Anatomy of an occupational hazard: Cabin air contamination in the air transportation industry**
Part 3. Aircraft, powerplants, repair and service. An evolutionary miscalculation leading to the proximate cause of contamination in cabin air

J.M. Lind*

CPCU ARM (USA)

Although the first commercial passenger jet aircraft used engine bleed air to heat and pressurize the cabin and provide breathing air, until about 1980 most airliners used external fresh air and turbocompressors for the job. Thereafter bleed air became standard. But the combination of increasing engine reliability and lower ticket revenue per passenger encouraged airlines to abandon time between overhaul (TBO) in favour of engine health management (EHM) and condition-based maintenance (CBM). Fume events leading to aircrew and passenger illness and, in extreme cases, pilot incapacitation, became more common, yet the severity was greatly downplayed, to the extent of routinely denying workers compensation to affected crewmembers.

1. 1950

Aircraft designers and engineers of the day were considering technical aspects of the world's first airliner, the de Havilland Comet. As the contributors to the magazine *Flight International* wrote, "the Comet enjoys a great advantage over all other pressurized airliners", namely, a new concept in pressurized aircraft intended for commercial passenger services. The writers were concerned about the cabin environment and its effect upon air travelers years into the future. Compressed air extracted from the engine compressors at 200 °C would be cooled, then sent through an air processing unit before entering the aircraft interior, where occupants would find it comforting and pure for breathing.

Bleed air, it came to be known, was cheap and plentiful, and would assure rapid and affordable public transportation while flying at a level englobing two-thirds of Earth's atmosphere (by mass). The experience would be worry-free for the air traveler.

Or would it? The air conditioning system was working very well. Designers, engineers, manufacturers and air carrier executives at the time had no definite reason to be concerned. But these technical experts appear not to have been entirely sure. As the *Flight International* article goes on to state: "It was at one time feared that contamination of the compressor air within the engine might prove a problem, but this has fortunately proved unfounded. In the few cases where an engine oil leak has occurred, the affected engine has immediately been shut off from the air supply".

How did the aircrew know "immediately" that an oil leak had occurred? Had the designers provided sensors that would alert the flight crew? Was the oil quantity gauge of a vernier scale design that would provide warning of the loss of tiny amounts of oil, ending up as oil mist in the air? If so, why do the aircrews of today not have that information? If sensors were once installed, did oil leaks from our modern engines become so frequent that warning devices were removed?[1]

For years the Comet and its successor aircraft operated to the best of this common-sense ideal with no known problems. Manufacturer-recommended time between overhaul (TBO) of engines of about 5,000 operating hours is assumed to have assured regular replacement of engine oil seals. We suggest this was routinely accomplished by air carrier executive order. Those were the years of dictatorial airline oversight by the Civil Aeronautics Board (CAB). All aircraft and engine maintenance costs were built into ticket prices. During the TBO era, which spanned the decades from 1938 to 1980 and beyond, no engine oil fumes of consequence leaked into areas occupied by air travelers. We are unaware of illnesses or injuries arising from smoke, fumes or particulate matter originating from the engines.

Nevertheless, the latter half of that era found the workhorse airliners (the Boeing 707, McDonnell Douglas DC8 and Convair 880/990) designed to provide breathing air using externally sourced fresh air via turbocompressors separately driven (by engine bleed air). For the

* E-mail: crewadvoc8@yahoo.com

** Dedicated to ill and disabled crewmembers and those who continue to be exposed to contaminated cabin air.

[1] The "Andorra syndrome", named after the legendary crash barriers on a mountain road that were removed because it became too expensive to continue repairing them.

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most part, engine bleed air was not used directly as breathing air. The US Air Force had some problems with fume-related injuries, mostly related to the J-57 engine. On the other hand engine bleed air served the Boeing 727 (1964) and Douglas DC-9 (1965) and other, smaller, airliners from about those years onward.[2]

It is not easy to corroborate the assertion that there were no illnesses or injuries arising from fumes. However, the present author was responsible for monitoring the frequency and severity of employee accidents and injury claims in support of airline workers compensation insurance programmes. His then employer, U. S. Aviation Underwriters, Inc., New York, N.Y., insured half of the major airlines of the day for hull, liability and workers compensation accidents. Reviewing accident and incident cases throughout the 1970s, no cases of oil leakage into occupied areas of aircraft ever came to his attention. No claims were ever made to cover the cost of work-related environmental illnesses. Although jet engine fumes were everywhere, and passengers had to walk across the tarmac at many airports, no official complaints were brought to insurance companies.

The same can be said about the other half of the industry. The competitor's workers compensation department manager was a companion during the triannual attendance at regular National Safety Council Air Transport Section meetings. Cabin fumes would have been discussed if any events had been known.

In addition, The Hartford and Travelers insurance companies employed a few aviation-savvy safety engineers. They provided field safety services to airlines (workers compensation) and airports (general liability) respectively. Neither brought any environmental complaints to our attention.

2. ENGINE HEALTH MANAGEMENT

Manufacturers of aircraft and engines prepared for the revolutionary new industry in advance of deregulation. They appear to have been aware that the new, highly reliable engines would be expensive to maintain. Multitudes of sensors were placed in and around these low- and high-bypass turbofan engines. The old TBO protocol, in place since at least 1950, was informally discontinued. The engine health management (EHM) concept would provide maintenance only when necessary, according to performance data recorded by the sensors and transmitted by satellite to monitoring stations. Operators and manufacturers would have continuous, real-time control over equipment efficiency into the future [1].

It should have been the best of all worlds. It is perhaps no exaggeration to assert that these new jet engines are the most highly engineered and reliable mechanical tools ever built. But the original assumption about engine oil leaks remains. No one considered the value of TBO over EHM and condition-based maintenance (CBM).[3] In fact, engine manufacturer sales departments sold new engines at a premium discount, expecting to recover some of their cost when they were returned for overhaul. Manufacturers were unaware that their airline clients would take advantage of abandonment of the 5,000 hour TBO protocol by operating engines continuously for 30,000, 40,000 and even more hours without significant maintenance.[4] Seemingly no one thought about deteriorating compressor bearing seals, oil leaks and cabin contamination [2].

Aircraft designs doubled and tripled in size and weight to embrace increased demand and higher-density passenger seating. Engine size and power increased from the turbojet (75 kN thrust) to the low-bypass (93 kN thrust) and high-bypass turbofan (510 kN thrust) in 2023 (see Figs 1 and 2). Overhaul cost increased respectively from about 250,000 USD to more than 3,000,000 USD [4,5]. We've noted hours-on-wing increasing from 5,000 to 40,000 during the period 2000 to 2023. One wonders about replacement of time-sensitive parts and bearing sump seals. Are these issues not important? Oil leak, fume and smoke sensor installation is avoided.

Figure 1. The JT8D is a low-bypass turbofan often used on early narrowbody jetliners.

[2] See https://aviation.stackexchange.com/questions/50697/what-is-this-hole-at-the-front-of-the-engine-pylon-on-a-boeing-707 for further comment.

[3] https://www.fiixsoftware.com/maintenance-strategies/condition-based-maintenance/. Note that fatigue or uniform wear failures are not easily detected with CBM measurements.

[4] Gleaned from remarks at an airshow: "High reliability that has become industry standard is hampering that spare-part business. CFM said that CFM56 engines delivered nearly a decade ago were due to come in after six years but are just now coming in for service. The revenue is thus arriving later than predicted. CFM spokeswoman Jamie Jewell has remarked: 'We have a pretty substantial population of engines that are at around 40,000 hours before their first shop visit'. In one case, an engine stayed on the wing 14 years before coming in for its first major repairs". While that negatively affects CFM's revenue, it is doubtless appealing to airlines.

Figure 2. GE90 High-bypass turbofan used on the B777.

3. CONSEQUENCES

As time passed and fumes became more noticeable (i.e., both more frequent and more severe), the industry failed to have cabin air quality sensors installed on aircraft. By then authorities must have been aware, yet they determined not to act. They apparently did not even investigate,[5] or if they did investigate, they may have found the information too sensitive to follow up and certainly too sensitive to mention outside the industry. Inquiring of a manufacturer why oil leak sensors were not installed, the present author received a rare reply: "We will not put anything on an aircraft not ordered by the customer".

Air carrier executives, having circumstantially learned that something was causing problems on aircraft, may have made themselves wilfully ignorant of such facts. If outsiders become aware that they know, they will need to act. Clearly, the courage among industry executives to act morally and ethically to protect public and occupational health is insufficient. If any one country, one airline official, one regulator, had acted responsibly, all would need to act responsibly; they would need to act to protect their reputations and their market share of passengers.

Unofficial records of crew illnesses and injuries over the late 20th century and early first decades of the 21st century confirm that pilots and especially flight attendants have suffered most. Sealed into their pressure-vessel workplaces[6] for hours each day for several days in a row, pilots breathe the same air as flight attendants. Neverthless, upon becoming aware of contamination, pilots have immediate access to aviators' breathing oxygen, unlike flight attendants. But when fumes occur without odour, as may often be the case, pilots have to become aware of the insidious onset of incapacitation to protect themselves. Failure results in two-pilot incapacitation events, which obviously can be catastrophic. Many close calls have been unofficially reported—"insidious" onset implies that it may be difficult indeed to sense.[7]

Flight attendants suffer from chronic exposure over time as well as the more immediately disabling effects of severe fume incidents. Their unofficial testimonials (see Appendix) confirm an often temporary but occasionally permanent disability condition. Without immediate access to oxygen, they must continue to be most dangerously affected until the captain diverts to a nearby airport or they arrive at destination. Crewmembers at most airlines must bear the costs of medical and loss of income when their employers refuse to aid them; workers compensation is regularly denied.

4. HUMAN HEALTH AND FLYING SAFETY TAKES A BACK SEAT

It is a matter of concern that EHM envisages no sensors for engine oil leaks nor sensors for cabin fumes; no indications other than visible haze or smoke, or developing symptoms of illness and the human sense of smell, are available to warn pilots of toxic conditions aboard their aircraft. Timely and appropriate response to these conditions will minimize resulting illness and disability. Failure to respond may lead to biological impairment, threaten occupational longevity, and among the most susceptible or exposed among crew and passengers, modify life experiences, and occasionally prematurely end life itself. One official reason given is that there would be too many false-positive alarms.

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[5] Ref. 3 provides a counterexample, albeit dealing only with small passenger aircraft.
[6] Although pressurized with respect to the external atmosphere, cabin pressure is only about ¾ of air pressure at sea level.
[7] It has been speculated that cigarette smoke may have covered up the odour of engine oil fumes in the aircraft cabin while tobacco smoking in airliner cabins was permitted. As a nonsmoker and moderately frequent airline flyer in the 1970s, the present author always sat in the nonsmoking section. Air turnover in the narrow and widebody aircraft of the day was continuous and similar to cabin air turnover today (i.e., mostly lateral, with little longitudinal movement [6]). He recalls only one occasion when the odour of smoke was a bother: his seat on that sold-out flight was immediately in front of the smoking section, located, as usual, aft in the cabin.

Appendix: Examples of fume events[8]

A1. DECEMBER 2022, A321 NEAR MIAMI

Airbus A321-200 from San Juan, Puerto Rico to Orlando, Florida, was en route at flight level 300 near Miami when the crew decided to divert to Miami after 8 crewmembers and a passenger became ill. The aircraft landed safely soon after. Fire–rescue paramedics treated the crew and passenger prior to transporting them to a local hospital. (Media source.)

A2. 1995, MD80

One flight attendant reported nausea, burning sensation in eyes, sinuses and airways, face flush and lightheadedness. Received workers compensation.

The flight was delayed for approximately one hour down-line due to a mechanical difficulty. The flight deck logbook describes smoke-filled cabin with fumes and odour of an oily nature when the packs were running. Oil was leaking from the APU compartment and, rather than have it fixed, it was decided that that the APU would not be used for the duration of the flight, or until someone decided that it had to be fixed. The APU was added to the minimum equipment list and the aircraft released for service.

Upon departure and with reference to a second logbook entry, fumes were again noticeable at climb-out. Upon arrival crew were told that there would be a further delay of the next leg because the aircraft ventilation system was compromised and that the filtration bags would have to be changed. Maintenance completed, the attendant was told that the aircraft was all right; it would have the oily residue smell for days, but it would not get worse.

En route to the next destination, fumes lingered in the cabin (smelling like "burning bug spray"). It was very irritating. En route on the return leg fumes suddenly started coming from the ceiling vents where the attendant was standing, mid-cabin. Passengers were ringing call buttons and asking what the smell was. They were becoming very anxious. The attendant could not breathe the noxious air being forced into the cabin from the vents, hence went forward and asked to stop taxi and open the doors. The flight deck refused and insisted that they would have the air cleared "any second" by whatever they were doing with the flight deck controls. The rapid airflow from the ceiling did then stop but the smell remained. After landing the attendant went into the crew rest facility and slept late. Next day, the aircraft was not taken out of service but continued to transport passengers and crew.[9] The attendant went to an emergency hospital for Haz-Mat exposure tests. At the time of the tests, it was >30 hours after landing and exposure, but tests still showed carbon monoxide poisoning.[10]

A3. SWISS INTERNATIONAL AIRLINES AIRBUS 320-200 FLYING FROM ZURICH TO GENEVA

Pilots reported smoke in the cabin and stopped the climb to cruise altitude at 15,000 feet. Return to Zurich was accomplished without incident. Emergency service was provided. No known illnesses.

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8 Investigators' *unofficial archives* are filled with stories like those given here. They were mostly gained through personal contact with flight attendants at various stages of illness and disability, and after recovery. Reliable authentication of each one remains elusive for the following reasons:
- Fear of retribution. Crew member identity must be protected.
- Government regulators, employers, unions and the airline industry overall have rules and regulations requiring smoke and fume incident reports. The rules are not enforced.
- Fear of public awareness.
- Pilots, particularly, try to distance themselves. Becoming associated with neurological incidents could threaten their medical certification. Therefore after exposure pilots typically try to avoid official medical help. Incidents of concealed pilot incapacitation periodically surface.

9 27 hours after the incident a flight attendant on the same aircraft was taken off, given portable oxygen, put into an ambulance and rushed to an emergency hospital. She was overwhelmed and incapacitated by the poisonous air of that aircraft. The fireman's meter was positive for carbon monoxide. The aircraft was then forced out of service.

10 Hospital discharge instruction: "Your exam shows you were exposed to carbon monoxide, an odorless, toxic gas found in all kinds of smoke and exhaust fumes, if enough is inhaled, it will cause poisoning because it combines with hemoglobin and other body chemicals to interfere with normal oxygen delivery. The symptoms include headache, dizziness, nausea, weakness, confusion, and blurred vision. Severe cases may require hospital care. The treatment is using high concentrations of oxygen until the symptoms are better. After going home, you should rest for 1–2 days, do not smoke, and avoid alcohol and sedative drugs. Be sure to correct the problem that caused the problem in the first place. A few people exposed to carbon monoxide will have problems with memory and thinking for several days afterward. Be sure to check with your doctor if you are not fully recovered within 1 week."

A4. 2018, B-767 FLEET # 256

A4.1 Flight attendant A

Charlotte, Aruba; passengers also ill.

A4.1.1 First aircraft

Crew symptoms: Headache, nausea, angina, troponin high, palpitations, chest pain, tremors, confusion. Lost ability to form words/sentences for weeks. Fourteen weeks suicidal thoughts. Neurological injury.

Chronic exposures, acrid odour—illness untreated over time between flights. Employer delayed medical assistance. Called her own taxi for trip to hospital. Long delay for transportation may have purged CO half-life evidence. Delay of this type became familiar after many fume incidents. Possibly employers are aware of CO and the half-life of carboxyhaemoglobin (COHb) in the blood of about 4 hours.

With diminished COHb test evidence, blood was nevertheless still positive for CO exposure. Company workers compensation representative (Sedgwick) changed her workers compensation First Report of Injury diagnosis to "headache, dizziness, nausea".

Local attorney disbelieved this flight attendant's story even with present author's corroboration. Attorney refused flight attendant's request for assistance.

This case, on top of her supposedly already weakened immune system, and possibly epigenetic health instability, necessitated two years away from work for recovery. She returned to work prematurely because her condition leaves her with no reasonable employment alternatives. She has one teenage child.

Forced into destitution, she filed for bankruptcy.

A4.1.2 Update 2021

Flight attendant has now fully recovered and returned to work.

A navy captain friend of the author requested a report of the FAA investigation (under the Freedom of Information Act). FAA conclusion—no violation of FAA standards on this flight. Odour was from oil spillage from APU. Non-toxic. Aircraft taken out of service and the matter corrected.

A4.2 Flight attendant B

Same flight. Symptoms: delayed. Felt unwell after landing. Employer refused travel assistance to hospital. Denied workers compensation.

These flight attendants have had many fume events over recent years. A previous fume event left one flight attendant with long term, untreated injuries. Denial of employers compensation for work-related injury medical costs and lost time (wage indemnity lost) forced bankruptcy filing.

Aircraft # 256 grounded by Aruba authorities.

A4.3 Second aircraft

Aruba companion story: B767 fleet # 284. Grounded because of unsafe fumes by Aruba authorities on the same day. This was the aircraft sent to recover passengers and crew ill and grounded on the first aircraft.

Passengers also smelled fumes. Some may have sought medical help.

Entire crew of pilots & flight attendants partially incapacitated. Symptoms: burning eyes, nose, chest tightness, disoriented, unstable equilibrium. Severe allergic reaction, blood pressure excessively high. Four days later COHb test showed trace carbon monoxide.

Fumes worse in flight deck. Captain appeared affected. Captain asked lead flight attendant the same question six times. Ultimately, she had to tell the captain to "snap out of it! Your mind is not functioning".

All claims denied by Sedgwick contract claims management services.

A5. 2020, B757[11]

PHL-DFW pushing back from the gate. Immediately there was a strong kerosene and shoe polish smell and the cabin became hazy forward from the exit row. Pax were coughing and covering their faces including myself and #1. (Cabin crew) #2 & #4 did not smell anything and were not affected. #1 immediately called the captain who told us it was normal at first. The smell became even stronger. We immediately called her back and told her we were dizzy and feeling nauseous and pax were coughing worse and it was NOT normal. Captain then acknowledged it wasn't normal and it was fumes and made a PA we were going back to the gate. PHL flight service & paramedics met us at the gate—they could smell the fumes from the jet bridge before the door opened, they said. The captain wrote a report up as an odor event and the plane went out of service. Flight Service in PHL was amazing and took care of us and had us call the IOD[12] number to direct us what hospital to go to for blood work right away. We told them we needed to get carboxyhemoglobin blood work within 4 hours. An FSM went to the hospital with us and stayed the entire duration until we were discharged.

[11] Anonymous testimonial given verbatim.
[12] Injury on duty.

I CAN'T STRESS THIS ENOUGH. If you are in a fume event, I don't care how bad (our CO levels were bad!) demand to go get your blood work done and have someone from flight service go with you to the hospital to speed up the process as you need that blood work done within 4 hours. The #1 & I had high amounts of CO in our blood. The hospital put us on oxygen to clear it out of our system and gave us fluids. Also, DO NOT take oxygen on the plane as that starts to clear it from your system and will not show up in bloodwork as the IOD desk asks you this when you call them! We had the lab work from the hospital to prove it—which was then sent over to Sedgwick. They APPROVED our IODs because we had the proof the CO fumes were in our blood.