Routine mechanical causes of aircraft air supply contamination

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The sources of air supply contamination are reviewed. They include the sometimes heavily contaminated air at ground level at an aerodrome that is inevitably drawn in to the air supply system. Volatile contaminants carried in the cargo hold of an aircraft can also find their way into the cockpit and passenger cabin. During a flight, throttle changes can exacerbate oil seal leakage and automatic control of the throttle is likely to force almost continuous changes in the loading imposed on seal configurations. Contamination from some of these sources could be significantly reduced by relatively simple changes in operating procedures.

Keywords: bleed air autothrottle, auxiliary power unit, exhaust gases, ground power unit, hold contamination

1. INTRODUCTION

The primary focus of this paper is routine mechanical causes of air supply system contamination—especially with oil fumes—in the cabin and cockpit of transport-certified aircraft during normal operations. Nonroutine "upset condition" oil fume events that are caused by mechanical failures or malfunctions are also referenced, but the primary focus is the routine mechanical sources of fumes supplied to the cabin and flight deck, which are typically not documented.

The content of this paper is derived from the author's 30-year career as a mechanical engineer, with extensive experience in the manufacture and functional operations of gas turbines, propellers, engine nacelles and airframe systems. In his capacity as a systems engineer with multiple airlines, he had contact with crews at airlines across Europe who formally reported cabin air incidents with a suspected or demonstrated mechanical cause. He was involved in handling and investigating the incidents that pilots recorded in the crew technical log, and personally interviewed and debriefed the crews. In his experience, most airline operators took technical log reports seriously. However, the subsequent maintenance investigations often fail to resolve and satisfactorily explain what occurred during the event period.

"Upset condition" fume events are usually characterized by an objectionable and persistent odour, which is sometimes accompanied by a visible smoke/haze. During the author's career, he often interviewed affected crews upon arrival in an effort to locate the mechanical fault. He noted that crew members often seemed confused and disoriented, and their accounts could differ regarding when the fumes were apparent and what they smelled like in flight. Various reports and analyses published by the UK Civil Aviation Authority and UK Air Accidents Investigation Branch describe similar findings.

To prevent "upset condition" fume events, most airlines are receptive to new technology in theory, but run into issues of budgets and the "return on investment calculation", which dictates how airlines operate.

In more recent years, the author has observed an increase in the frequency of documented "upset condition" fume events, as reported by both flight deck and cabin crew. He attributes the increased reporting to an increased general awareness of the potential health and safety consequences amongst crews. But, despite the growing awareness surrounding more prominent smoke/fume events, which may be sourced to identifiable mechanical failures, an area that continues to receive very little attention is the *routine sources of lower levels of oil fumes in the aircraft supply air during normal operations*. What follows is a description of some of these sources.

2. SOURCES OF CONTAMINATION

When an aircraft is on the gate area, it can be powered either by an auxiliary power unit (APU) or a ground power unit (GPU). The APU is part of the aircraft, but the GPU (Fig. 1) is connected to the airport terminal. It can be used merely to supply electricity (28 V d.c.) to the aircraft. In this configuration the aircraft interior will be unventilated unless the APU is running as well. Alternatively, air from the airport terminal building is fed through a large-diameter flexible hose to the aircraft environmental control system (Fig. 2).

Tests on the quality of the airport terminal air that supplies the GPU have identified particularly heavy particulate contamination, including various viral strains. Airport air conditioning systems are very rarely operated with suitable particulate filtration, and the terminal air is fed directly into the cabin and flight deck during

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Received 6 June 2014; *accepted* 8 December 2014

doi: 10.4024/18DA14R.jbpc.14.04

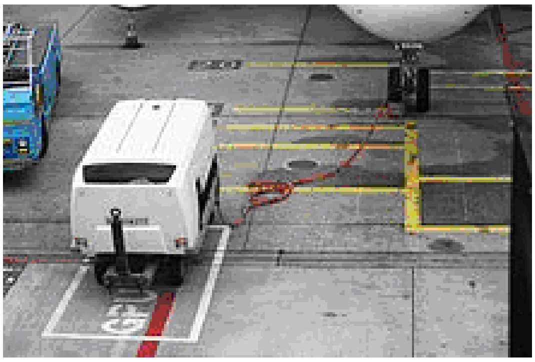

Figure 1. Ground power unit (GPU).

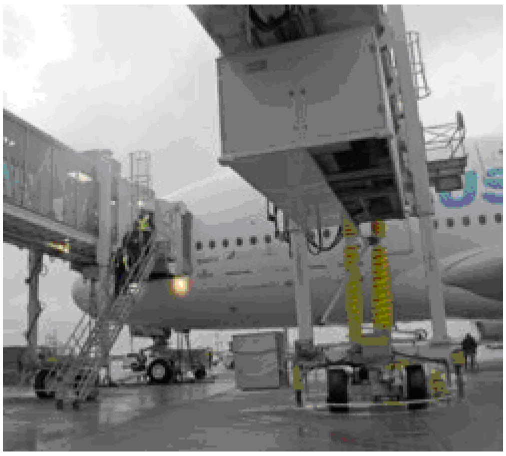

Figure 2. Ground power unit connected to an aircraft at the gate.

preparation for flight. The terminal system is maintained and controlled by the airport operator but, according to the author's knowledge, the quality of the air and cleanliness of the supply systems are unregulated.

In addition to the obvious ambient air pollution from operating aircraft at an airport, another heavy source of airborne contaminants that can enter the cabin during ground operations is the ground support vehicles and equipment, which are mostly powered by diesel fuel. Exhaust gases, soot and fuel fumes can be drawn into the APU, and even into the GPU, if the hose connexions leak air or if the terminal air intake is contaminated. Fuel and exhaust fumes can contain carbon monoxide and respiratory irritants. Disappointingly, most airlines and their service partners continue to use servicing trucks that are powered by internal combustion engines, rather than investing in nonpolluting alternatives such as hydrogen fuel cell-powered trucks.[1]

During at least part of the ground operations, the aircraft service doors are opened to permit the servicing of the cabin, including loading/unloading of catering supplies, garbage and provisions for the lavatories. The open doors create the possibility of direct ingress of exhaust and fuel fumes from the ground support vehicles and other aircraft. It is difficult for the onboard crews to avoid exposure to the airborne contaminants that circulate within the aircraft standing at the gate area.

The APU is one of the primary sources of aircraft air supply system contamination with oil fumes. It is the source of electrical power; the APU supplies compressed air to the aircraft air supply systems during ground operations, either when a GPU is not available, when an aircraft is parked remote from a gate, or during short turnarounds. In some cases, compressed air from the APU is routed to the cabin/flight deck for ventilation before the APU has stabilized on full load conditions, providing inadequate time for the shafts and bearings to correctly align. Airlines are motivated to operate the APU for the least amount of time possible in order to reduce operational costs (including fuel consumption), and to minimize exhaust emissions and noise in and around the airport. However, when the pilot selects the APU as the source of ventilation supply air without waiting for the unit to warm up, engine oil can leak through gaps in the misaligned components, thus contaminating the air supply system. Crew and passengers may notice the presence of oily fumes on APU start. This source of oil fumes could be avoided by amending APU start-up procedures.

Another source of APU air contamination with oil fumes relates to design. The use of hydropad-type seals and ejector systems to remove any oil leakage from the bearing sealing areas can prevent or at least minimize oil leakage in well maintained systems. Design choices are typically the result of the very tight commercial constraints applied to the maintenance contracts on the APU overhaul facility, intended to keep costs as low as possible to enable the support programme to maintain a commercial advantage.

As for the APU, poorly conceived operational procedures relating to main engine start-up sequences can cause air supply contamination. When the pilots elect to start the second engine by using the cross bleed air system, a strong smell of aviation fuel can fill the cabin. This will be familiar to regular fliers. The cross bleed is the use of high pressure compressor air from the running engine to initiate the start system on the second engine. Using the cross bleed reduces the load on the APU and flight deck. This practice of using cross bleed is prevalent throughout the industry. Crew members may routinely be exposed to the engendered fumes at engine start, and may consider it normal. Still, amending the start sequence could prevent this source of fumes, too. Passengers

[1] Typically, airline management teams and third party suppliers select servicing vendors based on price alone.

interviewed in recent UK and German documentaries and investigative news programmes have commented, generally adversely, on these fumes.

The modern aircraft has a very sophisticated flight management system that reduces the pilots' workload by giving the option for automated navigation, altitude and speed control functions, calculated by the onboard systems. One of the functions of this system is autothrottle, which assists the crew with thrust management during take-off, cruise, approach and landing, and also removes the input of the crew when flying at altitude on a prescribed course heading and speed. On certain aircraft, the system can chase the indicated air speed required to maintain the desired position in busy air traffic; an aircraft must hold and maintain its position at all times, which is especially complex when operating in busy controlled airspace. The constant automatic adjustments necessary for maintaining the required position mean that the engines are constantly undergoing acceleration and deceleration, which results in constantly changing compressor shaft loads on the seal assemblies. These constant adjustments put stress on the system, which can result in leakage of oil into the air circuit of the engine. It may also accelerate seal wear.[2] When these autothrottle systems are in use, the passengers may indeed become aware of slight variations to the noise of the engines. Even though these noise variations are slight, the pressure on the shaft to seal loading is significant. On some aircraft types, the pilots may disengage the autothrottle function during cruise to eliminate the constant changes, allowing them to manually control the speed by manipulating the throttles, which diminishes the constant changes in fuel flow—and overall fuel consumption.

When an aircraft taxis towards its assigned gate at busy main airports such as Frankfurt and London Heathrow, it often has to enter a queue on the taxiway to wait for the gate to become available (Fig. 3). The aircraft in the queue are situated close enough to each other such that the emission gases from the main engine and APU can be drawn into the air supply systems of neighbouring aircraft. Some flight deck crews will try—depending on space and the constraints imposed by ground control—to point their aircraft at a slight angle to avoid the flow of exhaust emissions over the main body of the aircraft, but this practice is normally frowned upon by crew management and the airport operators.[3]

During the taxi sequence and subsequent stopping and starting, the aircraft is thus likely subjected to the ingress of the exhaust gases from the forward aircraft and the surrounding ground support equipment, gases which are drawn directly into the main engine intakes as well as the air inlets to the APU. This air is subsequently passed into the cabin system without filtration.

Figure 3. Line of aircraft waiting in sequence.

Another source of air supply system contamination is the front freight hold. This is where an airline is most likely to carry any hazardous freight. It is also the location of the recirculation system for the environmental control system (Fig. 4). The freight hold air is drawn into the recirculation box and mixed into the cabin air system. If properly installed and maintained, filters should remove particulate contaminants but volatiles (and semivolatiles, depending on temperature) will be distributed to the cabin and cockpit via the air supply system. If the cargo hold is suspected of engendering contamination, then the maintenance service must identify the type of cargo by reviewing the aircraft manifest. Freight is an important revenue generator for most mainline airlines, but is often overlooked during cabin air investigations.

Figure 4. Airbus A320 series front baggage bay recirculation air system and filters (panel removed).

[2] Note another exacerbating factor—the trend to prolong engine life well beyond the original designed lifetime.
[3] The flow of exhaust emissions can also entrain debris lifted from the taxiway and aprons, which is then drawn into the engines, damaging their fan blades.

During the inbound taxi to the assigned gate, the pilots configure the aircraft, either for the next flight if they are on a transit turnaround, or for the prescribed shutdown check requirements if they are completing their service rotation. On such occasions the flight deck instruments may indicate a low bleed air supply. Pilots often manage this warning by accelerating the engines to improve the bleed flow into the air supply system. The bleed control system is designed to be handled by the bleed monitoring computer via preset valves, but pilots and engineering staff consider the practice of accelerating the engines to be an acceptable method of stabilizing the bleed flows, and it suffices to cancel the warning caution. However, accelerating the engines by rapidly moving the throttles for an interim power increase does not give the engine seals sufficient time to settle into a proper sealing configuration; in consequence oil may leak through the compressor main seals into the bleed air. On final taxi, the oil is extremely hot and, therefore, has diminished viscosity, enabling it to flow more freely, exacerbating the effect of a seal that may have worn sufficiently to permit leakage past the sealing face [1]. Thus, in accelerating the engines, the flight deck crew can inadvertently promote the introduction of some engine oil into the bleed system.

In addition to the APU and main aircraft engines, the ventilation ducting itself can be a source of oil fumes supplied to the cabin and flight deck, if not cleaned properly after a fume event. When oil fumes—whether from the main engines or the APU—contaminate the aircraft environmental control system the oil can leave a staining residue on the interior ducting and pipework.

Most airline maintenance crews are instructed to implement a "pack burn", in which hot air is delivered through the metal ducts upstream of the mix manifold. The intention is to burn off oil residue [2] on the interior surfaces of the ducts. Unless this contaminated air is vented overboard, though, the procedure only serves to transfer some of the residue from the upstream metal ducts to the downstream fibreglass ducts. The only effective method of removing this contamination is actual removal of the ducts and proper cleaning, which is normally only done during major servicing of the airframe during a hanger input check, because the duct systems are so inaccessible.

3. CONCLUSIONS

There is ample opportunity for exposure to low levels of oil fumes in the cabin and flight deck of transport-certified aircraft on a routine basis. This is particularly disquieting for crews, who must work in aircraft environment on a regular basis.

The aerospace industry claims that it is essentially able to self-regulate because all major countries have dedicated and talented people working in their companies to ensure safety. Perhaps this contributes to the complacency typically shown by aviation licensing regulatory and investigation bodies. Given the inherent financial conflicts of interest between safeguarding health and satisfying corporate shareholders, the present arrangements should be carefully scrutinized and appropriately altered to eliminate such conflicts.

Despite published studies describing the health and safety risks of exposure to oil fumes, there seems to be a general disregard of the need to implement controls. There are procedural changes (e.g., revised main engine/ APU startup sequences) that could be readily implemented to enhance the cabin environment and reduce the risk of exposure to oil fumes for both the crews and passengers.

Design modifications could also be implemented. As one example, the present author instigated the design and certification of a new concept of compressor seal for both fan engines and APUs on a number of aircraft applications. This "hydropad" seal is used by major APU manufacturers and some engine manufacturers in selected programmes to satisfy compressor shaft sealing requirements. Sealing design is still an area worthy of additional research and development.[4]

The major manufacturers closely protect operational data for their aircraft systems, making it very difficult for component manufacturers and innovators to propose suitable innovative designs. Some trial installations have, moreover, been impeded by improper operation, leading to premature rejection.

The aerospace industry needs to seriously consider operational and design modifications to ensure that everyone has a safe working environment and safe carriage to their destination.

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[4] Regrettably, though, some manufacturers will not adopt a given design feature—however good—if it is not their intellectual property.