

# CONTAMINATED AIR OVERVIEW



# **GCAQE**

Global Cabin Air Quality Executive

The Global Cabin Air Quality Executive (GCAQE) established in 2006 is the lead organisation internationally focussed on addressing the issue of bleed air contamination. There is extensive data compiled over the last 60 years confirming that contaminated air poses both a flight safety and health risk for those exposed that should not be ignored.

This overview document provides a one page 'contaminated air made simple' introduction, followed by a more in-depth look at the different aspects of the contaminated air debate; it is intended to provide readers with an insight into the issue only. It should be reviewed in conjunction with the educational film on the GCAQE website and other additionally available books, literature and peer reviewed papers. Future updates of this document can be obtained from the GCAQE website.

November 2014

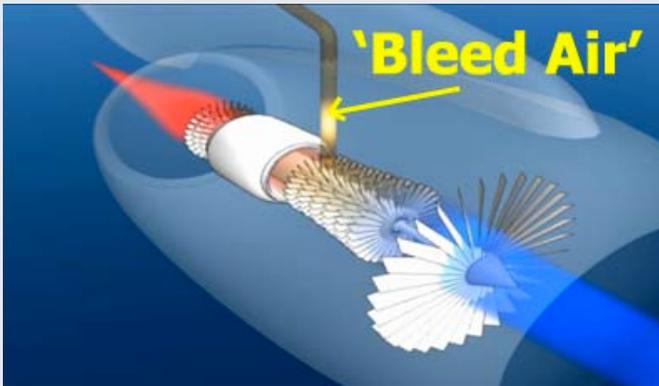
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## 1. Contaminated air made simple.

To enable you to survive onboard an aircraft at high altitude, you need to be provided with a breathing air supply.

The air you breathe in-flight, onboard all currently flying commercial passenger jet aircraft, is provided to passengers and crews from the compression section of the engine in a process known as 'bleed air.'



The 'bleed air' will be contaminated in varying amounts with pyrolysed (decomposition of organic material at elevated temperatures) synthetic jet engine oil combustion products as a feature of the system design.

Apart from being cooled by air conditioning packs before entering the aircraft cockpit or cabin, the 'bleed air' is not filtered.

'Bleed air' is used for breathing air on every pressurised aircraft you fly on, from the latest wide body jet to a regional turboprop aircraft, except for the Boeing 787 Dreamliner that uses electrical compressors.

Most modern jet aircraft also re-circulate some of the aircraft cabin air to reduce the amount of 'bleed air' they constantly take from the engine. This re-circulated air can be filtered for bacteria and viruses using HEPA filters, but is not filtered for hazardous jet engine oil by-products that can contaminate the air supply, such as carbon monoxide.

In addition, hydraulic or de-icing fluids may also contaminate the cabin air supply.

As well as engine oils contaminating the engine bleed air supply, the Auxiliary Power Unit (APU), the small jet engine usually located at the tail of the aircraft, which can provide air conditioning and electrical services to the aircraft, can also be responsible for contaminated air events.

Many of the chemicals that have been measured during a contaminated air event are odourless and colourless, such as carbon monoxide.

Aircraft have no form of contaminated air detection system fitted to warn when the air is contaminated.

Contaminated air exposures are significantly under reported, and they are a flight safety and health issue of significant concern to the GCAQE and our members.

## 2. Origins of contaminated air.

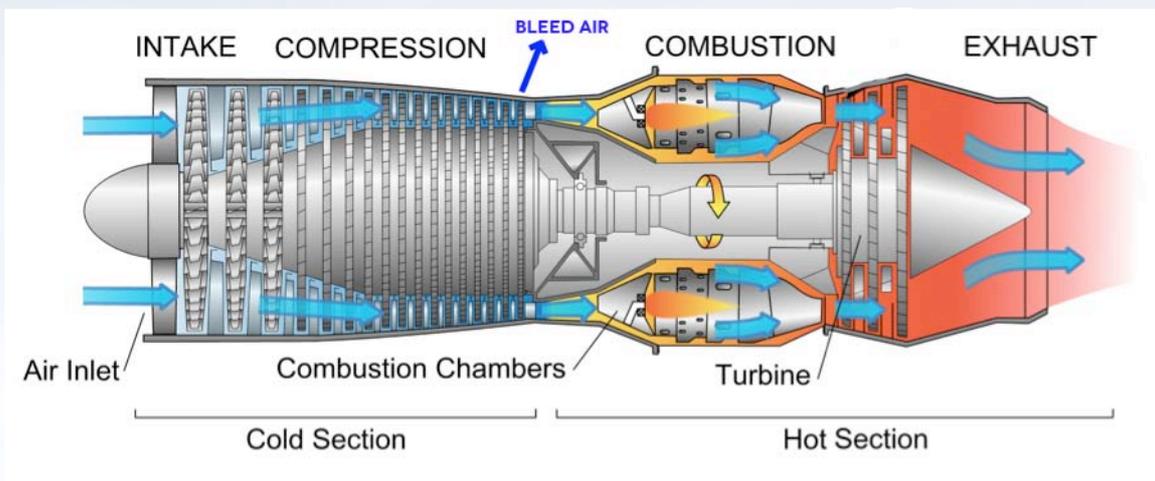
A basic jet engine is composed of a compressor, which has blades like wings that spin very quickly at the front of the engine. This draws in air and compresses it into a high-pressure gas. Fuel is then injected into the gas and ignited. This makes the gas both high-pressure and high-temperature. As the hot, pressurised gas is expelled out the back of the engine at high velocity, thrust is generated. The exhaust gas turns a turbine(s) that rotates the compression section(s) at the front of the engine. Like car engines, jet engines need engine oils for lubrication.

Early jet aircraft used mineral oils for engine lubrication. However, with the rapid advancement of engine technology and rising internal temperatures within an engine, newer man-made or 'synthetic' jet engine oils were developed and introduced in the early 1950s. Unlike mineral oils, synthetic oils contain a number of additives of concern such as organophosphates, which are typically triaryl phosphates (TAPs) such as tricresyl phosphates (TCPs).



1944 – Lockheed F-80 Shooting Star

The introduction of jet engines also brought a dramatic change in the operational envelope of aircraft in both speed and cruising altitude from propeller aircraft. This, in turn, brought a need to provide crews with a pressurised and heated cabin and cockpit. This was achieved by way of a process known as 'bleed air' in which air is 'bled' off the hot compression section of jet engines and provided unfiltered to the cockpit and aircraft cabin as needed.



It was with the introduction of synthetic jet engine oils that US Air Force pilots first started to report adverse health and flight safety issues in the early 1950s.

“Approximately 40 minutes after take-off, I experienced blurred vision, became nauseated and experienced considerable dizziness. I recall no strange or unpleasant odors, nor did I taste anything out of the ordinary. I did feel a definite dryness of mouth and throat. This condition lasted possibly a minute or two. As I became more aware of the situation or nearly to the passing out point...”

William J. Van Every – USAF - 15 May 1954 (Loomis, 1954)

Based on significant research, recommendations were made at that time that passenger aircraft use turbo compressors or blowers to pump in outside air into the passenger cabin for pressurisation, rather than use engine 'bleed air' taken from the compression section of the engine, which was now common practice in the military.

Cabin blowers had been extensively used in the pre-jet era to great effect. Consequently, early commercial jet aircraft such as the Douglas DC-8, Boeing 707, VC-10, or Convair 880/990 did not use a direct engine 'bleed air' system in normal operations.

The use of turbo compressors or blowers was very efficient at providing clean air, but heavy and were not a very fuel-efficient solution.

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With a growing need to reduce fuel consumption, the Rolls-Royce RA-29 Avon powered Sud Aviation Caravelle was introduced into airline service in 1959, providing unfiltered 'bleed air' for passengers and crews to breathe.



Sud Aviation Caravelle  
(Photo: Peter Ehrbar)



Vickers VC-10  
(Photo: Steve Fitzgerald)

The Vickers VC-10 aircraft that first flew in 1962 was the last aircraft to be built with these safer air supply systems. Since 1962, all passenger, transport, military, and corporate jet aircraft have been designed to provide passengers and crews with breathing air through the use of 'bleed air,' with the exception of the Boeing 787 that first flew in 2009. The Boeing 787 now uses electrical compressors to supply outside air to the air conditioning system.

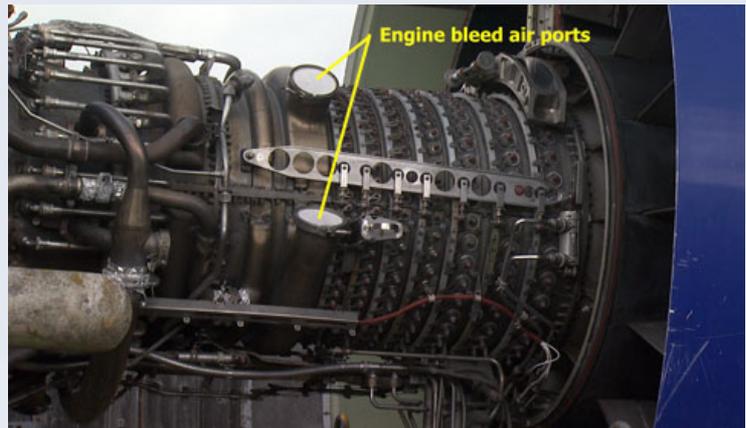
Aircraft 'contaminated air' refers to the contamination of the breathing air supply by pyrolysed synthetic jet engine oil lubricants, hydraulic, and de-icing fluids. Such contaminated air events are generally, but not always, non-visible in nature, and may be described differently

by people. Most commonly they generate a smell described as dirty sock, wet dog, gymnasium, vomit, oily or chemical.

Its important to note that early passenger aircraft used to allow smoking on-board aircraft, so the majority of contaminated air events that occurred were likely masked by cigarette smoke fumes, until the smoking ban came widely into effect in the late 1980s early 1990s.

In modern jet airliner engines, 'bleed air' is provided from two regulator valves on the high stage or low stage engine compressor section of the engine that usually turn on and off automatically.

Low stage air is used during high power setting operation, and high stage air (see picture right) is used during descent and other low power setting operations. Because the low stage air is significantly lower temperature than the high stage air, the pyrolised engine oil decomposition products will differ and provide a different smell in the cabin and cockpit due to a different chemical mixture.



The images below show the air supply ducting on a VC-10 removed from an aircraft at the end of its service life. Compare this to the bleed air ducting from a Boeing 737 engine, which is black from pyrolised oil contamination.



Bleed air off take port from a Boeing 737.  
Interior is black from oil contamination.



Air supply ducting on a VC-10.  
Interior is dirty and dusty but has no oil.

The air you are supplied to breathe in flight, on all commercial jet aircraft (except for the Boeing 787), is taken from the compression section of the jet engines. Engine bleed air is NOT filtered.

### 3. Flight safety issue

If flight crew suspect the air is contaminated onboard an aircraft, they should don 100% emergency oxygen and follow the emergency checklist procedures appropriate for the aircraft type. Flight safety has been compromised by crews who have failed to do so.

Aircraft cockpits and cabins have information on cabin temperature and cabin pressure altitude, but aircraft have no detection systems to warn when the air is contaminated. This can create a serious risk to flight safety because, within minutes, crews (even if they have a good sense of smell) lose the ability to smell any constant level of contamination. They may simply assume the smell has passed, and some may not notice when they start to become mentally slow and partially incapacitated.

Despite no detection systems being fitted, some within the industry acknowledge that crews can be exposed to oil fumes in-flight, and that these exposures can cause acute symptoms, which can compromise flight safety (AAIB, 2012; AAIB, 2007; SAAIB, 2006; AAIB, 2004; FAA, 2004; CAA, 2002; ATSB, 1999; Rayman, 1983; Montgomery, 1977).

<b>AIR SAFETY REPORT</b>									
1. TYPE OF EVENT	ASR (Box 31/32) <input checked="" type="checkbox"/>	APPROX (Box 31/32) <input type="checkbox"/>	ATC PROCEDURAL (Box 31/32) <input type="checkbox"/>	TCAS RA (Box 31/32) <input type="checkbox"/>	WAKE TURB (Box 33) <input type="checkbox"/>	BIRD STRIKE (Box 34) <input type="checkbox"/>	CAA OCCURRENCE NR		
TICK ALL THAT APPLY INCLUDING RELEVANT BOXES ON REVERSE OF FORM									
2. CAPTAIN T. LORRAINE		CODE LORET		CO-PILOT		CODE		OTHER CREW	
3. DATE OF OCCURRENCE 02 / FEB / 06		4. TIME LOCAL/UTC 1418-1616		5. FLIGHT NR/CALLSIGN BAW 952		6. SECTOR LHR-HUC		7. SOLAWK M/A	
8. A/C TYPE B757		9. REGISTRATION G-CPEN		10. PASSENGERS/CREW 67 / 8		11. FUEL JETTISONED		12. ETOPS YES ( )	
13. ALTITUDE FL VARIOUS		14. SPEED / MACH NR VARIOUS		15. A/C WEIGHT VARIOUS		16. TECH LOG REF 83/24		17. FLIGHT PHASE TOWING / PARKED /	
17. FLIGHT PHASE PUSHBACK / TAXI-OUT / TAKE-OFF / INITIAL CLIMB /		18. AIRPORT + STAND		19. GEOG. POSITION / CO-ORDS FIR		18. AIRPORT + STAND		19. GEOG. POSITION / CO-ORDS FIR	
20. MET IMC		21. WX ACTUAL WIND VIS. CLOUD TEMP QNH		22. SIGNIFICANT WX RAIN / SNOW / ICING / FOG / TURBULENCE HAIL / STANDING WATER / WINDSHEAR		23. RUNWAY		24. RUNWAY STATE DRY / WET / ICE / SNOW / SLUSH / RVR	
23. RUNWAY		24. RUNWAY STATE		25. CONFIGURATION A. PILOT / A. THRUST / GEAR / FLAP / SLAT / SPOILERS		26. SUMMARY [CONCISE DESCRIPTION OF THE EVENTS INCLUDING OTHER A/C DETAILS. IF APPLICABLE, EG A/C TYPE, MARKINGS, COLOUR, LIGHTING etc.] CONTAMINATED AIR SHELL AFTER ENGINE START, DURING TAKE OFF + IN CLIMB. SOME CABIN CREW 'FEELING VERY DROWSY'		26.a. MOR If you consider this event to be a Mandatory Occurrence under CAP 382 please tick the box and it will be forwarded to the Safety Data Unit of the CAA <input checked="" type="checkbox"/>	
27. EVENT AND CAUSE (DETAILED DESCRIPTION OF THE EVENT AND ITS IMMEDIATE CAUSE) AFTER START CONTAMINATED AIR SHELL BRIEFLY AFTER ENGINE START INTO A HEADWIND, DURING TAKE OFF AND DURING CLIMB ON BRIEF OCCASIONS. OXYGEN NOT USED AS OCCURRENCES APPEARED BRIEF AND CLEARED. NO SHELLS NOTICED DURING REMAINING OF FLIGHT. CABIN SERVICE DIRECTOR COMPLETED 'INCIDENT FORM' REPORTING 4 CABIN CREW DURING TAXI/CLIMB 'FELT VERY DROWSY AND SLEEPY-UNUSUAL DELAY IF ANY'									
28. ACTIONS AND RESULTS (ACTIONS TAKEN, THEIR RESULT AND ANY SUBSEQUENT EVENTS) DURING THE DAY, ALL OF CLUB WERE ASLEEP..... A CARBON MONOXIDE OR CONTAMINATED AIR DETECTION SYSTEM WOULD HAVE ENABLED THE POSSIBLE LINK MORE CLEARLY TO BE ESTABLISHED.									

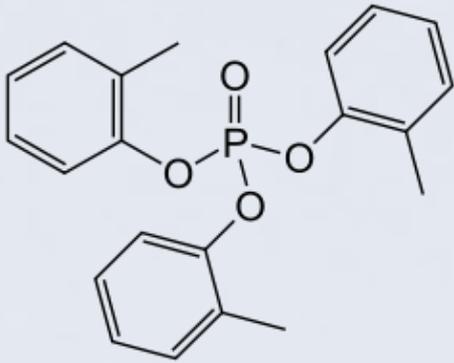
Typical Air Safety Report

There is extensive data showing that in-flight impairment is occurring to both crew and passengers. In one study, crew experienced some degree of impairment through to incapacitation in-flight in 32% of fume events, with some cases of two-pilot incapacitation or entire crews being impaired (Michaelis, 2010). Further, 45% of pilots reported "Aerotoxic" symptoms during or soon after flight, thus supporting that exposure to oil fumes can compromise flight safety (Michaelis, 2010). The incident summary below is taken from a Boeing 757 incident in the UK in 2000. It highlights how a crew failed to slow an aircraft on approach until air traffic control reminded them to do so. Again, like hypoxia, contaminated air is a serious flight safety issue.

Oily smell on outbound sector. On return sector crew unaware that they were becoming partially incapacitated. P1 then forgot to slow a/c. AAIB report: "Oily metallic smell had also been evident during previous sector. On this occasion, numerous ATC calls were missed, prompting ATC to ask a/c if everything was all right. P1 then forgot to slow a/c during approach until reminded to do so at 3.7d. Crew unaware that they were becoming partially incapacitated."

#### 4. What is in the oil and fluids?

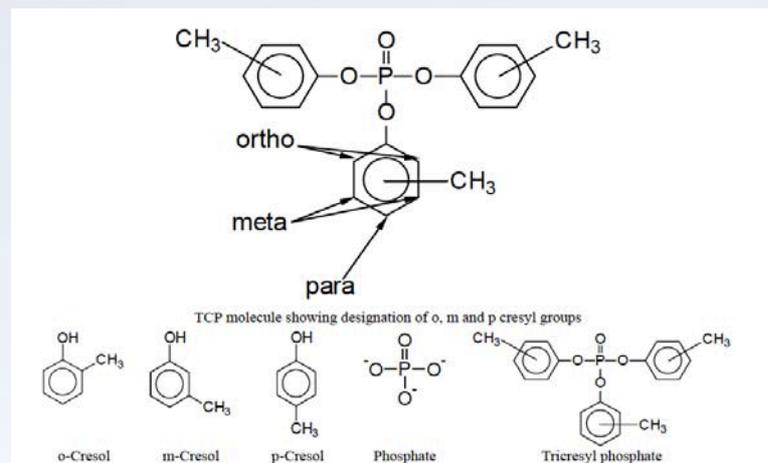
“The United States Environmental Protection Agency lists organophosphates as very highly acutely toxic to bees, wildlife, and humans. Recent studies suggest a possible link to adverse effects in the neurobehavioral development of fetuses and children, even at very low levels of exposure” (EPA, 2013).



Tricresyl phosphate structure

Ninety-five percent of a typical synthetic jet engine oil consists of an ester base stock. In addition, the oils contain triaryl phosphate (TAP) antiwear additives at around 3% (by weight), including tricresyl phosphates (TCPs). The TCP blends used in jet engine oils are a complex mixture of structurally related compounds, including 10 TCP isomers (isomers are molecules with the same molecular formula but slightly different configurations), and other phenol and xylenol compounds, some of which are known to have neurotoxic properties (Mobil, 1999; Winder, 2002).

The number of triaryl phosphate combinations in TCP is very high and is not limited to the 10 that can be formed from ortho, meta and para cresol (Mobil, 1999). Additionally, the oils contain antioxidants, such as N-phenyl-alpha-naphthylamine (PAN) at around 1% (by weight), its contaminants (Category 1A carcinogen beta naphthylamine), and other proprietary substances.



Because the oils are exposed to extreme temperatures up to 500°C (932°F) in the compressor air, a wide variety of pyrolysis (degradation) substances are generated, and those will also contaminate the air supply.

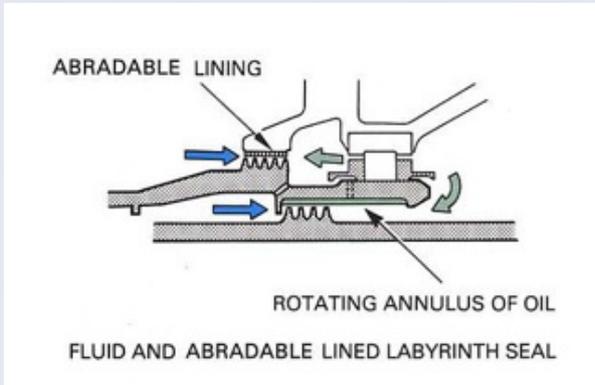
Hydraulic fluids contain very high levels of organophosphates such as tributyl phosphate (TBP) and other phosphates such as triphenyl phosphate (TPP), while deicing fluids contain ethylene or propylene glycols, plus various proprietary additives.

It is important to note that when these synthetic oils are pyrolysed (heated) and contaminate the breathing air supply (bleed air), you will be exposed to a complex cocktail of chemicals.

The toxicological impact of inhaling this mixture is different to any exposures you may have to the cold oil in a can.

## 5. Engineering issues.

Engine oil seals will leak oil into the air supply as a feature of their design.



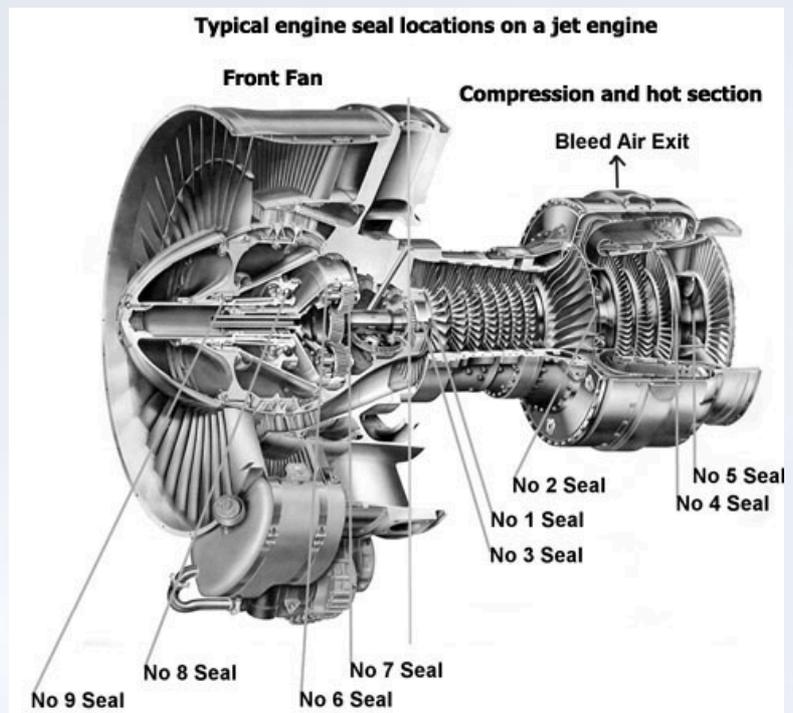
Labyrinth seal design

Bearing chambers in aircraft engines are cooled and lubricated with the use of oil. In an attempt to keep the oil in the engine, a number of different sealing options are available.

The system relies upon a controlled leakage of pressurised air from the engine compressor to make an air seal. The objective is to retain the oil in the chamber and prevent leakage out of the bearing sump. By design, these air/oil seals will leak.

Engines have a large number of seals at different engine locations. Engineers have access to a wide variety of seal designs such as carbon or labyrinth seals, but labyrinth are the most common.

A variety of factors, including transient engine operations (changes in thrust) and wearing seals, can allow the pressure acting on the outside of the seals/sump to fall below what is required to retain the oil inside the chamber. This allows oil to leak out through the seals and into the bleed air supply, if the leak is upstream of the bleed air off-take point.



Although the industry publically acknowledges the rare cases of failed oil bearing seals as the source of cabin fumes, lower level oil leakage is an expected design and operational factor of using the bleed air system, and explains the frequency of oil fumes leaking into the air supply (Michaelis, 2010).

In 1969, it was recognized that the main sources of oil loss were oil leaking past the seals, oil passing through the engine breather, and losses during servicing (Rolls Royce, 1969).

“The origin of the haze and smoke in the flight deck and cabin was determined to be the No 2 engine. A fractured seal ring in the No 1 bearing on the LP shaft had allowed engine oil to leak into the compressor air path. The reason for the failure could not be determined but the seal ring contained no material defects and did not diverge significantly from design dimensions or geometry.”

UK AAIB Bulletin: 6/2009 G-BYAO EW/C2006/10/08

## 6. Toxicity of tri-aryl phosphates.

In 1954, it was reported that TCP caused trace demyelination of nerves (Aldridge, 1954). Sixty years later, in 2014, the pathology report of a deceased 43-year-old pilot who had been exposed to TCP and other pyrolysed jet engine oil products showed demyelination of the nerves and nervous system injury consistent with organophosphate-induced neurotoxicity (Abou-Donia, 2014).

The form of TCP that has been most closely studied is tri-orthocresyl phosphate (TOCP), due to mass poisonings in the 1930s and the recognition that it causes a specific type of neurological damage. Some studies and reports wrongly suggest that, given the low levels of TOCP present in jet engine oils and the low levels of TOCP found in aircraft air sampling or swab tests, there should be no reasons for concern because, they claim, the other isomers of TCP are safe. This is untrue.

It is important to understand that many components of TCP other than just the TOCP can be neurotoxic (Mobil, 1990 & 1999). Furthermore, TOCP is but one of six ortho isomers of TCP, the other five being known for six decades to be five and ten times more toxic than TOCP, and present in the engine oils at orders of magnitude greater than TOCP. These other ortho isomers often referred to as DOCP and MOCP are rarely mentioned in industry funded research papers (Henschler, 1958). Additionally, tri-para cresyl phosphate (TpCP) and Durad 125, a commercial mixture of TAP esters used in jet engine oils, are inhibiting various enzymes and physiological processes (Baker, 2012). Some of these enzymes are clearly linked with cognition and detoxification processes and white blood cell activity. Neurological damage related to demyelination of nerves has recently been found in a pre and post mortem case study of a pilot, with damage shown consistent with organophosphate exposure (Abou-Donia, 2013 & 2014).

Chronic low-level exposures to a complex mixture is also a key factor of concern. Many industry papers state that the amount of chemicals you could be exposed to is too low to be of concern. A European Commission study noted: the risks posed by complex chemical mixtures have rarely been tested under environmentally relevant scenarios. The need for precautionary actions on the assessment of chemical mixtures, even in cases where individual toxicants are present at seemingly harmless concentrations, is raised (Carvalho, 2014). Additionally, risk assessments based upon single chemicals, rather than mixtures and low dose exposures may underestimate toxicity (IGHRC, 2009).

Repeated low-level exposure to some organophosphates can result in organo phosphate induced chronic neurotoxicity (OPICN) (Abou-Donia, 2004, 2005), with chronic or subchronic exposures to small doses of organophosphate compounds being more neurotoxic than large single doses (Abou-Donia, 2005, 2014).

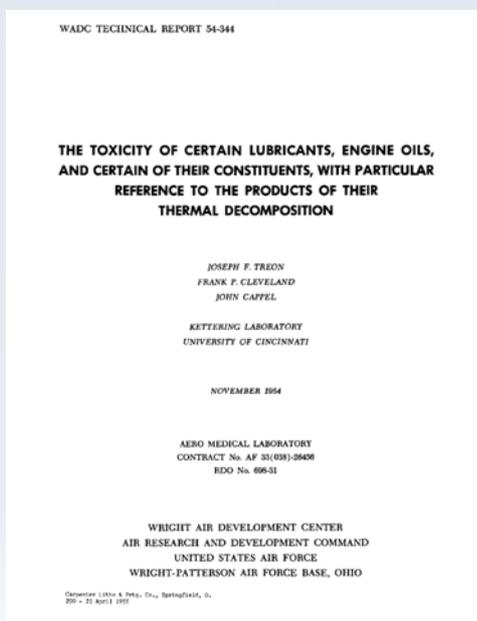
“However, functional neurotoxicity has been observed with very low TOCP concentrations, and in the absence of structural damages, suggesting that TOCP exposure may lead to cognitive deficits in the brain that are relevant with contaminated air exposures” (Hausherr, 2014).

## 7. Research into contaminated air.

Internal BAe Complaint of Difficulty Report No. 27803 dated 10 Feb 1991.

“Can Hatfield provide a definitive statement on the medical implications of fumes/smells in the cabin (Dan Air cabin crew have complained of headaches and nausea... Here we have a reported case of fumes and nausea and despite a two year wait we still have not statement on health and safety. Can you please hasten an answer at this point.”

In recent years, numerous crews unions, scientists and even broadcasters have carried out swab testing of aircraft walls to confirm the presence of organophosphates present in synthetic jet engine oils and hydraulic fluids. The majority of these have tested positive, but research actually started as far back as the 1950s.



In the early 1950s the US military commissioned studies that found the oils, when exposed to very high temperatures, such as those in the compressor section of the engine, created a wide spectrum of hazardous chemicals when inhaled, causing brain, lung, kidney and liver degeneration (Treon, 1955).

There was clear concern that reports were being made about adverse effects in crews (Boeing, 1953; DAC, 1954; Loomis, 1955; Kitzes, 1956).

Manufacturers acknowledged at the same time that the toxic effect of exposure to the lubricants was “still unknown,” and much more could be done to “reduce the contamination at the source” (Boeing, 1953; DAC, 1954).

Since the early 1950s, more than 100 industry supported or funded studies have investigated these issues (Michaelis, 2014), and millions of dollars have been spent. Yet in 2013, the US Federal Aviation Administration (FAA) advised the US Congress that the decomposition reactions of the oils and fluids are still “largely unknown,” as is the potential toxicity of exposure to such contaminants.

Crews are being exposed to a complex mixture of chemicals, yet no inhalation studies have ever been published (they may have been carried out) to better understand their impact on, not just crews, but also the travelling public, including the unborn.

In 2013, Frans B. Horjus, Global Aviation Lubricants Sales Manager for ExxonMobil Fuels & Lubricants stated that:

“OSHA and ACGIH are two organizations who establish exposure limits for chemical substances in ambient conditions. However, to the best of my knowledge, neither of those organizations have addressed the decomposition product of synthetic jet engine oils.”

## 8. Documented exposures.

Exposure to the oils and substances including the organophosphates in the oils and hydraulic fluids (TCP, TBP, TPP) are being repeatedly found in industry studies during what is said to be “normal flight operations”. This confirms oil and hydraulic fluids are contaminating the air supply, not just in major contaminated air events, but on routine flights. Consequently, crews face a chronic exposure to hazardous chemicals in the work place through out their working careers.

Airborne TCPs (components of oil) were measured during 23% of 100 monitored flights, while airborne TBP (component of hydraulic fluids) was found in 73% of flights in a UK Government study, all during flights without any contaminated air events being documented. TBP and TPP, the organophosphates in hydraulic fluids, were found in 100% of urine samples taken from German crew (Schindler, 2013).

A recent Dutch study found TCP in 46% of flights, again during normal operations without reported fume events. The TCPs found in the cockpit were stated to: ‘originate from (leakage of) the engine oil’ (de Ree, 2014). This is supported by recent studies showing TCPs emitted during a fume event will be present in the air in the same relative amounts as in the oils (Havermans/ASHRAE, 2013). While many take comfort in the fact that one of the ortho isomers of TCP (TOCP) is often not found, TOCP was found in 15% of 90 in-flight air samples (Rosenberger, 2013).

Passengers breathing the same air are also at risk and oil leakage out into the environment is an additional factor.

Offshore workers have reported similar exposures to airline crews whilst working on the aeroderivative jet turbine engines they use, which also use the same type of oils as in aviation.



The GCAQE, through support from its member organisations and the Royal Australian Air Force (RAAF) has led the way into research to develop a blood test to confirm exposure to specific tri-aryl phosphates in synthetic jet engine oils. This research being conducted at the University of Washington in Seattle also seeks to understand the toxic mechanism of exposure, and is ongoing.

On 3rd September 2010, 18 years after a cabin crewmember’s documented exposure to fumes, the High Court of Australia upheld a ruling made by the courts on the 5th May 2009, that:

“The plaintiff was exposed to pyrolysed effects of Mobil Jet Oil II on 4 March 1992” and “that pyrolysed effects of Mobil Jet Oil II are harmful to the lungs.”

Other studies clearly show that engineering and ramp personnel are also being exposed to contaminated air in addition to the air crew (Solbu, 2010; Denola, 2011; IOM, 2012; Schindler, 2014).

## 9. Exposure standards.

An occupational exposure limit is an upper limit on the acceptable concentration of a hazardous substance in workplace air, for a particular material or class of materials. Most chemicals do not have exposure standards. Exposure limits apply to a single compound only and are ground-based standards not created for high altitude and will not protect all workers.

It is often stated that various industry-supported studies have shown that all levels of contaminants measured onboard aircraft are below established limits. However, such ground based exposure standards should not be used for the cabin at altitude, (ACGIH, 2014; ASMA, 2002) and are not available for most chemicals including all but one type of TCP. Also, occupational exposure limits do not apply to the public, especially not the unborn, young children, sick or the elderly. Also, for those that exist, they apply to single chemicals only in their original state and not to either complex mixtures of chemicals or thermally degraded substances.

A major UK Governmental study reported that “it is possible that interactions between chemicals may change the dose response relationships for chemicals tested in isolation, leading to adverse effects at lower than expected doses, or additional toxic effects that would not be predicted based on the toxicity of individual components” (IGHRC, 2009).

Standards often cited for safe TOCP exposure are inappropriately applied (WHO, 1990; Mobil, 1998 & 1999; Henschler, 1958). Therefore, the commonly stated position, that all levels found are below government set or regulatory standards, is incorrect.

In 2005, the British Government confirmed that there are no exposure standards that apply to the complex mixture passengers and crews are exposed to. Yet, exposures continue with interested parties persevering a well-orchestrated misinformation campaign by claiming everything is below a non-existent exposure standard.

**The Countess of Mar** asked Her Majesty's Government:

What exposure standards currently apply to any synergistic effects of simultaneous exposure to numerous chemicals which may be experienced by aircraft passengers and crew during a contaminated air event in a reduced pressure environment.  
[HL1761]

**Lord Davies of Oldham:**

None. European airworthiness regulations for aircraft and engine design are written in objective terms that stipulate that the air provided to the passenger and crew compartments must be free from harmful or hazardous concentrations of gases or vapours.

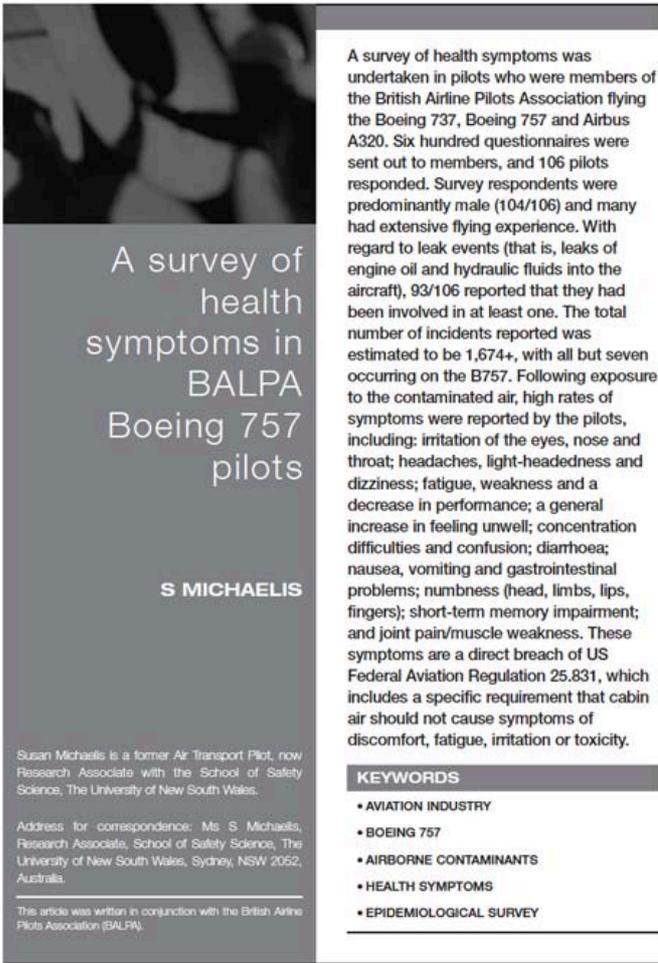
Inhalation toxicity data related to the effects of crews and passengers inhaling heated engine oil fumes onboard aircraft have never been published, yet the airline industry continues to let crews and passengers be exposed.

## 10. Under reporting.

If the cabin or cockpit were to fill with smoke, such events would most likely be reported. However when contaminated air events occur without a visible element, such as a smell in the cabin or cockpit, published crew surveys confirm that less than 4% of such events are ever reported (Michaelis, 2003).

For a variety of reasons, including lack of crew education about contaminated air events, under-reporting of these events is common and well recognised by crew unions, the FAA, and European Aviation Safety Authority (FAA, 2006; EASA, 2011), even though the majority of fume events have been recognised as being related to oil leakage (EASA, 2009).

Contaminated air events have frequently been regarded as a nuisance, rather than a flight safety issue, despite the fact all events are required to be reported.



**A survey of health symptoms in BALPA Boeing 757 pilots**  
S MICHAELIS

A survey of health symptoms was undertaken in pilots who were members of the British Airline Pilots Association flying the Boeing 737, Boeing 757 and Airbus A320. Six hundred questionnaires were sent out to members, and 106 pilots responded. Survey respondents were predominantly male (104/106) and many had extensive flying experience. With regard to leak events (that is, leaks of engine oil and hydraulic fluids into the aircraft), 93/106 reported that they had been involved in at least one. The total number of incidents reported was estimated to be 1,674+, with all but seven occurring on the B757. Following exposure to the contaminated air, high rates of symptoms were reported by the pilots, including: irritation of the eyes, nose and throat; headaches, light-headedness and dizziness; fatigue, weakness and a decrease in performance; a general increase in feeling unwell; concentration difficulties and confusion; diarrhoea; nausea, vomiting and gastrointestinal problems; numbness (head, limbs, lips, fingers); short-term memory impairment; and joint pain/muscle weakness. These symptoms are a direct breach of US Federal Aviation Regulation 25.831, which includes a specific requirement that cabin air should not cause symptoms of discomfort, fatigue, irritation or toxicity.

**KEYWORDS**

- AVIATION INDUSTRY
- BOEING 757
- AIRBORNE CONTAMINANTS
- HEALTH SYMPTOMS
- EPIDEMIOLOGICAL SURVEY

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It has been accepted by many, including regulators, manufacturers, the UK Committee of Toxicity (COT), the GCAQE, International Federation Airline Pilots Association (IFALPA) and European Cockpit Association (ECA) that fume events are to be regarded as a flight safety issue and must be reported as indicated in the various regulations as shown below.

Likewise, it is often said that contaminated air events are very rare, occur only when an engine seal fails, and are therefore not a serious issue. However, reports of the frequency of oil fumes reported by pilots vary from 1% of flights according to the UK Committee of Toxicity (COT) to 1 per day based on US FAA records (Murawski, 2008). These figures do not incorporate transient contaminated air events, which are incorrectly seen by many as 'normal'.

The industry delays taking action, due in part to a failure of crews to report all events, which creates an inaccurate understanding of the frequency of these events. Every contaminated air event should and must be reported.

It is absolutely vital that all contaminated air events are reported, not just to your airline and national safety authority, but also to your union representative. It is also important that you keep a detailed record of all such events and exposures.

## 11. Aviation regulations.

### VENTILATION AND HEATING

#### CS 25.831 Ventilation

- (a) Each passenger and crew compartment must be ventilated and each crew compartment must have enough fresh air (but not less than 0.28 m<sup>3</sup>/min. (10 cubic ft per minute) per crewmember) to enable crewmembers to perform their duties without undue discomfort or fatigue. (See AMC 25.831 (a).)
- (b) Crew and passenger compartment air must be free from harmful or hazardous concentrations of gases or vapours. In meeting this requirement, the following apply...

The aviation regulations and certification standards clearly support that clean air is an airworthiness requirement, and therefore a flight safety issue. FAR/CS 25.831 'a' and 'b' require that there must be a sufficient amount of uncontaminated air to enable the crew to undertake their duties without undue fatigue or discomfort, and that the air must be free of harmful or hazardous concentrations of gasses or vapours.

Symptoms expected in flight as a result of exposure to the heated lubricants and fluids amount to discomfort or adverse effects/harm and, thus, support indicate that the design regulations are not being met in operation, as required.

<b>Specific Hazards</b>	: Hazardous combustion products may include: A complex mixture of airborne solid and liquid particulates and gases (smoke). Carbon monoxide. Unidentified organic and inorganic compounds.
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Typical warning on a synthetic jet engine oil regarding decomposition products

Oil data sheets report that decomposition of the oils exposed to high temperatures give off irritating and or harmful gases, vapours/fumes with symptoms including headaches, nausea, eye nose and throat, skin irritation. Many accept exposure to contaminated air is a flight safety issue, these include: aviation regulators, air accident investigation reports, worker organizations and air safety reports. Additionally, oil fumes that cause crew impairment must not occur more frequently than 1 in 100,000 flight hours, yet a UK Government study has found that oil fumes are reported on 1% of flights.

The design basis of using pressurised air to seal the oil in the engine chamber explains why lower levels of oil are being found repeatedly in normal flight operations, and are expected during transient power changes within the engine. There are also clear regulatory requirements for warning systems in the flight deck (FAR/CS 1309C). Also, pilots are required to report all cases of suspected oil fumes in the aircraft technical log, as well as to the regulator under the mandatory occurrence scheme (EU). However, there is clear evidence that the regulations are not being applied by the manufacturers and airlines, and are not being enforced by the regulators.

## 12. Health effects.

Email from an airline Captain, now sadly deceased due to a brain tumour:

*"I am worried about my cognitive functions while flying and neurological damage. Something definitely happens when I breathe the stuff in!"*

The lubricant and fluid material data sheets, chemical database information and regulations (e.g. REACH/CLP) provide a range of expected adverse effects upon inhalation and dermal exposure to heated synthetic jet engine oil and deicing/hydraulic fluids. These include irritant/sensitizing and neurotoxic effects, all consistent with adverse effects reported in association with exposure to contaminated air.

The term 'Aerotoxic Syndrome' was first suggested in 1999 by members of an electronic global 'e-group' called Aerotox (Winder, Balouet & Hoffman, 1999). The published literature supports a variety of both short and long-term adverse health effects related to exposure to jet engine contaminated air. Short-term effects related to exposure, such as headaches, nausea, eye, nose and throat irritants, in addition to being listed on chemical data sheets, are accepted by a number of airlines and some manufacturers. These represent a clear flight safety hazard given their ability to degrade crew performance. Chronic ill health effects reported in the literature include a common pattern of respiratory, central nervous system, neuropsychological, cardiovascular, other general effects and cancers.

Typical 'Aerotoxic Syndrome' medical effects (Winder, 2006; Harrison, R. 2009)	
Short term exposure	Long term exposure
<p><b>Neurotoxic symptoms:</b> visual changes, blurred or tunnel vision, nystagmus, disorientation, shaking and tremors, loss of balance and vertigo, seizures, loss of consciousness, sleep disturbance, parathesias;</p> <p><b>Neuropsychological or Psychotoxic symptoms:</b> memory impairment, headache, light-headedness, dizziness, concentration difficulty, slowed mental processing, difficulty multi-tasking, confusion and feeling intoxicated, depression;</p> <p><b>Gastro-intestinal symptoms:</b> nausea, vomiting, diarrhoea;</p> <p><b>Respiratory symptoms:</b> cough, breathing difficulties (shortness of breath), tightness in chest, respiratory failure requiring oxygen;</p> <p><b>Cardiovascular symptoms:</b> increased heart rate and palpitations;</p> <p><b>Irritation</b> of eyes, nose and upper airways;</p> <p><b>Other:</b> fatigue, muscle weakness, anxiety, PTSD, rash.</p>	<p><b>Neurotoxic symptoms:</b> slowed mental processing, difficulty multi-tasking, tremor, numbness (fingers, lips, limbs), sleep disturbance, balance problems, parathesias;</p> <p><b>Neuropsychological or Psychotoxic symptoms:</b> memory impairment, forgetfulness, concentration difficulty, lack of co-ordination, headaches (sometimes severe), dizziness, slowed mental processing, difficulty multi-tasking, sleep disorders;</p> <p><b>Gastro-intestinal symptoms:</b> salivation, nausea, vomiting, diarrhoea;</p> <p><b>Respiratory symptoms:</b> breathing difficulties (shortness of breath), cough, tightness in chest, wheezing, respiratory failure, susceptibility to upper respiratory tract infections;</p> <p><b>Cardiovascular symptoms:</b> chest pain, increased heart rate and palpitations;</p> <p><b>Skin symptoms:</b> skin itching and rashes; skin blisters (on uncovered body parts), hair loss;</p> <p><b>Irritation</b> of eyes, nose and upper airways;</p> <p><b>Sensitivity:</b> signs of immunosuppression, chemical sensitivity leading to acquired or multiple chemical sensitivity;</p> <p><b>Other:</b> muscle weakness and fatigue (leading to chronic fatigue), exhaustion, rash, joint pain, PTSD, rash, muscle pain.</p>

A major study undertaken found chronic ill health consistent with exposure to aircraft contaminated air at a rate of 13% in UK pilots (Michaelis, 2010). Other studies have reported neurological symptoms and cancer at 10 times the national average in aircrew, with an average age of 41 (Passon, 2011). A recent Harvard study found an increased rate of female reproductive cancers, and what seem higher-than-expected rates of neurological symptoms serious enough to seek medical care in US flight attendants (McNeely, 2014).

Neuropsychological and respiratory complaints consistent with lung injury as a result of hydrocarbon inhalation have been seen in aircrew (Burdon, 2012), while cognitive deficits in aircrew have also been shown (Coxon, 2002; Mackenzie Ross, 2006). More recently, of 12 jet airplane passengers tested, six were positive for TOCP exposure (Liyasova, 2012).

A range of published literature supports that symptoms and diagnosis reported are consistent with exposure to aircraft contaminated air substances, an issue that was clearly highlighted within the industry in 1954.

Exposure to heated jet engine oils, hydraulic and deicing fluids present an appreciable hazard. The wide range and serious regulatory hazard classifications listed above necessitate the application of the various national occupational health and safety regulations and risk mitigation measures. The hazard warnings are consistent with some of the reported symptoms.

In 2012, members of Prof. Furlong's team at University of Washington published a paper that, arguably, is one of the most influential papers on the oil fumes issue today. They demonstrated a physiological effect in mice that had ingested either Durad 125 or the tri-para isomer of TCP (i.e., one of four sorely understudied isomers that dominate both commercial TCP blends added to aviation oils). Specifically, the activity of liver acyl peptide hydrolase (APH) and carboxylesterase1 (CES1) – was inhibited (Baker, 2012). Assuming these findings apply to human inhalation exposure to these same TCPs, they are highly significant because:

- (1) The APH enzyme is implicated in cognition (Pancetti, 2007; Richards, 2000). Thus, the finding that TCPs (after being bioactivated in the liver, as well as other tissues, including the brain) suppress APH activity may help to explain the prevalence of individuals who report cognitive effects after inhaling these types of TCPs during airline flights; and
- (2) The CES1 enzyme plays a role in the body's detoxification processes (including the lungs and central nervous system), and the inhibition of CES1 has been shown to suppress the activity of an important type of white blood cell, which can affect overall immune function and the control of tumor cells/inflammatory processes (Markey, 2011).

Thus, the finding that TCPs (after being bioactivated in the liver) suppress CES1 activity may help to explain reports of immune system deficiencies, as well as reduced tolerance to subsequent exposures of toxic compounds, among affected airline crews. CES1 activity is known to vary widely between people, influenced by genes, gene expression, and environmental factors (NCBI, 2014; Ross, 2012). So, it is possible that low CES1 activity (whether naturally low or artificially depressed by a fume event) may increase a person's susceptibility to ill effects following exposure to oil fumes. Likewise, high CES1 activity may offer some protective effect.

In addition to informing your employer in writing, if you are exposed to a contaminated air event the GCAQE recommends you document and report the exposure and any symptoms that may be attributable to the exposure, to your doctor and union. Some exposure symptoms may be delayed.

### 13. Solutions.

Early jet aircraft avoided this problem with the use of turbo compressors and blowers. Today many crews and passengers see contaminated air as a normal event, yet it is anything but normal. Greater crew and passenger education into the issues of contaminated air needs to take place. This is something the GCAQE is leading the way on, in co-operation with its member organisations. With an industry and crew increased awareness of the problem of contaminated air, there will be an increase in reporting of events. This, in turn, will increase pressure on airframe manufacturers, engine manufacturers and airline operators to seek technical solutions for current and future generations of aircraft.



Boeing 787 does not use 'bleed air' for pressurisation or air-conditioning  
(Photo: Dave Sizer)

Suspected contaminated air leading to undue discomfort or fatigue is a clear contravention of the ventilation airworthiness requirements, given that crews are required to operate aircraft without their performance being impaired or degraded.

Some in the industry claim that the air you breathe is filtered. Only the cabin re-circulated air is filtered. This is done by way of high-efficiency particulate air (HEPA) filters, which effectively remove viruses and bacteria, if maintained correctly. Some HEPA filters also offer an activated carbon filtration feature to remove some odours. These are in the re-circulated air and offer no protection to bleed air contamination events. Some technical solutions such as bleed air catalytic converters were trialled some twenty years ago but these were ineffective. Some Boeing 757 operators currently have activated carbon filtration systems fitted to the cockpit supply air, although these do not offer a totally effective solution.

Today, solutions exist to the contaminated air problem. The Boeing 787 air conditioning system architecture no longer uses either engine or APU bleed air for pressurisation and air conditioning. Non-bleed designs should become mandatory on all future aircraft designs. Additionally less toxic oils and bleed air filtration systems should be introduced for the current generation of aircraft as well as real time detection and warning systems.

The GCAQE believes the only totally effective solution to the contaminated air problem, is for all aircraft air conditioning systems to be designed with a 'bleed free' architecture.

## 14. Warnings and labelling.

### CLP/GHS - Classification, labelling and packaging of substances and mixtures

CLP is the Regulation on classification, labelling and packaging of substances and mixtures. This Regulation aligns previous EU legislation on classification, labelling and packaging of chemicals to the GHS (Globally Harmonised System of Classification and Labelling of Chemicals). Its main objectives are to facilitate international trade in chemicals and to maintain the existing level of protection of human health and environment. The GHS is a United Nations system to identify hazardous chemicals and to inform users about these hazards through standard symbols and phrases on the packaging labels and through safety data sheets (SDS).



Based upon the United Nations/EU Globally Harmonized System of hazard classification, the synthetic jet engine oils, hydraulic and de-icing fluids contain a range of hazardous substances.

The Classification Labelling and Packaging (CLP) mandatory regulation shows that the hazard classifications for the substances at levels in the oils and fluids include the following warnings: harmful if swallowed, dermal or inhalation exposure, skin/eye irritant, skin sensitization; suspected to and may cause cancer; suspected to and may damage fertility or the unborn child, toxic to the nervous system/organs (single exposure) and repeat/prolonged exposure may cause damage to organs; very toxic by inhalation; germ cell mutagenicity; suspected to/may cause genetic defects; irritating to the respiratory system, respiratory sensitizer; may cause allergy or asthma symptoms or breathing difficulties if inhaled and may cause drowsiness/dizziness.

Additionally, organophosphates used in the oils and hydraulic fluids have been listed as endocrine disruptors, for which there is no safe level of exposure. Some are recognized as being bioaccumulative.

The GCAQE believes that most of the chemicals crews and passengers are being exposed to are incorrectly classified under the REACH CLP (Classification) regulations and continues to work with the European Commission to address this.

REACH is the European Union (EU) regulatory system for chemicals. It came into force on 1<sup>st</sup> June 2007, and will involve the registration of some 30,000 chemicals. Amongst the many objectives REACH has, the European Commission believes REACH will provide a high level of protection to human health and the environment.

A CAS Registry Number, also referred to as CASRN or CAS Number, is a unique numerical identifier assigned by Chemical Abstracts Service (CAS) to every chemical substance described in the open scientific literature.

## 15. Answers to the seven most frequently asked questions.

### 1. "What is the contaminated air problem?"

The breathing air on aircraft is provided unfiltered from the compression section of the engines in a process known as 'bleed air'. This bleed air gets contaminated with heated engine oils that contain hazardous chemicals, which crews and passengers breathe in and may also be absorbed through the skin as a dermal exposure.

### 2. "Aren't the concentrations of the oil-based chemicals too low to cause harm?"

Exposures are to a complex mixture of chemicals, which most likely have a synergistic effect of exposure and no inhalation toxicity testing has ever been published. Also, most chemicals do not have a recognised safe exposure level.

### 3. "Aren't all the chemicals below exposure the standards?"

There are no standards for the mixture of chemicals you are exposed to. Furthermore exposure standards do not apply at altitude, only apply to single chemicals on their own, do not apply to complex mixtures, and do not apply to the traveling public - especially to the unborn, children, and the elderly.

### 4. "Are fume events rare?"

Aircraft are not equipped with detection systems to warn when the air is contaminated, many chemicals are odourless and under reporting is widespread through out the industry. Consequently, it cannot be stated that these events are rare. It can only be stated that the frequency of events remains unknown.

### 5. "Is it not true that too few people are effected for this to be a health concern?"

Exposure to contaminated air will most likely impact individuals in different ways in both the short and long term, based on a number of variable factors: levels and types of chemicals present during an exposure, previous exposure history to not just contaminated air but other chemical exposures such as pesticides, genetic make-up, age, medical condition, and potentially any medication you may be prescribed.

### 6. "Isn't it true there is no evidence of exposure?"

Oils used in engines leak into the air supply by design. Their chemical signature has been repeatedly found in aircraft cabins and cockpits. Extensive evidence confirms exposures are occurring and health and flight safety is being compromised.

### 7. "How can contaminated air events possibly compromise flight safety?"

Regulations state that crews are not allowed to fly if they are fatigued or have consumed alcohol or taken certain medications in a pre determined time period before they fly. This is to ensure crews are alert and able to deal with any complex emergencies they may face. Inhaling contaminated air will and has impacted crews' cognitive ability to fly – this is a flight safety issue.

## **16. Further reading and information.**

### **Internet.**

Education film on GCAQE website at: [www.gcaqe.org](http://www.gcaqe.org)  
Aerotoxic Association: [www.aerotoxic.org](http://www.aerotoxic.org)

### **Media.**

An extensive list of media articles and TV coverage can be found on the media page of the GCAQE website.

### **Films, videos and documentaries.**

Toxic Flyer - 60 Minutes (2013)  
Welcome Aboard Toxic Airlines (2007)  
Broken Wings (2011)  
Angel Without Wings (2011)  
A Dark Reflection (2014)  
Education film on GCAQE website at: [www.gcaqe.org](http://www.gcaqe.org)

### **Books.**

Health and Flight Safety Implications From Exposure to Contaminated Air in Aircraft (2010)  
Author: Dr. Susan Michaelis  
ISBN: 978-0-9555437-7-7, Hardback: 931 pages

Aviation Contaminated Air Reference Manual (2007)  
Editor: Susan Michaelis  
ISBN: 9780955567209, Hardback: 844 pages or available as .pdf

Contaminated Air Protection: Proceedings of the Air  
Editor: Prof Chris Winder  
ISBN: 0733422829, Paperback: 318 pages

## 17. Why join the GCAQE.

Since 2006 the unique expertise the GCAQE holds on the specific issue of contaminated air has seen the GCAQE grow in size and influence globally. Whatever the size of your union or organisation, if your organisation would like to be part of the GCAQE's efforts to address the issue of contaminated air; whether it be to be part of the on going scientific research, educational programs, negotiations and discussions with governments or industry, or to simply access our in-depth knowledge base, we would welcome you as members.

The GCAQE is a budget-minded not for profit organisation advocating for change, and members pay annual membership dues to contribute to the functioning of the GCAQE, recognising it as the leading, credible worker voice on this issue. The membership dues enable the GCAQE to cover its minimal operating costs and fund limited travel for its officials to attend a small number of conferences and meetings with regulators, industry, and other crew unions, in order to advocate for crew and passenger education and protection from exposure to oil fumes on aircraft. In addition to the satisfaction of contributing, collectively, to such important work, members also enjoy the following benefits:

- Regular updates on current and emerging regulatory, scientific, legislative, and legal developments around the world relevant to the oil fumes issue on aircraft by way of electronic newsletters, enabling unions to easily stay informed and current on the technical and political aspects. For example, a recent GCAQE newsletter (8/2014) includes articles on the following: an investigation conducted by the German accident investigator into onboard smoke/fume events (5/2014); the leaking of an email written by a senior Boeing engineer on the notable failure of the FAA to regulate oil smoke/fumes (4/2014); an update on the authority of the US labour department to regulate aspects of cabin crew workplace safety and health (3/2014); the results of a major cabin crew health survey, published in an open access journal (3/2014); a fumes investigation conducted by the Spanish aircraft accident authority which classified the event as an aviation accident (2/2014); research publications regarding a direct pathway for inhaled toxins to access the brain via neural pathways in the face (2014); an influential research study that describes TCP and TBP oil/hydraulic additives as endocrine disruptors (12/2013); the decision of the European Chemical Agency to classify TXP (another oil additive that is toxic to the brain and reproductive systems) as a “substance of very high concern” (12/2013); an update on a joint US government-industry research project intended to characterise oil fume constituents and develop sensor technology (6/2013); a report solicited by the US Federal Aviation Administration regarding means to study the health impact of exposure to oil fumes (6/2013); and a relevant online petition circulated by an advocacy group calling for mandatory bleed air sensors (ongoing). Clearly, it would be challenging for member unions to learn about and review all of these documents and developments, but the GCAQE compiles and summarizes the information, enabling members to stay informed so as to advocate more effectively at their respective airlines;
- Access to “members-only” crewmember educational tools (newsletter articles, information cards, bulletins, what affected crews need to tell their doctors, etc.) to enable unions to educate its membership on the risks of exposure to oil fumes, and provide practical advice on actions to take if exposed to fumes. Materials are provided in English but some translation services may also be available; and
- An invitation to attend and participate in the GCAQE annual information exchange meeting, held in London every spring. The annual meeting includes excellent networking and information sharing opportunities with other crew unions; updates on relevant regulatory,

scientific, legislative, and legal developments around the world; and presentations from top-tier researchers that describe relevant research projects underway. Members pay a nominal attendance fee, but can participate in additional “members-only” closed sessions.

GCAQE is largely funded by union membership dues, so for each union that joins the coalition, our efforts to raise awareness amongst airline worker unions and broaden the scope of our advocacy work both grow.

GCAQE goals and planned action: The GCAQE has defined a list of goals and planned actions to reach those goals for the next four years. By taking a bold, but scientifically defensible, position crew unions represented by the GCAQE should finally be able to motivate the airline industry to introduce solutions that exist today in order to protect the welfare of all airline workers, globally.

Administrative details for joining the GCAQE:

To join the GCAQE, we encourage you to contact our administrator ([admin@gcaqe.org](mailto:admin@gcaqe.org)) for further membership details, current membership rates or questions.

Current GCAQE membership fees are:

≤ 3,000 members	UK£800
3,001 – 9,000 members	UK£1,000
> 9,000 members	UK£1,200

The subscription year is April 1 through 31 March. PLEASE NOTE: As of November 2014 the GCAQE Board is currently reviewing a proposal to reduce the membership fees for smaller unions.

≤ 250 members	UK£250
251 – 1,000 members	UK£500
1,001 - 3000 members	UK£750

**18. Current GCAQE members.**

At the time of issuing this newsletter current GCAQE members included:

ABRAPAC - Brazilian Association of Pilots of Civil Aviation;  
ACPA - Air Canada Pilot's Association;  
Aeropers - Swiss Air Line Pilots Association (Swiss ALPA);  
AFA-CWA - Association of Flight Attendants;  
AFAP - Australian Federation of Air Pilots;  
ALAEA - The Australian Licensed Aircraft Engineers' Association;  
CUPE - Canadian Union of Public Employees;  
FIA - Icelandic ALPA - Icelandic Air Line Pilots Association;  
FIT CISL - Italian Transport Federation;  
FSC-CCOO - Federation of Citizen Services;  
HTW - Holiday Travel Watch;  
IAM - International Association of Machinists and Aerospace Workers;  
IPA - Independent Pilots Association;  
NF - Norsk Flygerforbund - Norwegian Airline Pilots Association;  
PARAT - PARAT;  
SAFE Norwegian Union of Energy Workers;  
SNPL - Syndicat National des Pilotes de Ligne;  
SNPNC - Syndicat National du Personnel Naviguant Commercial;  
TWU - Transport Workers Union;  
UFO - Unabhängige Flugbegleiter Organisation - Independent Flight Attendant Organisation;  
Unite - Unite The Union;  
Vereinigung Cockpit - German Airline Pilots Association;  
VNC - Vakbond Van Nederlands Cabinpersoneel;

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