Anatomy of an occupational hazard: Cabin air contamination in the air transportation industry**
Part 1. History—Evolving cabin air contamination
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This paper succinctly describes the aircraft cabin air contamination problem. It can be kept within acceptable bounds by good engine maintenance. Following airline deregulation, there is relentless pressure to cut operating costs. Streamlined maintenance may preserve thrust, but the quality of bleed air suffers. Although the antiwear turbine oil additive tricresyl phosphate, a well-known neurotoxin, has long been suspected of causing aircrew ill health by leaking into the cabin, there appears to be stronger evidence for carbon monoxide as the main cause of ill health.

1. INTRODUCTION

This is the story of air contamination on commercial aircraft. It begins with the US Airline Deregulation Act of 1978, passes 1 January 1985 when the US Civil Aeronautics Board (CAB) was disbanded, and proceeds to the present in a continuous battle for air carrier survival. But the story is not the point of this work: It needs to be recognized that airline employees and the flying public are occasionally threatened by air contamination that may be present in the air travel environment.

Every person is entitled to have a safe place to work. The aircraft flight deck and passenger cabin become dangerous when engine oil fumes escape confinement. Too often the pilots and flight attendants will not realize they are in danger because their employers, and the manufacturers of the equipment, have decided not to tell employees they are at risk. They also do not inform their passenger-customers that the air they breathe might at times be unhealthy.

Investigators and researchers of contaminated cabin air are, however, informed. They also know that the cost of eliminating the problem has always been formidably high [1,2].

2. AN ACT OF CONGRESS (24 OCTOBER 1978)

The Airline Deregulation Act of 1978 [3], promulgated by the 95th US Congress, was signed into law. It did little more than to impose upon the air transportation industry a questionable economic theory, 18th century Scottish moral philosopher Adam Smith’s “invisible hand” [4,5]. It was applied in the form of free market competition; heretofore airlines had never before, in the 40-year history of the industry, competed on the basis of ticket price. What followed was a self-flagellation that nearly destroyed the entire industry [6]; only four of perhaps twenty-four major air carriers survived.

3. COEVOLUTION OF EVENTS IN THE AIRLINE INDUSTRY, 1970 TO 1985

Prior to the Deregulation Act of 1978 and the subsequent disbanding of the CAB [7], it can be safely assumed that aircraft engines, both civilian and military, were operated mostly within the manufacturers’ maintenance guidelines, i.e. approximately 5,000 hours since new or between overhauls (time between overhaul, TBO). New engine maintenance protocols and deregulated airline management evolved together after 1978. New engine overhaul procedures perfected to lower the cost of power plant maintenance matched the lower revenue per passenger, soon to become the standard of airline profit-and-loss accounting.

Exceptions to the 5,000-hour maintenance standard would have needed to be made for the large, new generation engines powering the wide-body Boeing 747, Douglas DC10 and Lockheed L1011. Presumably manufacturers recognized the greatly elevated overhaul costs for these large, new engines and their heavy lift airframes. New protocols for engine maintenance had been in development throughout the 1970s. I recall reading an early “Aviation Week” article about vibration sensors being installed on a King Air PT-6 engine. It was an early realization of devices to warn of engine trouble or performance deterioration. That it would lead to engine health management (EHM), condition-based maintenance (CBM), and predictive maintenance (PM) protocols in the 21st century could not then have been guessed. Supported by arrays of sensors monitoring most aspects of engine performance, generating data fed to a collection point on the aircraft, whence sent by satellite to land-based stations, these new engines could be operated without major maintenance as long as the data confirmed performance to be “in the green”. Interestingly, as easy as it might appear to include cabin air quality sensors, there were none in the beginning, and there are none today.

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** Dedicated to ill and disabled crewmembers and those who continue to be exposed to contaminated cabin air.
“Now they are on their own”, stated the last administrator of the Civil Aeronautics Board. “Free markets do a better job than government”. His falling gavel placed a period behind a history of airline regulations and micromanagerial protectionism that had governed the airline industry since its formal inception in 1938 [8].

Chaos ensued when the air carriers of the day clashed over ticket prices in a survival-of-the-fittest contest for market share; air carriers tried to eliminate each other. Facing ever-decreasing revenue from the new low fares necessary for survival, aggressive operating cost cutting ensued. Among the early cuts were wages, employee benefits and customer services. Important maintenance was first postponed; then curbed because of insufficient funds; state-of-the-art evolution in high-bypass turbojet engines increased overhaul costs to such a degree that historical maintenance protocols had to be abandoned. Digital recording and communication of engine performance data gave birth to new engine health management protocols which, although cost-effective, set a dangerous precedent when human health and safety began to be compromised. In conclusion, the 95th Congress, steeped in zealous ambition to lower fares without regard to consequences, blew its opportunity to usher in for a new, more pleasant air travel experience.

Some turbojet and low-bypass turbine engines might have continued to be overhauled regularly to the extent that funds remained available to pay the cost; approximately $250,000 for each overhaul. However, we speculate that high-cost journal entries of this type fell from the ledgers. High costs of maintaining the newer, larger engines soon became difficult to support in the low-fare environment of deregulation. Aggressive cost cutting across the entire management landscape became the industry norm. We also assume that:

a) All engine maintenance gravitated toward delayed maintenance under EHM protocols;

b) Engines entered the new maintenance protocol era at various logged hours of operation;

c) Aircraft engine parts, as components of industrial equipment, deteriorate, hence performance wanes over time;

d) Seals in engine bearing compartments are located within the most dynamic gradients of temperature and pressure anywhere in the engines except for the burner section;

e) Engine oil leaks, and fumes were not included in sensor designs for the new engine monitoring systems.  
f) The human senses of smell and vision were selected by default to become the early warning systems for cabin air contamination.

In conclusion, the 95th Congress, steeped in zealous ambition to lower fares without regard to consequences, blew its opportunity to usher in for a new, more pleasant air travel experience.

Symptoms began to appear among flight attendants and some passengers. Headache, nausea, vomiting, dizziness, deep fatigue, numbness, tingling, tremors, eye/nose/throat irritation, chest tightness, confusion, cognitive and concentration difficulties cover most of the common sensations. This list was collected from among aircrew experiences.  

All makes and models of aircraft with bleed air-supplied environmental control systems can occasionally suffer oil leaks and related toxic fumes in
the cabin and flight deck. From time to time, all can potentially, repeatedly and unpredictably impose hazardous fumes upon unsuspecting passengers [11].

A considerable number of dangerous incidents and accidents have occurred in the first two decades of the 21st century (Fig. 2), some prematurely terminating lives [12]. Most of these cases have never been investigated and, therefore, we have no ample reference basis from which to estimate the likelihood of future accidents. Existing rules requiring fume incident reports are not enforced. Investigators are too few in number to keep up with the apparently increasing frequency and severity of fume events. Hence, statistically the safety and health situation in the airline industry is blind.

Figure 2. From left to right: a clean passenger cabin; cockpit with fumes; fumes entering the starboard side of the passenger cabin; a severe fume event.

6. A PERSISTENT, INSIDIOUS, DANGEROUS PLACE

Up to 1980, throughout the years before deregulation, there were no fume events of note reported to airline workers compensation underwriters; no fume-related workers compensation claims were filed. Being Director of Safety at U.S. Aviation Underwriters, Inc. and keen to watch for trends in injuries and illnesses on the job, I combed cases over a nine-year period. My job at USAU was lost in mid-1980, when every US airline CEO canceled his airline’s workers compensation insurance policy. Looking at the situation during the past twelve years, I conclude that the airline industry is not in compliance with state workers compensation laws.

Fume events began to appear c. 1985 and by 1995 had become more common. At the beginning, lawmakers, manufacturers and airline operators were taken aback. Manufacturers’ and airline operators’ executives were doubtless concerned about discovery of this issue, certainly by employee injury experience, and possibly feared negative public opinion. Their response was swift: they became silent. They denied and deflect. They would not openly investigate fume events. The US Federal Aviation Administration (FAA) presumably also investigated, but to this day no opinion about contaminated cabin air has been offered, except to imply “no such thing”. Air carrier managers and regulators continue to remain silent or otherwise deny the issue.³

Deny, deflect, dispute: the FAA and National Transport Safety Board (NTSB) hide behind Federal Air Regulation definitions by categorizing fume events as incidents, not accidents. In this way they have and continue to avoid responsibility. They falsely try to assure the public and employees that nothing of concern was or is now happening on airliners. “The air in aircraft cabins is purer than the air in your home” is the go-to explanation. “HEPA filters clean the air to operating theatre purity”— untrue, but good press all the same.

Fume incidents have increased in frequency and severity throughout the years following deregulation as aircraft systems maintenance languishes. As mentioned, regulators require incident reports but compliance is weak and the rule is not enforced. Through this neglect anyone wishing to assist the safety effort cannot easily learn about toxins in the air. Flight attendants have become more and more exposed to cabin air contamination on their flights, yet remain mostly unaware that they, above all other air travelers, are most susceptible to chronic exposure to contamination. They are carrying the burden of their employers’ legal liability with their health and personal finances.

7. CONTAMINATION IN ENGINE OIL

Tricresyl phosphate (TCP), widely used as a fire retardant, plasticizer (especially in PVC), and as an antiwear agent in high-performance lubricants, is listed as

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³ Anecdote from a U.S. Airways aircrew: “Failure to investigate”: in 2017, with the captain deceased by his own hand, the first officer and flight attendants (all but one permanently disabled), met with the FAA, NTSB and a senator in Washington DC to request that their nearly catastrophic, 16 January 2010 fume experience on U.S. Airways flight 1041 be investigated. They submitted a box containing details of the incident and medical records for each crew member. The FAA agreed to consider the evidence and report back. Their box was returned three months later, unopened and without comment. We should be aware that from the loss-of-control viewpoint, incidents are precursors of accidents (see also ref. 12).
a chemical of concern on synthetic turbine engine oil containers, warning of its dangers, especially when ingested [13]. Given its very well established neurotoxicity, researchers thought TCP must be the problem contaminant. From my personal, professional viewpoint, the airline industry truthfully asserted that TCP in the small concentrations present in engine oil was very unlikely to cause illness among aircraft occupants.\(^4\) Research to establish the validity of this assumption continues. More than thirty years of aircrew testimonials and biomedical research indicate that the toxic contaminant of most concern is carbon monoxide (CO). Considering the hydrocarbon content of engine oil, aircraft engines and auxiliary power units (APUs), in which combustion takes place, are doubtless the prime producers of this most dangerous of gases. But this has not yet been sufficiently investigated through measurements of cabin air during flight or other on-site observations. Aircrew medical diagnoses, observed symptoms, injury recovery experiences, disabilities and death provide the only evidence at present for the presence of toxic concentrations of CO.

Researchers are also concerned about chemical reactions among a mix of various compounds in oil and cabin interior materials. Toxic residues from wipes of interior aircraft surfaces, and blood screenings, add to a long list of potential hazardous exposures. Such issues would need to be researched at length under many variants of chemical concentration, temperature, pressure and altitude, and combinations and permutations within the mix. Such a project has never anywhere been accomplished.

8. 2019 TO 2023

In 2019, just before the Covid 19 pandemic, fume events and injuries appeared to peak. Reportedly one airline had 60 pilots on leave for fume-injury recovery. One wonders why the FAA did not ground these pilots. Because of the current pilot shortage, is a neurologically impaired pilot better than no pilot at all?

Aircraft placed in storage during the pandemic have now been recovered for service going forward. But new challenges have arisen to complicate our story still more, as will be described in the succeeding Parts.

9. CONCLUSIONS

The risk management process must at times act upon convincing circumstantial evidence, to avoid unsafe acts and conditions being allowed to persist at high cost in human suffering. This paper asks for three measures to be enacted:

- A declaration that an occupational hazard and a public health hazard exists on airline aircraft;
- In the event of toxic exposure, medically supervised administration of pure oxygen as near (spatially and temporally) to any exposure as practicable;
- Installation of carbon monoxide sensors in the engines, auxiliary power unit (APU), environmental control system (ECS), and human-occupied areas of all aircraft in which the cabin is heated and pressurized using bleed air, in order to warn pilots of the likelihood of exposure to toxic fumes, enabling them to take timely and appropriate emergency action.

Implementation of these measures will moderate illnesses and prolong lives; failure to implement them will injure the most susceptible (estimated as 10–20%) air travelers. It should be borne in mind that whenever a crewmember is injured, passengers are also exposed, but they are not warned of the hazard. Failure to act ultimately implies that the airline industry ranks government and corporate interests above the welfare of its employees and customers.

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REFERENCES


\(^4\) Cf. “The estimated exposure to tricresyl phosphates of the neurologically injured pilot is considerably smaller than current paradigms would suggest is sufficient to cause his neural degeneration and associated problems” [14].
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