued its transit to Heathrow and during descent, the cabin crew advised that the same odour had returned but this time it was more pronounced. A PAN was declared,

and the commander and co-pilot donned their oxygen masks. The aircraft landed and taxied to stand. The passengers were unaffected and disembarked normally. The affected crew were treated by paramedics and taken to a local hospital for further checks but were all later medically discharged.

Subsequently, the likely cause was found to be a burnt pastry in an aft galley oven.

Airbus A320-232 G-EUUP

During the cruise over France on route to Heathrow the purser reported that one of the cabin staff had noticed an unusual odour in the rear galley area. It was described as being similar to "cheesy feet" and that initially it was quite a strong smell but had become less pronounced. It only seemed to be apparent in the rear galley area and had made one of the cabin staff feel "heady". One of the passengers, who had been in that area also commented on it. The other passengers in the main cabin appeared not to have noticed anything unusual.

The exact source of the smell could not be identified and as a precaution the commander initiated the smoke and fumes abnormal and emergency procedures. As the flight deck was not affected, the pilots decided not to go onto oxygen. An option to divert was also considered and preparations were made should it have been necessary.

The odour appeared to have dissipated to the extent it was barely detectable. However, one member of the cabin crew still felt unwell and moved to the flight deck to see if her condition improved. In the meantime, the odour appeared to return, and a second cabin crew member started to feel unwell. The commander declared a PAN to air traffic control, proceeded to Heathrow and landed without further incident.

The presence of the fire service and paramedics prompted the commander to inform the passengers about the situation and that the crew had been dealing with an issue. The passengers disembarked as normal with no comment being made. Paramedics attended to the crew member who was feeling unwell. During the wait, some of the cabin crew commented on varying degrees of itchy eyes and sore throats. No odours or symptoms were experienced on the flight deck.

After carrying out the troubleshooting process the No 1 engine was replaced.

Airbus A319-131 G-EUPO

The aircraft was flying from Brussels Airport to Heathrow when, at approximately 4,000 ft on final approach, the flight crew noticed acrid fumes within the flight deck, described as smelling like "strong sweaty socks". The Smoke and Fumes Abnormal and Emergency Procedures were actioned and both pilots donned oxygen masks. A PAN was declared and the approach was completed to a normal landing with the airport fire service in attendance. The aircraft was stopped on the taxiway and the pilots carried out the after landing checklist. The flight deck side window was opened, and the oxygen masks removed.

During the NITS brief the SCCM reported a very faint odour on entering the flight deck. Discussion with the cabin crew established that none of the other crew members or passengers had been affected.

G-EUPO commander's observations

The absence of any effects on the cabin crew or passengers confirmed that the fumes were confined to the flight deck. The fumes were very noticeable and "difficult to ignore" but they were not debilitating. The commander had detected a very faint odour on the climb out from Brussels and discussed it with the co-pilot. The commander's experience suggested that the faint fumes on climb out were a precursor to fumes during descent as had occurred in this case. Their experience also showed that this sort of event was more prevalent in damp humid conditions such as mizzle, as had in fact been encountered in Brussels. The commander also considered that the main cabin is less susceptible to lingering fume events because the outflow valve has opened, reducing the effect in the cabin.

Summary of common factors

The evidence does not appear to show an obvious single precursor to all these events. However, several common traits were reported by the crews:

- The incidents took place both on the short haul European inter-city flights and with regional flights of less than two hours duration.
- The aircraft often arrived in, and stayed for varying periods of time, usually overnight, in damp humid environments with drizzle or rain present.
- In many cases the pilots described a faint smell during climb out on departure.
- The flights usually continued normally with no signs of any fumes during the cruise phase.
- When events occurred, the pilots described the fumes and odours reappearing on descent and in a number of cases at about 4,000 ft AGL in stable flight.
- The presence of fumes can have a rapid and adverse effect on flight crew.
- The crews described similar smells and odours, such as sweaty socks, manure and farmyard smells, which were unpleasant and distinctive.
- The fumes described in these events were invisible.
- FDR recordings did not show any correlation between the engine settings or other system selections or settings and the point in the flight at which the fumes appeared.
- In most cases the cabin crew were unaware, until they were told, of any fumes or odours; the problem seemed to be confined to the cockpit.
- When the fumes were detected by the cabin crew, they appear to linger in the galley areas.

- In those cases, the passengers were usually unaware and unaffected.
- In the more severe cases, the fumes prompted the pilots to declare a PAN and go onto oxygen.
- The generation of fumes appeared to be transient and dissipated very rapidly, in some cases before landing and in others very shortly after landing.
- In most cases when other individuals were given access to the flight deck after landing, they could not detect any smell or odour.
- In the small number of cases where those entering the flight deck were initially able to detect something, it did not have any adverse effect on them and seemed to go away very quickly.
- There were no detectable traces of condensate, solid compound or dust present in the flight deck afterwards.
- The use of the smoke and fumes abnormal and emergency procedures appeared to alleviate, but not completely eradicate, the effects in the main cabin.
- The use of aircraft washing fluids, detergents and anti-icing fluids. In most cases washing or anti-icing operations had not been carried out prior to the flights in which the events occurred.

To date, operators have not been able to reproduce the exact symptoms on the ground. It has not been possible to capture a sample of the fumes because of the rapid onset and transient nature of the fumes which do not linger after the event.

Other information

The human olfactory system is extremely sensitive and complex and can detect minute concentrations of airborne compounds; as few as four molecules can give a recognisable smell[10]. The ability of a person to interpret a smell requires a cognitive process and therefore the perceived intensity and the effect of a smell will vary between individuals[11].

When exposed to an unusual or stressful situation a person will experience an unconscious 'stress' response based on several factors, including: the context of the event, any prior anticipation of the situation, the perceived level of danger the situation presents and previous experiences of a similar situation. This reaction can produce physiological effects which differ markedly from person to person[12] [13]. For example, the act of cutting up an onion often causes an extreme reaction resulting in excessive tear production, stinging and

Footnote

[10] https://journals.plos.org/plosbiology/article?id=10.1371/journal.pbio.0020146 [accessed 14 April 2020].
[11] https://www.frontiersin.org/articles/10.3389/fpsyg.2013.00819/full#B125 [accessed 14 April 2020].
[12] https://www.simplypsychology.org/stress-biology.html [accessed 14 April 2020].
[13] https://psychologyhub.co.uk/the-physiology-of-stress-including-general-adaptation-syndrome-gas-the-hypothalamic-pituitary-adrenal-system-hpa-and-the-sympathomedullary-pathway-sam-and-the-role-of-cortisol/ [accessed 14 April 2020].

watering of the eyes. In a kitchen environment where cutting up an onion is quite normal the affected individual can quickly and easily understand what is happening and, although uncomfortable, it is not a cause for concern. However, if the same adverse stimuli, watering and stinging of the eyes, occurs in a situation that cannot be explained by the context of the environment, a person will experience an increased level of stress and associated physiological response.

Other safety investigations

Smoke and fume events have been sporadically occurring in recent years in various types of commercial aircraft. These have been reported via the normal channels and have led to investigations being carried out. To date these investigations have not been able to determine the exact cause in all but a few events. Those that have been able to establish the exact cause, have often identified a precursor fault such as an engine oil seal failure that allowed oil residue into the gas path within compressors upstream of the air bleeds.

The investigations that have not identified a source were of great concern and so the German Federal Bureau of Aircraft Accident Investigation (BFU)[14] carried out a safety study which focussed on the potential health impairments of such events. Despite a large range of data and evidence, a common physical cause of these events could not be identified. The report concluded that in the events that were examined no significant reduction in flight safety occurred. It also found that fume events can result in health impairments, but it had not been possible to assess the long-term effects.

In 2004 the AAIB published Aircraft Accident Report 1/2004, an investigation into a serious incident involving cabin air contamination on a BAe 146, registration G-JEAK, which resulted in the incapacitation of one flight crew member. The report also examined other reported events across a number of different aircraft types.

Sections 2.3.2 and 2.3.3 contained the following statements:

> *'Irritants may affect people in different ways, due to slight physiological differences and their individual sensitivities to different substances. This may explain why in some reported events, where flight crews are exposed to the same environment, one person is affected more than another.'*

and:

> *'The research so far indicates that substances acting as an irritant(s) may be the cause of the effects experienced by the flight crew on G-JEAK, and possibly during other incidents. The donning of oxygen masks at the first indication of the problem would have reduced the exposure time to these suspected irritants, reducing their effects, and may have prevented the apparent incapacitation of the first officer and the reduced capacity of the commander to operate normally.'*

Footnote

[14] https://www.bfu-web.de/EN/Publications/Safety%20Study/Studies/140507_Fume_Events. html?nn=817288 [accessed 30 March 2020].

In addition, the AAIB made Safety Recommendation 2001-47 in May 2001:

> It is recommended that the CAA should consider issuing additional advice to the crews of jet transport aircraft on the best operational practice when there is a suspicion of flight deck or cabin air contamination. The advice should include the necessity for all flight crew to use oxygen masks selected to 100% and the importance of cabin crew taking an active part in monitoring the flight crew in such circumstances.

This resulted in the CAA publishing a number of FODCOMS[15] on the subject and subsequent changes to flight crew operating manuals instructing flight crew to don oxygen masks when contamination of cockpit or cabin air is suspected

Analysis

This event was one of many very similar occurrences that had taken place with this operator and other operator's fleets of aircraft. These events had been reported via the operator's safety system and as MORs to the CAA. With the majority of these events, no immediate adverse effects on the flight crew were reported. It is not known if there are or will be any long-term health effects.

The fumes and odours are usually not visible but have a similar characteristic pungent smell. In some cases, this has resulted in stinging eyes and the sensation of "catching in the throat". However, it does not have the same effect on every individual. In this case, G-EUYB, one of the flight crew was affected to the extent they were incapacitated by feelings of nausea. After removing their oxygen mask, they vomited and were eventually taken to hospital for checks. Regarding the wider issue, crew opinions vary; some individuals describe it as an irritation and as "an annoying" trait of the aircraft type, whereas others consider it a significant flight safety hazard and a cause for concern.

Abnormal events in the cockpit, such as the presence of smoke and fumes, could be the first indication to the flight crew of a hazard which threatens the safety of the aircraft and requires an immediate response from the flight crew. The unique way individuals interpret smells, coupled with their unconscious response to a stressful situation can result in markedly different physiological reactions between flight crew members. The donning of oxygen masks as part of the flight crew actions when smoke or fumes are detected should isolate them from the source of the smoke and fumes.

Outside influences

In all the cases mentioned in this report, the possibility of influences from outside the aircraft has been considered, such as the use of aircraft washing fluids and detergents or anti-icing fluids. However, in most cases, washing or anti-icing operations had not been carried out prior to the flight in which the event occurred.

Footnote

[15] CAA Flight Operations Division Communications.

Damp and rainy conditions were often reported during these events and so is considered a potential factor. It is not known specifically why this is the case but ambient humidity around or within the aircraft and its systems may be a contributory factor.

Actions by the manufacturer

The manufacturer has been investigating fume events based on reports and information received from operators. The nature of the unidentified fume events has meant there has been no residual physical evidence of the fumes which could be identified as the source and thereby lead to specific measures to address the causes of these events. The unpredictable nature of the events has also meant that it has not been possible to construct an experimental flight test schedule to capture more data. This has left the manufacturer reliant on reported data, making the issue difficult to resolve in practical terms.

Technical cause

It has not been possible to obtain a sample of these fumes for scientific analysis. However, there are a few features and characteristics which may be relevant. The evidence indicates that it is likely that these fumes are derivatives of contaminants entering the ECS. It may not be a single compound but a combination of compounds which react and then become airborne in the bleed air supplies passing through the ECS. The fumes may have similar traits to hydrocarbon compounds combined with water vapour in low concentration which are liberated as water vapour condenses when it enters cooler conditions, for example as it passes into the flight deck or cabin via ducts. The suggestion that aircraft operating in damp or rainy conditions are more susceptible to fume events may add some weight to this theory. This is supported by the manufacturer's observation that the fumes decrease, or in many cases disappear, when the humidity of the air in the cabin decreases at higher cabin altitudes.

Consideration has also been given to whether the source may have been from plastic materials used within the ECS ducting, but this is thought less likely because the plastics tend to be used in the delivery of ECS air to the cabin rather than in production where hot and high energy air is used. The aircraft sub-variants, engine types and ages of the aircraft in which fume events occurred was also considered. This produced no conclusive evidence linking these events to a specific aircraft subset.

The operator of G-EUYB had developed a post fume/odour and smoke event maintenance procedure to tackle the issue. Its development was based on experience and findings over several years and has been successful in identifying the source of many of the previous events. The procedure is based around looking for evidence within supplier and receiver systems. It directs maintenance staff to look for evidence to establish whether engine air/oil seals have malfunctioned. However, in the most recent set of cases, the operator's post-fume check procedure has not been able to pinpoint faults or malfunctions which could have generated fumes. In all but one of these recent cases the engines have not been the source of the fume events.

The procedure for start-up and shutdown of the APU seems to have an effect. The operator has recently advised all flight crew to ensure the correct delay is applied between starting the APU and selecting bleed air and this seems to have reduced the number of events. The theory is that at APU start the generator and load compressor run-up from cold. It then takes a short amount of time for the bearings and seals to 'warm' up and stabilise to be effective. If bleed air from the load compressor is selected early, oil mist or residues can be released and drawn into the ECS airflow.

It does not seem logical that the APU can be a source of these events particularly as they often occur on descent whilst the APU is not in use. However, it is possible that entrained contaminants generated on initial APU start may linger, either as vapours or condensate, upstream of the ECS packs whilst the more predominant bleed air from the engines supplies the system. These contaminants are then entrained into the ECS system as air flow and temperature changes take place during descent. ECS system schematic diagrams are not able to show where and how this may take place. However, in practice the ECS consists of numerous straight, bent and curved ducts, leading to and from valves and conditioning components positioned and shaped alongside numerous other unrelated components. It is therefore possible that small amounts of contaminants could adhere to various internal surfaces or become trapped in 'pockets' within the system.

Conclusion

While it has not been possible to positively identify the compound that was responsible for the fumes and odours experienced in G-EUYB, or any of the other recent events, a number of common factors have been identified. The majority of events occurred after the aircraft had been parked or operated in precipitation. The fumes become apparent during the later stages of the descent, sometimes preceded by a minor event during the climb phase. The generation of fumes appears to be transient; they dissipate rapidly and leave no detectable trace. No link between changes to engine power or changes in other system settings and the generation of fumes was identified.

In some cases, the presence of fumes has resulted in physiological reactions which have interfered with a flight crew member's ability to carry out their normal duties. However, by following the smoke and fume checklist, and donning oxygen masks the flight crew were able to ensure the continued safety of the aircraft.

Safety actions

Although a specific cause has not been found in these and other recent events, the operator and aircraft manufacturer have taken several actions based on current knowledge to alleviate the odour and fume events.

Safety actions undertaken by the manufacturer:

> Project FRESH has been initiated by the manufacturer to investigate and regularly inform operators of fume event arisings.

Published an In-Service Information paper (Ref ISI 21.00.001.139) setting out all the known aspects of fumes and smoke events and includes the details of a filter and sensor product research and development programme.

Safety actions undertaken by the operator:

Developed the post-smoke and fume events maintenance procedure.

Taken action to ensure that the correct APU start up bleed air selection and shut down procedures are used.

Will consider the installation of the manufacturer's ECS air filtration modification when it becomes available

Carried out a fleet-wide check to confirm that oxygen masks were correctly stowed and issued a Quality Alert Bulletin to all engineering staff to reminded them of the importance of stowing the masks in accordance with the AMM.

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