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Aircraft Air quality incidents, symptoms, exposures and possible solutions

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Aircraft air quality problems have been experienced by pilots, flight attendants, as well as passengers over the years. In many instances the complaints of these individuals are often dismissed as anecdotal since the available information is incomplete preventing these incidents to be written up in a scientifically accepted format. In 1998 an article by van Netten and Hilliard (1), entitled "Air quality and Health Effects Associated with the operation of BAe 146-200 Aircraft" was published in the peer reviewed literature. This article appeared to spark the interest, not only of pilots and flight attendants, but also of the industry and their lawyers. Although the authors of the above article submitted the manuscript for publication in good faith, meaning that identifying the problem would benefit the industry and thus work towards improving the air quality within aircraft, they did not expect to be legally challenged and instructed not to publish the article. Nevertheless

after some negotiation between the lawyers and one of the authors, the lawyers agreed that publication of the article was in the best interest of the industry and gave their permission. Although the upset conditions described in the article were nothing new, one can appreciate why very few, if any, of these events have been published.

A previous 1986 NRC publication (2) identified a number of problems in the general cabin air environment and made numerous recommendations some of which were acted upon such as a ban on smoking on all domestic aircraft. In spite of some of the changes made, the complaints by flight crew members and passengers did not disappear and the NRC was instructed to revisit this area of research (3) including the sporadic air quality incidents, or upset conditions that were addressed in the 1998 article (1) mentioned above. Since 1998 a number of new inquiries have been conducted including one in Australia on BAe 146 aircraft (4) and a report by the House of Lords in London (5). Although the former inquiry was very extensive, and in depth, the latter was not. It is therefore no surprise that the final conclusions reached by each of these inquiries were not consistent.

Numerous air quality incidents have since been reported in local and regional newspapers (6) some of which narrowly escaped accidents such as the November 5, 2000 Birmingham incident (7), Oil smell in cabin, Pilot felt "dreadful", "seeing double when landing".

and another on November 12, 2001, Braathens Malmo incident (8), Oil leak in engine #2, "Poisoned pilots almost crashed", "Pilots close to blacking out", Passengers seemed "passivated". The latter two incidents both involved BAe 146 aircraft whereas the former incidents involved MD-80 aircraft.

The frequency of these air quality incidents has been reported by van Netten et al based on information obtained from 3 North American Air carriers (9). The results have been summarized in table 1.

Table 1. Air quality incident frequencies, based on flight incident reports submitted to 3 North American air carriers by flight crew members

<u>Aircraft type</u>	<u>Average number of incidents per aircraft</u>	
	<u>per year</u>	<u>per 1000 cycles*</u>
BAe-146	6.4	3.88**
MD-80	1.01**	1.02**
A-320	1.67	1.29
B-747	0.34	1.25
DC-10	0.38	1.04
B-767	0.21	0.63
B-737	0.07	0.09

* A cycle is defined as: a take-off, flight, and landing sequence.

** based on incomplete data and estimates.

It should be emphasized that the reported frequencies are highly dependent on local maintenance and operating procedures, which can differ substantially from operator to operator. Nevertheless some trends can be observed specifically with BAe-146, MD-80 and A-320 aircraft.

The reported symptoms associated with these incidents (9) have also been summarized and are displayed in table 2 below.

Table 2. Symptoms associated with air quality incident reports

<u>Symptom</u>	<u>Air Carrier</u>		
	<u>X</u>	<u>Y</u>	<u>Z</u>
Any symptom	58%	78%	82%
E,E,N,T*	38%	16%	25%
CNS**	45%	72%	64%
Intoxication	45%	70%	63%
Neuropsych.	3%	3%	2%
Other	6%	19%	8%
Respiratory	9%	16%	28%
Gastro intestinal	16%	30%	21%
Skin	7%	10%	3%
Cardio vascular	2%	3%	2%
Total incident reports	128	598	299

* E,E,N,T, eye, ear, nose, and throat

** CNS, Central nervous system

It can be observed that the majority of symptoms were associated with the central nervous system in all 3 carriers whereas symptoms associated with the respiratory system ranked relatively low and were in 2 of the carriers, even less frequent than those associated with the gastrointestinal tract.

Since the central nervous system appears to be affected most often, one has to ask the question whether any agent or agents are present in the aircraft that have a known neurotoxic effect. As identified in the 1998 article by van Netten in the BAe-146, jet engine oil can enter the aircraft ventilation system when there oil seals are wearing out allowing jet engine oil to leak oil into the air. MD-80- aircraft have an additional source of oil contamination into their air supply. This additional route involves the APU, Auxiliary Power Unit. The APU is also a jet engine which is used to supply power and air to the aircraft when the main engines are not running or when full power is required during certain phases of flight and bleed air cannot be spared from the main engines. Although all aircraft have an APU and are also vulnerable to potential jet engine oil leaking into the ventilation system, MD-80 aircraft have an additional problem. In this aircraft there appears to be a small orifice in the rear of the aircraft that allows hydraulic fluids and spilled oils that accumulate in the bilge of the aircraft to be dumped overboard. The location of this orifice happens to be directly in front of the air intake of the APU, which will ingest it and release it at high temperature into the ventilation system of the aircraft. For these reasons a number of engine oils and hydraulic fluids have been investigated for constituents that might be released into the cabin air environment. In addition, since bleed air is extremely hot when it leaves the engine and enters the ventilation system of the aircraft the possibility of pyrolysis of oil constituents also has to be addressed.

This was investigated and reported on by van Netten et al in a number of articles (10,11,12,13). Aside from the finding that the organophosphate, tricresylphosphate (TCP) was present as an undisclosed ingredient in one of the hydraulic fluids investigated, the main findings were that CO is produced when oils and fluids are subjected to these temperatures and TCPs are released into the air, remain airborne, and consequently can be captured from the air at room temperature.

The acute toxicology of CO is well known (14,15) and exposure to this agent in the aircraft could very well explain the acute neurological symptoms experienced by the pilots of the Birmingham and Malmo incidents. The chronic toxicity of CO is coming into focus and this agent appears to damage central nervous system resulting in symptoms that have been compared to Parkinson's disease. (). This is not surprising as it has been recently recognized the CO is a neurotransmitter. ()

The toxicity of TCP is also well known (14,15) and has centered around the ortho isomer (TOCP). This agent has been linked to delayed chronic neurotoxicity symptoms. For this reason there is a clear statement on the back of some jet engine oil cans that warns that the oil contains an organo phosphate esters belonging to a group known as tricresyl phosphates which, upon exposure, can cause nervous system disorders.

The symptoms associated with, and the toxicity of organo phosphate esters has recently been reviewed by Abou-Donia 2003 (16) in involve three main categories

1, Organophosphate Ester-induced toxicity due to Acetyl cholinesterase (AChE) inhibition. Recent human exposures occurred in Japan during a number of subway attacks these include:

the 1994 Sarin attack in Matsumoto, Japan, where 600 individuals were exposed, resulting in 58 hospital admissions and 7 death. Another sarin attack took place in 1995 which targeted the Tokyo subway. This resulted in the hospitalization of 5000 individuals and one death. Many CNS symptoms were reported.

It was interesting to observe that when the recommended, and standard test for exposure to these organophosphates, i.e. red blood cell AChE inhibition returned to normal, there were still signs and symptoms of central nervous system effects including pupillary constriction present with normal AChE levels

2, Organophosphate Ester-Induced Delayed Neurotoxicity, (OPIDN)

are the effects that have been directly linked to TOCP exposure (14,15). Exposure to this agent will result in the slow destruction of the peripheral and central nervous system. The standard test for exposure to this agent is Neuro Target Esterase (NTE) inhibition.

One unexpected finding from the Tokyo experience was that humans more sensitive to sarin induced OPIDN than animals.

3. A third class of organophosphate ester toxicity is currently being recognized and has been referred to as Organophosphate Ester-Induced Chronic Neurotoxicity (OPICN). This condition is associated with Chronic neurological problems persisting for years, which are distinctly different from AChE and OPIDN effects. This conditions has often been referred to in the literature by various names such as: "Chronic neurobehavioural effects", "Chronic organophosphate induced neuropsychiatric disorders (COPIND) ".

These effects are the result neuropathological lesions of cortex, cerebellum, hippocampal formation and other central nervous system targets. These lesions appear to be linked to destruction of certain nerve cells as well as an inability of the system to cull out abnormal nerve cells by preventing their normal and programmed cell death referred to as delayed apoptosis.

Since these organophosphate esters are blocking normal function of a number of essential enzyme systems either reversibly and/or irreversibly, they are prime agents to have their toxicity increased many fold when exposure occurs in the presence of another agent that can act as a synergist. This phenomenon has been well appreciated by pesticide applicators who, for instance, add piperonyl butoxide to a mixture to enhance the toxicity of the actual pesticide. The final toxicity of this mixture is not the sum of the individual toxicities but in fact is many times higher. Adding piperonyl butoxide to a mixture produces a potentiation effect making the initial pesticide, in some instances, 110 times more toxic.

TCPs inhibit among other enzymes, carboxyesterases, an enzyme group that is essential in the metabolism for a number of pesticides allowing them to persist longer in the tissues enhancing their toxicity. Pesticides that can be encountered within an aircraft can include permethrin and phenothrin, both are currently used as disinsectants in the aircraft industry, (17).

Permethrin for instance is destroyed by the action of carboxyesterase to 3-phenoxy benzyl alcohol and 3-phenoxy benzoic acid. One can see that a previous and/or current exposure to TCP or any other agent that inhibits carboxyesterase activity, would make such a person highly susceptible to the effects of a relatively low toxicity agent such as permethrin that the body is now incapable of breaking down.

This concept might be the reason why certain individuals are highly affected by "acceptable" levels of a particular agent whereas another individual, present in the same environment does not experience ill effects. The effects experienced by certain soldiers that have been classified

as Gulf War Syndrome (18) might very well be due to the action and presence of certain synergist. In this respect it should be appreciated that permethrins are liberally used in the armed forces for mosquito control and apparently often impregnates this compound into uniforms. TCP exposure is also likely to be present in this environment as gas turbines are used to power heavy equipment such as tanks and require the same class of lubricating oils as aircraft jet engines.

At this point in time there is good evidence that flight crew members are reporting symptoms that are consistent with having been exposed to an agent, or agents, that appear to have an important effect of the nervous system. There is also clear evidence that jet engine oils and hydraulic fluids can release neurotoxic agents into the ventilation system of the aircraft. What is missing at this point in time are direct measurements and the quantification of actual personal exposure to these agents during these rare, and often unpredictable, upset conditions. Without direct exposure measurements it becomes more difficult to link the reported symptoms to the presence of neurotoxic agents on aircraft.

Exposure assessment

From an Industrial hygiene point of view direct personal exposure measurement are the most preferred method and most useful. Biological monitoring is also very useful but requires that the agents of interest are known along with their metabolites which should be succinctly different to eliminate other non work related exposures. Without actual measurements under upset conditions in the aircraft this information is only available from extrapolation using laboratory simulations. Direct measurements under upset conditions are difficult to obtain primarily due to the relatively low frequency and unpredictability of them occurring. In order to capture these infrequent exposure events one would require large numbers of identical equipment to be placed on board of many aircraft to be activated during an upset event when it does happen to occur. One can appreciate therefore the reluctance of the aviation industry to participate in such a study specifically since current equipment would be too awkward and intrusive during normal day to day operation and would require a trained technician to be present.

Since direct exposure measurements are not realistic at this time, one could ask the question whether there are indicators on board of aircraft that can provide some insight into the quality and nature of the contaminants that might be present in the air. One obvious source of this information is found in an analysis of the air filters that filter the air from the cabin before it is recirculated back, and mixed with a certain percentage of fresh air, into the cabin. Any contaminant that is present in these filters has been captured from the air to which passengers and crew members have been exposed.

Another source of information regarding the quality of bleed air is an analysis of the coalescer bags. These textile bags are present between the source of bleed air and before the air enters the cabin as fresh air. These bags are present to remove excess water from this air source. Since they also seem to filter the air to some degree an analysis of these bags will provide information as to what contaminants are present in the bleed air. They do not provide information regarding exposure as one could argue that, since they are located prior to the air entering the cabin, they are effective in cleaning the air, hence no exposure.

One additional indicator of exposure that provides useful information is an analysis of the uniforms that are used by crew members. The presence of contaminants would be an indicator of surface and/or air contamination. The results could also be an indicator of dermal exposure.

The results from GC-MS analysis of a number of items from various locations in aircraft have been summarized in table 3 below.

Table 3. Results from GC-MS analysis from various locations in the aircraft environment.

<u>Filter analysis</u>	<u>TCP presence</u>
Flight deck roof vent BAe -146	+ ve
Forward Lavatory BAe -146	+ ve
Flight deck roof vent B -757	+ ve
B-737 Lavatory filter (+ve for cocaine and amphetamines)	- ve
Prefilters form re-circ air BAe -146	+ ve
HEPA filter analysis B-757 (30 micro grams TCP/filter (total area 4.5 m ²))	+ ve
Analysis of a pilot pants (.17 micrograms/ pair of pants)	+ ve

Aside from the presence of recreational drugs in one the lavatories, other agents found on filters, among many others were Tripropyl phosphate (Fyrol), Triphenyl phosphate (fire proofing agent), Phthalate esters (plasticizers), Brominated compounds (fire retardants) Some of these are potential synergists with the exposure effects of TCPs, to what extent this is important needs to be validated.

The data summarized in table 3 above clearly illustrates that TCP isomers air present in the air that passengers and crew members breathe. These data show the presence and exposure to TCPs and other agents but do not tell us to what extent. In order to address this question one needs to measure the level of exposure during an actual incident.

As mentioned before current available instrumentation is rather bulky, consisting of a personal sampling pump, along with a tygon tube that has to be connected to a cassette that houses a filter. In order to take an air sample the tygon tube has to be connected to the filter cassette from which two stoppers have to be removed and replaced after exposure. Although not complicated for a technician, it is not recommended for crew members such as a flight attendants or pilots. This is specifically true during upset conditions when other things are more important. Since the frequency of these events are relatively low and unpredictable, requiring the presence of a large number of technicians is also equally unrealistic.

In appreciation of these problems this author designed and manufactured a very simple self contained air sampling pump which is a small plastic cylinder 2 inches in diameter and three inches tall which easily fits into a purse, briefcase, or a pocket. The unit contains a battery

powered sampling pump and accommodates a standard preassembled 37 mm cassette filter that is totally enclosed. With a 45° twist of the cap of the cylinder, the system is activated and the filter is exposed to outside air that is pulled through the filter at flow rates between 1-3 liters of air per minute for 20 to 30 minutes, depending on the type of filter and the batteries present. A reverse twist of the cap will isolate the filter from outside air and stops the pump. The whole assembly is small enough to be conveniently send by mail to the laboratory for analysis and reassembly.

This device has now been patented and is referred to as the VN sampler.(xx)

In addition the cost of each unit are small enough to allow many of these air samplers to be provided to pilots and flight attendants to be activated when needed.

Although an analysis of these filters will provide some direct evidence of what contaminants might be present in the air at the time of activation it does not address the question of the acute exposures to toxic gases such as CO.

Information of CO levels during flight are essential as they can provide clues to potential oil seal failure before these result in to a serious air quality incident. Monitoring for CO by one flight attendant during a number of flights showed elevated, but “acceptable” levels of CO many days before an oil seal failure was detected in the APU. In addition since many aircraft are now outfitted with activated carbon filters the passengers and crew are deprived of an early warning system, i.e. the presence of a burning smell or smoke that alerts them of a pending problem. Since CO is not captured by these filters, in flight CO monitoring is essential and, in fact, is one of the recommendations of the 2002 NRC committee(3).

Since the air samplers described above are capable of capturing agents that can have a more chronic effect such as TCPs, it would be highly useful if they could also be used to assess acute hazards such as CO. For this reason a small data logging CO monitor has been developed has been incorporated into the VN sampler and now referred to as the VN^{+CO} sampler. This CO component although incorporated into the sampler is totally independent from the sampler itself and provides a LED incremental bar readout of current levels. The LED readout was chosen based on pilot’s input as they would have problems reading a LCD screen at nighttime. Seriously elevated CO levels during flight could also provide a trigger to activate the sampler. After activation of the sampling pump and return to the lab the CO memory can be downloaded to provide an accurate history of the CO levels previous to, and during, the last flight when the sampling pump was activated.

It is interesting to note that when the author of this article was member of the NRC committee, he argued strongly for a number of recommendations including CO monitoring. This was in fact included in the final recommendations. He also made two other suggestions, 1, that the level of pressurization in the aircraft should be changed from an 8000 feet equivalent altitude to 6000 feet in order to avoid hypoxia in individuals who have a compromised respiratory system. And 2, that a large number of the current bleed air problems could be entirely by-passed by not using a bleed air system to pressurize the cabin. In the past ram air from outside the aircraft was used (19). For economical reasons this was abandoned in favour of the current bleed air system. The experts on the committee strongly opposed this idea as they claimed “it could not be done”. It was therefore extremely gratifying to learn

since then that the new Boeing 787, initially referred to as 7E7 (18) is, for also for economical reasons, not using bleed air to pressurize the cabin, in addition it will pressurize the cabin to an equivalent altitude of 6000 feet. This was made possible with the use of composites for the construction of the fuselage, rather than the usual aluminum alloys, preventing the problems of metal fatigue that go along with the pressurization-depressurization cycles to which an aircraft is subjected.

Although the B-787 is slated to become available in 2008, it does not solve the current problem of a large fleet of aircraft that is totally dependent on bleed air system technology in order to supply air to, and pressurize, the cabin. For this reason it is essential that close attention is paid to the potential exposures that are the result of bleed air contamination and put into place an effective surveillance system that protects pilots, flight attendants and passengers from injury.

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