A conference most revealing: aircraft cabin air quality

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These impressions from the Workshop were compiled while the event was still fresh in my mind with the help of notes taken during the day and without having read any of the papers, even in draft, that are published in the remainder of this issue.

1. INTRODUCTION

In 40 years of attending conferences of a scientific nature around the world, I have never encountered a workshop/conference such as the one I attended at Cranfield University on 11 October this year. Entitled "Inhalable toxic chemicals on board aircraft", it was organized and chaired by Professor Jeremy Ramsden, himself not one of the authors of the final report of the "Aircraft Cabin Air Sampling Study" produced by Cranfield University, partly in response to questions raised in the Houses of Parliament concerning reported instances of illness of air crew and passengers, and which triggered the conference. Unfortunately the report has received a great deal of adverse criticism, both from campaigners trying to improve cabin air quality and from scientists, but nevertheless had been used by the UK Transport Minister to declare that air travel was safe and contaminated cabin air was not a problem.

I thus attended the conference having read the Cranfield report with an open mind but in the knowledge that the report itself left many unanswered questions, particularly regarding the concentrations of organophosphates measured in the cabin air and the link to illness and indeed the mechanism by which these organophosphates, tricresyl phosphates (TCP), could cause damage to human beings. However, I was unprepared for what followed. I had assumed that the Workshop would answer these questions and that I would be reassured that air travel as a passenger was safe. As the day progressed my comfort zone was severely shaken as the conference provided an eclectic mix of scientific papers and emotional personal diaries of pilots and passengers affected by air travel. The mix of professional science reporting followed almost immediately by evocative and emotional personal stories and some individuals' fights against the system evoked a seesaw of emotions ranging from logical objectivity, empathy and compassion to pride and hope that individuals can fight and win against "big brother" society.

The following is a summary of the day's events; the individual presentations and papers are published separately but the overall impression and the questions that followed are reported here in order to give a flavour of the proceedings from a personal point of view. During the day there was considerable humour and the level of sustained interest of the 50 or 60 people present until late at night was quite extraordinary.

2. THE DAY ITSELF

The day started with the Chairman outlining the history of the Cranfield research and some of the criticisms since the publication of the final report, which had shown from the limited measurements made on various aircraft that TCP was present in vaporized form in the cabin air at low concentrations. However, early work in Germany on the toxicities of the various TCP isomers in the 1950s had demonstrated nervous system damage even at very low concentrations. TCP is present as a vital antiwear additive in many synthetic gas turbine oils and its boiling point is about 200 °C, so that under typical domestic conditions it would not vaporize.

The next speaker, Dr Susan Michaelis, outlined the problem and its effects on cabin crew and passengers. Typically, jet engine oil contains about 3% TCP and the problem started in the 1960s with passenger aircraft that flew high and required pressurized cabin air. For the aircraft manufacturers the cheapest and most expedient means of providing this was to bleed air from the low pressure turbine stage of the engine. More recently the demand for higher fuel efficiency has led to engine temperatures considerably increasing so that dynamic oil seals designed to "weep" oil will produce TCP in vapour form, which will in turn enter the cabin air. Although the airlines are aware of this fact they are reluctant to provide data concerning maintenance and oil usage other than for major maintenance failures. It would appear that aircrew report symptoms of illness but are reluctant to make formal complaints due to pressure to retain their employment. However, from confidential interviews the instance of aircrew illness might be as high as 11%.

There then followed a very humorous talk by Dr Halvor Erikstein detailing instances of workers suffering from symptoms like multiple sclerosis during or after service on offshore oil rigs. Such rigs use gas turbines for power and lubricant oil overpressure is vented off the rig, exposing engine maintenance workers to vaporized organophosphates.

Journal of Biological Physics and Chemistry **11** (2011) 216–220
Received 17 October 2011; *accepted* 1 November 2011

doi: 10.4024/22HO11A.jbpc.11.04

At this point the tenor of the presentations changed dramatically from calm, logical science to the harrowing story of one pilot, Len Lawrence, who was discharged by his airline as being mentally unfit and placed under a restraining order. His story was one of costly legal battles to prove that his brain injury was due to chemical exposure and that he was not mentally unfit. What emerged was a story of incompetence by the medical profession, who lacked knowledge of the symptoms following exposure to neurotoxins and the unfairness of the legal profession in not allowing him to see data concerning his own personal records in their reluctance to tackle those culpable.

In discussion, what emerged was that the authorities in all countries are not interested in the possibility of cabin air contamination. Pilots exhibiting symptoms consistent with myalgic encephalomyelitis (ME) are retired early and no data is published by the airlines. In the Netherlands it was estimated that perhaps a third of pilots exhibit so-called burnout symptoms and that general practitioners generally have little experience of neurology and almost none of neurophysiology, to the extent that symptoms reported by air staff are usually diagnosed as psychosomatic. A recurring theme of sufferers was the difficulty of obtaining a proper diagnosis and the view that only post-mortem brain examination would provide a causal link to organophosphates. Another recurring theme was ignorance. It is apparent that both oil companies and airline manufacturers are aware that TCP can be present in cabin air but this information is not imparted to aircrew to the extent that the pilots and aircrew are not generally aware of the possibility of neurotoxin exposure until after they have become severely ill and begun exploring websites for similar sufferers.

The next speaker, Dr Sarah Mackenzie Ross, is a psychologist based at University College London (UCL), who conducted a study on pilots, some of whom had complained of illnesses. The study compared those who thought they had been exposed to contaminated air and those who thought not but found little to distinguish between their performance in terms of abilities to multitask. Disquietingly, attempting to get a further study funded by the UK Department for Transport raised considerable barriers—the Department required a proven link between contaminated air and pilots' performance impairment while the pilots union and the UK Civil Aviation Authority (CAA) both refused to coöperate, to the extent that the CAA attempted to terminate all future research in the area on the grounds that it was not ethical! Fortunately, UCL robustly rebuffed the CAA attempt, declaring that the only unethical behaviour was theirs. Spontaneous applause erupted as this David versus Goliath battle story was told.

Dr Byron Hyde, a specialist in myalgic encephalomyelitis (ME), then provided a very convincing description of the identification and diagnosis of this disease. Typically, 50% of ME is caused by viral infection but there is now increasing evidence that it is also a consequence of chemical toxicity. Again, the pressure on general practitioners to describe any symptoms as psychosomatic was recounted. After an incident in 1934 in the USA when a hospital erroneously treated victims of an ME epidemic and insurance companies were forced to pay compensation, pressure has been applied by insurance companies on "expert" medical witnesses for them not to admit a true diagnosis in many neural disorders. An insidious form of corruption seems to exist whereby specialists can earn considerable fees from insurance companies by obfuscating the real cause of illness; for example, in the cases of ME sufferers seeking compensation through the courts. Nevertheless, a feature of ME is low blood flow in the brain and various techniques are available to detect this effect such as transcranial Doppler, positron emission tomography (PET) and single photon emission computed tomography (SPECT) scans. Also, there appears to be a tendency for ME sufferers to develop Parkinson's disease in later life and another typical symptom is an aversion to alcohol, which reduces blood pressure and thus exacerbates the ME sufferers' pain.

At this point the discussions highlighted both the lack of knowledge of general practitioners of the diagnosis and treatment of ME and the degree of pressure exerted by vested interest groups in suppressing facts: it was almost the stuff of fiction and the plot of a novel.

There then followed science and hope. Dr Michel Mulder, himself a former pilot, works as an airline medical examiner in the Netherlands. He described the effect of TCP isomers on the generation of all of the four neurotransmitters. The reduction in particular of the production of dopamine results in symptoms typical of ME. A concentration of TCP isomers of 100 $\mu g/m^3$ is currently considered as the standard safe limit but some isomers will cause enzyme damage and limit the production of dopamine in the brain at 10 $\mu g/m^3$. Treatment using synthetic neurotransmitters such as levodopa show improvements in brain scans after an interval of about two months. Baggage handlers have also exhibited symptoms as they are often working behind the engines after shutdown. The problem for pilots seems to stem from the fact they are asked whether they are "fit to fly", and one of the symptoms of neurotransmitter deficiency is an inability to answer such a question objectively—while the pressure to minimize illness in order to continue employment further exacerbates the reluctance of pilots to report symptoms. The instance of

illness potentially related to TCP contamination in aircrew in the Netherlands could be as high as 10%.

Professor Clem Furlong continued the search for scientific cause and effect with his ongoing work on the metabolism of organophosphates in the body. Ingestion through the lungs is the easiest method to absorb quantities of organophosphates. The liver then metabolizes the various isomers in TCP to a cyclic phosphate, which is a known neurotoxin more potent than the most potent TCP isomers. This then binds to the enzyme that enables the production of various neurotransmitters in the brain. There is also a genetic susceptibility that affects enzyme expression. Biomarkers are currently under development to detect the presence of the cyclic phosphates in the blood but at present it is not possible to relate concentrations in the air and concentrations at the cellular level that cause destruction of the enzyme tyrosine hydroxylase. Work has started with a French oil company, Nyco, to assess the toxicity of the various TCP isomers in lubricating oil and one in particular shows a considerable reduction in toxicity but, so far, only the one oil company appears interested in the problem.

After the very convincing science of the causal link between TCP and brain damage, the conference returned to the emotive descriptions of the illnesses and fights for recognition by a number of aircrew.

Dee Passon, a British Airways cabin crew member, suffered depression and anxiety and as a consequence set up a website for fellow sufferers. From the data gathered from respondents it would appear that aircrew contract cancer 10 times more frequently than the average population.

David Zaharik, a Canadian pilot of 33 years experience and having flown large passenger aircraft, was diagnosed with ME and retired from flying. His symptoms included an extended interval when he was sleeping 18 hours a day, which was followed by a gradual return to health and fight for reinstatement. The greatest concern was the lack of information given to aircrew on the possibility of health risks due to cabin air contamination, especially when some aircraft at engine start-up generate the so-called "fume" events when the air is obviously—visibly—contaminated. It was also worrying given the long-term effects of these neurotoxins that this pilot was back in the air, given that although a damaged brain will compensate for loss of function but there will be a point when this is no longer possible.

John Hoyte, another ex-pilot suffering ME symptoms and now retired, has formed the Aerotoxic Association as a private organization to support sufferers. Its website, which has been running for about six years, has gained considerable acclaim as a valuable source of information.

The following discussion centred on work to produce oils with reduced levels of TCP, air filtering and various means, including scrutiny of pilots' e-mails, to establish the real depth of the problem. Temperature extremes in jet engines and the environmental peculiarities of aircraft cabins make alternative lubricants and air filters ineffective. Various unknowns were identified, such as TCP's half-life in the human body and to what degree a foetus in pregnant aircrew would be affected.

Jeremy Ramsden outlined an optical fibre multisensor that could be developed to continuously detect the various isomers of TCP, while Robert Morris described some filtration techniques which might be usable to remove contamination.

The German journalist Tim van Beveren showed a dramatic video from his television slot of a "fume event" recently captured by a passenger and raised questions already asked about the safety of air travel. If pilots are aware of air contamination especially during fume events and they use oxygen for their own safety, it creates a major incident report for the airline and pilots are under pressure not to make such reports. Under the European Air Safety Agency (EASA) regulations cabin air should contain no harmful vapours although this is presently honoured more in the breach than in the observance. The recent lawsuit (and out-of-court settlement resulting from it) in the USA gives some hope that the airlines may now start to take cognizance of the potential for illness during flight and the flouting of existing regulations. The German pilot who sought compensation from his airline after suffering severe ME symptoms only lost his case because he was unable to unambiguously identify the fume event that presumably contained the neurotoxins which caused his illness.

More harrowing stories followed. Philip Parsons, a frequent air traveller, was diagnosed with ME. Having lost his job and now dependent on the benefit system, he outlined the individual cost to the UK economy in terms of lost taxation revenue from his personal income, lost commercial revenue from his company and the now-needed health care, which in total amounted to about £300,000 *per annum*.

Tristan Loraine from the Independent Pilots' Association again highlighted the vested interests of airlines, oil companies supplying them and insurance companies servicing them. These institutions are beginning to listen but reluctant to admit culpability, with only Boeing with its new "Dreamliner" (787), in which bleed air is not used, taking definite action. Perhaps Boeing believe that if all is swept under the carpet for a few more years they will no longer be liable for past deficiencies. Another problem is the lack of relevant exposure limits and the

fact that the ban on smoking has resulted in a big increase in the reporting of cabin air smells.

Frank Brehany of Holiday Travel Watch gave the perspective from the consumers' viewpoint. For many years travellers complaining of illness assumed the problem was the hotel, which resulted in considerable investigation of the hotel industry with no obvious cause of the reported illnesses. The advent of awareness of the potential for cabin air toxicity would now appear to provide an explanation. Many of the problems in seeking compensation from travel companies or airlines stem from a change in attitude following the ruling by a US High Court judge that businesses should not be held to ransom by private litigation and that businesses should be more aggressive in denying liability. This seems to have become common practice across the world, with businesses campaigning to discredit complaining individuals.

From the discussions it emerged that most airlines know from the complaints that they have a problem but are understandably reluctant to admit responsibility due to fear of litigation. The media are also reluctant to broadcast issues of a scientific nature since science reporting is facing a reduction of airtime as television companies doggedly follow ratings and promote "reality" shows.

The final speaker, Prof. Malcolm Hooper, gave a pulpit-thumping presentation (with Biblical quotations) lambasting the airlines, insurance companies and governments. The fact that TCP was known as a neurotoxin almost 60 years ago, that doctors are encouraged to call the symptoms psychosomatic and the vested interests of the airlines, governments and insurance companies promote injustice (well exemplified by the corruption of UK MPs), are inexcusable and unacceptable.

3. CONCLUSIONS

My own view, formed while listening to the science, the emotive personal stories, the instances of corruption and the pressure on individuals by vested interests, was indeed profoundly affected by the day. The science elucidated most eloquently by Prof. Furlong and Dr Mulder on the effects of organophosphates on human beings was professional and incontrovertible. TCP ingested through the lungs is metabolized in the liver producing an organophosphate compound that destroys some of the enzymes that are used in the brain to produce neurotransmitters. The result is myalgic encephalomyelitis (ME) with its symptoms of headache, nausea, memory loss and loss of functionality. Treatment using synthetic neurotransmitters is possible, and over considerable periods, possibly years, recovery occurs but long-term irreversible brain damage is nevertheless a possibility. As dopamine deficiency can lead to suicidal tendencies it was particularly worrying that pilots might still be flying after apparently recovering from ME-like symptoms.

The other incontrovertible fact seems to be that modern jet engines running at high temperatures and using the low pressure turbine stage to produce air that is then bled into the cabin will vaporize some of the lubricating oil and generate airborne organophosphates. Dynamic oil seals will inevitably "weep", and the question seems to be, how much? But as the airlines refuse to provide maintenance data it is difficult to quantify the potential contamination from this source. The Cranfield Aircraft Cabin Air Sampling Study attempted to measure these levels of vaporized TCP but failed to distinguish between the various TCP isomers and moreover failed to recognize that one in particular, even below the supposed safe level, was particularly toxic.

Much is made of the so-called "fume" events, when passengers and crew become aware of smell and fog inside the cabin. This is particularly prevalent on some aircraft and usually occurs at engine start-up or during the initial phases of take-off. However, since no fume event was actually measured in the Cranfield study the contents of the cabin air during such an event have not yet been quantified. Since the pure organophosphates are colourless and odourless, the smell associated with such a cabin fog points to products of pyrolysis of the base oil and its additives being present in the atmosphere.

Herein lies the problem. The causal link between measured and documented contaminated cabin air and illness, although substantiated by numerous individual cases, is not proven. It is thus understandable that the German pilot lost his compensation case against the airline, not because the airline denied that he was ill from breathing TCP, but because he was unable to identify the particular event when it occurred. Indeed, the cause might well have been continuous exposure during a number of flights. One of the problems of our increasingly technologically sophisticated world is that the law's understanding of science and scientific principles seems actually to be diminishing relative to the level required. Hence, legal deliberations tend to be limited to a fairly primitive level of understanding.

It thus seems essential that continuous monitoring of all the organophosphates likely to be present in cabin air is established, especially for the cockpit, and that safe levels for human beings are established. Until this link is forged it would seem that litigation will be dependent on individuals recording "fume events" and then illness when, in fact, it may well be due to continuous exposure to a low level over the entire course of one or more flights.

Boeing have obviously realized the problem and appear to have a long-term plan envisaging that, provided

they can survive the next three or four years until their new airliner, the 787 (not using bleed air) enters service, they will avoid the culpability issue and litigation on the grounds that at the time of building the extant aeroplanes they were unaware of the potential for contamination. Unfortunately most large corporations now only understand change as a consequence of the effect on their profit margins. Thus, even though Boeing seem to be accepting the dangers, airlines, which are in many cases national entities funded by governments, will be reluctant to introduce changes to improve safety for two reasons: the cost of introducing an alternative air pressurizing system and the fear of massive litigation on a scale similar to that facing the tobacco industry.

It is difficult to see, once the cat is out of the bag, how to resolve this problem. Obviously affected individuals and particularly the airline staff who have been exposed for long periods need to be compensated for the damage to their health, but airlines and insurance companies will fear that every passenger leaving an aircraft complaining of a headache will seek a financial settlement.

For the airlines, perhaps the most viable solution is to install an organophosphate monitor in aircraft using bleed air, at the very least in the cockpit, and to define an acceptable safe concentration level. In all probability such a monitor would provide a useful indication of the health of the engines themselves, but if passengers demand and obtain individual dosimeters like radiation badges, the airlines will face a much worse litigation scenario with possibly millions of claimants.

4. THE NUMBERS

A frightening aspect of air travel is the number of people nowadays involved: it is estimated at approximately 3 billion[1] people-flights per year.[2] In the nuclear industry, acceptable risk is usually taken as one person in a million per year suffering a severe illness or death.[3] Probably there are less than a million people working in the nuclear industry in the world,[4] so this equates to an average of only one person in the industry being affected per year, although Fukushima rather overwhelmed the assessment for this year. If a similar probability were acceptable for air travel risk it would mean that over a million people a year would be suffering severe illness. At this level it would be called a pandemic. The implication is that if an acceptable number of severely affected people of, say, a few hundred is ethically justifiable, and in all probability culpable airlines could make provision for compensation without going bankrupt at this sort of level, then the risk per year of exposure to organophosphate neurotoxins would have to be set at almost two orders of magnitude lower than for the nuclear industry. This has serious implications in the setting of safe environmental limits and the sheer scale of the numbers involved may require a fundamental rethink on the way such limits are set.

As a personal action I will continue to fly as infrequently as possible and preferably with the larger airlines with newer aeroplanes, which I hope are better maintained. Meanwhile funding is urgently needed to develop on-board sensors and biomarker diagnosis to identify susceptible pilots.

[1] US billions (i.e., milliards), 10^9, are used in this paper.

[2] The International Air Transport Association (IATA) has released passenger and freight traffic forecasts projecting that in 2011 the air transport industry will handle 2.75 billion[1] passengers (620 million more passengers than in 2006) and 36 million tonnes of international freight (7.5 million tonnes more than in 2006). From http://www.iata.org/pressroom/pr/pages/2007-24-10-01.aspx dated 24 October 2007.

[3] *The Tolerability of Risk from Nuclear Power Stations*. HMSO (1992). The upper and lower bounds of such individual risk for land use planning purposes are 10 in a million per year and 1 in a million per year respectively (1 in 1 million suffer the general risk of death in a fire or explosion from gas at home).

[4] *World Nuclear Industry Status Report 2010–2011*. As of 1 April 2011 there were 437 nuclear reactors operating in the world.