Aerotoxic Syndrome: A new occupational disease?

-Adverse health effects experienced by aircrew exposed to aircraft contaminated air

ICOH- Accident prevention 02 May 2018

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Who am I?



PhD (UNSW, 2010) - <u>http://handle.unsw.edu.au/1959.4/50342</u> <u>MSc: (Cranfield, 2016) - http://www.susanmichaelis.com/caq.html</u>



Presentation outline

- History
- Hazards
- Flight safety
- Airworthiness
- Health
- Science
- Way forward



1935 – P.R.Bassett

MARCH, 1935

J. A.E. S.

Passenger Comfort in Air Transportation

Presented at the Air Transport Session, Third Annual Meeting, I. Ac. S. P. R. BASSETT, Sperry Gyroscope Company

"In some early attempts at cabin heating, air was heated by the exhaust manifold and then taken into the cabin. Such air frequently smelled scorched or occasionally smelled of oil. The condition was found unbearable. Even a trace of smell causes extreme discomfort in the air."



VOLUME 1

1938 - 1st Pressurised Airliner



Boeing Model 307 Stratoliner



1947 - Boeing 377 Stratocruiser



Carbon Monoxide Detectors and Filters Sea level cabin at 15,000ft - Max 6.55 PSI



Jet engine and 'Bleed Air'







1952/53 – J57 Engine



B-52 and the F-100 – Bleed Air



The J57 (JT3) Engine was the first Pratt & Whitney-designed turbojet.

Early use of MIL-L-7808 Synthetic oil Type I or 3 centistoke jet oils



15 May 1954

WILLIAM J. VAN EVERY 1st Lt, USAF



"At approximately 1530 hours on 15 May 1954, I was flying aircraft number 52-1436, an RB-57A, in a three (3) plane formation from Shaw Air Force Base, South Carolina. Approximately 40 minutes after take-off while flying over an overcast at 7000 feet, 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 I recall dropping back from the formation and opening the clear vision window and unhooking the oxygen mask. Fresh air from this open window seemed to relieve the unpleasant conditions I felt."





October 1955

North American Aviation

Aware of oil contamination issue for last two years – suspect compressor bearing seals main source

In-depth look at filter options.

Solutions:

The Separate Compressor As A Solution – This method of eliminating contamination is considered to be the most positive... also the heaviest, most complicated and most expensive.



1954 – Dash 80 (Boeing 707)



Turbo compressors



Royal Aeronautical Society - 1954

- Air can be taken off compressor if:
- Intake not contaminated with exhaust gasses & harmful fluids (deicing...)
- Enough pressure at high altitude/ engines throttled back



Compressor provides 'simple and convenient means of obtaining pressurizing air'



27 May 1955 – Caravelle 1st Flight



1st airliner to use Bleed air for pressurisation



1963 - Boeing 727



Bleed Air



1973



ANALYTICAL CONSIDERATIONS CONCERNED WITH CEPHALAGIA ON THE DC-10 Prepared by: J. G. Gaume, M.D., Manager. Aviation Medicine and Safety Research

Science Research

20 February 1973

After preliminary examination of these possible sources, it appeared to be quite probable that the source of the headaches could be contaminants derived from the engine bleed air source for cabin pressurization. This report is limited to consideration of this aspect, and the analysis of the report quoted in the introduction of this report. The contaminant, from its odor and description by personnel affected, would appear to be an irritant gas, although it may well be accompanied by asphyxiants such as CO or CO_2 . This report elaborates on this premi-

1981 BAe 146 arrives



1984 December SIL 21-7 BAe 146 Service Information Leaflet: Oil Contamination of Air Conditioning System which stated: "If the system becomes contaminated by oil, unpleasant cabin odour may be alleviated by:" and goes on to make suggestions of how to manage the problem.

"Captains were making a Public Announcement to passengers and apologising for the "sweaty socks" smell."



Substances – Oils & Hydraulic fluids

Synthetic ester base stock ~95% ('sweaty socks')
Antiwear additive - Triaryl phosphate (OP) ~3% – TCP - includes orthos isomers/TOCP... & TXP...
Amine antioxidant – (1%)
Proprietary substances
Wide variety of pyrolysis substances
Endocrine disruptors (TCP; TBP; TPP)

Hydraulic and deicing fluids – can leak into air supply

Routinely identified in CAQ monitoring studies : eg: EASA (2017)



Oils and fluids are hazardous

- Material safety data sheet: Boeing, ExxonMobil...
- Oil can label
- EU regulations: EU <u>Classification</u> reg. 1272/2008
- Chemical databases
- 1954 patent
- USAF (Treon 1954) Oils heated above 600degF
- Heated complex mixture Cannot define toxicity (howard 2018)



Ram Air Cabin Pressurizing System- Boeing Patent 1954



• One difficulty with utilizing the air compressor of a turbojet engine, for example, as the source of pressurized air for the airplane pressure cabin is the danger of air contamination. Lubricant decomposition products of a noxious and even toxic nature can be produced in the operation of these engines which, in the absence of sufficient precaution, may be carried into the pressure cabin with air delivered by the compressor. Suitable decontamination filters entirely adequate to meet this situation have not been forthcoming.

https://patentimages.storage.googleapis.com/64/26/91/36748605d2a867/US2767561.pdf



EU/UN Hazard Classifications (CLP /REACH) Oil, hydraulic, deicing fluids: HAZARDS

Harmful if swallowed/dermal:	Eye/skin irritant & ? Respiratory irritant
May (suspected) cause damage fertility or harm the unborn child	Skin sensitizer
Single exposure & repeated target organ toxicity - nervous system	Very toxic by inhalation
May cause genetic defects	May cause allergy/asthma or breathing difficulties if inhaled
May (Suspected) of causing cancer	May cause drowsiness or dizziness

TXP – Substance of Very High Concern (SVHC) – REACH

May cause harm to the unborn/Impair fertility



United Nation

Oil warnings

MSDS - Boeing 2007

 MJO II: Signs & symptoms of exposure: Irritation of eyes, skin, nose, throat & lungs. Neurotoxicity may be characterized by dizziness, headache, confusion & "intoxication".

Oil can label



Do not breathe mist of vapor from heated material



Conflicting views

• Boeing & FAA

1953: Unknown mixture /Hazardous/toxic - Boeing

2006: "Who knows what the byproducts are in hot synthetic turbine oil." - Boeing

✤ 2013: "Decomposition reactions of engine oils & hydraulic fluids are largely unknown." - FAA

Levels are too low to be harmful

BUT

Ground based chemical limits should not be applied to aircraft environment & not available for most substances.....



Inapplicability of OELs

Minimal O2 content- ACGIH TLVs



FIGURE F-1. Plot of oxygen partial pressure (pO2) (expressed in torr and kPa) with increasing altitude (expressed in feet and meters), showing the recommended oxygen partial pressure of 132 torr.

- Adverse physiolgical effects
 - Above 5000 feet / Below 132 torr (oxygen partial pressure
- Industry insists OELs are not breached





Flight safety BA 286 – October 2016

Air Traffic Control

Emergency Landing- Vancouver



PAN PAN PAN due to Toxic Fumes on Board a British Airways A380 (ATC)





Flight286 – A 380 – 432 crew/ passengers

- 'Fume event' : "toxic fumes, toxic gas type fumes
- SFO-LHR -Diversion into Vancouver
- Strong noxious smell (intoxicating fume smell)/ dirty sock odour
- 11 cabin crew effected & some passengers
- All crew taken to hospital precautionary
- Acute –Long-term effects- consistent pattern
- Advised noxious substance (passenger)? /CAA ??
- Galley fumes- airline ??

Flight Safety

- Under reporting is occurring
- Flight safety issue widely recognized
 - ICAO (2015) CIR 344-AN/202
 - Fumes- negative impact on safety issue
 - Slow degradation of performance/not recognized
 - FAA SAFO (2018) enhance flight crew
 procedures that mitigate the risk to passengers
 and crew in the event of odors, smoke and/or
 fumes.



Bureaus of air safety

Bleed air supply contamination

- Numerous reports
- 26 key recommendations and findings
- 9 bureaus of air safety
- Mid 1990s 2016
- 9 countries, 2 continents

Refer: Loraine T. Air Accident Investigation Findings and Recommendations. Presentation at International Aircraft Cabin Air Conference, Imperial College London. 19-20 September, 2017: https://www.aircraftcabinair.com/films



AAIB Bulletin: 7/2007 G-CPET – 2006 – Boeing 757

- During the descent, both crew members began to feel disorientated and found that they had to concentrate hard to carry out their normal duties. At this point the commander began to feel 'confused'.
- The flight crew expressed concern that neither had detected the slow degradation in their performance as this only became fully apparent after they had donned oxygen masks and began to recover.

Cause: Oil leak from engine entering air supply



AIB Key Findings

- Many including:
- Subtle impairment occurring/lack of awareness
- Pilots not using O2/emergency/abnormal checklist (focus on fire/smoke)
- Maintenance difficulty in identifying source
- Lack of reporting/ detection systems
- Not generally safety issue/OHS issue
- Fumes not new/numerous aircraft types
- Regulations focus on design/ignore effect on people
- Filters not designed to filter oil fumes



Flight safety - Impairment

- BAe 146 study*: Immediate/ST effects = 44%
- 15 incidents study*:
 - Impairment = 93% (73% involved pilots)
 - 33% full or partial incapacitation of 2 pilots
 - 87% positive oil identification
- Other Crew impairment rates
- CAA MORs: 2006-2011 30%
- BFU 27%
- Michaelis (PhD, 2010) 32%

* Michaelis S, Burdon J, Howard CV. Aerotoxic Syndrome: A New 16. Occupational Disease? Public Health Panorama 2017; 3: 141-356.

http://www.euro.who.int/ data/assets/pdf file/0019/341533/5 OriginalResearch AerotoxicSyndrom ENG.pdf



ICAO Annex 13 and EU Reg 996/2010

- Serious incident: Annex 1
 - Events requiring emergency use of oxygen by pilots
 - Pilot incapacitation
 - Fires and smoke in the passenger compartment
- Accident:
 - Serious injury
 - Hospitalization > 48 hrs (commence within 7 days)
 - Injury to internal organ
- Investigate incidents if safety lessons could be drawn. ? (Eu Reg 996/2010)



Reporting requirements- EU

- REGULATION (EU) No 376/2014 Reporting:
- Commission Implementing Reg (EU) 2015/1018

→4(3) Contaminated air in the cockpit or in the passenger compartment which has or could have endangered the aircraft, its occupants or any other person.

Serious under-reporting continues



Airworthiness

- Oil leakage seen in 3 main ways:
- Rare bearing seal failure
- Failure condition + operational factors- Oil spillage, seal wear....
- Design factor- low level leakage of oil in normal flight
- Therefore...
- MSc completed in 2016 (Cranfield University, UK)
- How oil leaks out of bearing compartment



Oil seals

Oil bearing compartment



Oil seals

- Labyrinth: Clearance (200-400nm)
- Mechanical/face seals: lubricated face (250-1000nm)
- → rely on pressurised air
 → Responsive to thermal/ mechanical changes in structures & pressure changes

All dynamic seals designed to leak - in normal operation
 Path to enter cabin air supply

MSc research

- Interviews with:
 - experienced engineers & seals experts
 - FAA & EASA airframe & engine certification
- Key findings:
 - Seals not absolute design/will leak in normal ops & with varying operational factors
 - Low level emissions not given due consideration
 - No set process to show compliance
 - Focus on incapacitation /ignoring impairment

Michaelis (2016) http://www.susanmichaelis.com/pdf/2016_Susan%20Michaelis_MSc%20Cranfield-Clean%20air%20requirements%20using%20bleed%20air%20system.pdf



Key conclusions

Regulations

Clean air standards & AMC exist - not being met - open to interpretation

Design

Low level oil leakage over the bearing seals into the bleed air: Expected normal condition -various phases of flight

Certification req's not being met (despite appearance they are)

Oil leakage past seals associated with impaired/ degraded performance occurs more frequently than 'major' effects (remote/ improbable) <10⁻⁵ / efh...

Oil leakage (impairment) - Guidance material

• Probable or above >= 10⁻⁵ / efh...



Conclusions





Summary

- Engines consume oil- Permissible rate (0.2-0.8 US Qt/engine/hour) - NORMAL
- Oil leaks in 2 ways:
 - low level in normal operations Design
 - failure conditions less frequent
- Permissible consumption level regarded as not requiring maintenance/reporting (EASA 2018)
- Human exposure- Ignored

Michaelis et al (2017)

BAe 146 pilots study

- 70% + response rate (274 pilots)
- Work environment confirmed to leak oil by manufacturer- BAe Syst.
- Most reported lower level normal fume events/ not failures
- 63% report symptoms consistent with exposure to oils/fluids
- 13%- chronic ill health/ retired with ill health....

15 Incidents review

- 80%- fumes only
- 100% transient engine ops
- 80%- climb or descent
- 93%- impairment –incapacitation
- 33% full/partial incapac' of 2 pilots
- 53% LT adverse effects
- 47% 10-23 symptoms
- 87% positive oil findings (93%)
- 66% fumes reported before / after
- ST & LT medical findings/diagnoses
- Consistent pattern
- Cause & effect identified linking environment to adverse effects
 - Occupational disease: Aerotoxic Syndrome
 - Supported by literature (not just OPIDN/TOCP)



Michaelis et al 2017

Results – Study A (5)

(BAe 146 pilots)

Overview of the 13% of pilots who lost medical certificate to fly or experiencing chronic ill health/deceased



- Study B- 15 events:
- Medical findings/diagnoseswide variety:

Eg:

- Short-term: toxic effect of fumes; Incr Carboxyhemoglobin; Inhalation injury
- Long-term: Occupational asthma;Toxic encephalopathy; Cognitive dysfunction, Wallerian degeneration, Aerotoxic syndrome.....

https://www.aircraftcabinair.com/films - Burdon /2017

Results – Study A (5)

(BAe 146 pilots)

Overview of the 13% of pilots who lost medical certificate to fly or experiencing chronic ill health/deceased



- Neurological
- Neuropsychological
- General
- Respiratory
- Cardiovascular

HEALTH

Aircraft air supplies contaminated by engine oil and other aircraft fluids are reasonably linked to acute and chronic symptoms and findings/diagnoses creating a cause and effect outcome.

New occupational disease?

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New Occupational Disease



Science

- Chronic low level exposures + acute events: (Howard 2018)
 - More susceptible
 - Diffuse pattern
 - Ultrafine particles/OPs/complex mixture
- Repeat low level exposure to OPs greater damage than only acetylcholinesterase mechanisms (Terry - 2012)
- Chronic pre exposure to OPs increases susceptibility (Axelrad 2003)
- UFPs generated with heated oil under all normal conditions (Jones 2017) ("piggyback effect"- Howard 2018)



EASA-Health

- EASA "Health issues are not within the primary scope of the Agency.'s mandate. However, the Agency would take action whenever a health case is evidenced by competent health authorities which would require a change in the design of aircraft."
- EASA, CRD to A-NPA (A-NPA) 2009-10 (2011)
- CAA "We rely on guidance from scientific experts based on the results of a number of independent studies and evidence reviews - including Government commissioned research. Long term ill health due to any toxic effect from cabin air is understood to be unlikely, although such a link cannot be ruled out."
- CAA interview for The Daily Telegraph: 20/6/17
- <u>http://www.telegraph.co.uk/travel/news/world-health-organisation-report-toxic-cabin-air/</u>



What is happening here?

- FAA (2002):
 - Rulemaking may not have kept pace with public expectation and concern about air quality and does not afford explicit protection from particulate matter and other chemical and biological hazards.
 - Aircraft do not meet FAR 25.831- no detection systems (despite AIB recommendations)
- Studies undertaken to give answers needed
- Committees formed to give industry required answers COT, CEN, SAE, ASHRAE...
- Politics but not science



Epidemiological study 1/2

	Overview of Epidemiological Study Design
Lower	
A	Descriptive Studies (Hypothesis-Generating)
	Population-based (correlational studies)
x	Individual-based
xit	Case/Anecdotal Reports
ple	Case Series
OB I	Cross Sectional/prevalence surveys
CC	Analytic Studies (Hypothesis-Testing)
OSI	Observational Studies
0	Case-control studies
	Cohort studies (retrospective, prospective)
V	Intervention Studies
Higher	Randomized Controlled Trials (RCTs)

Figure 1.1. Overview of epidemiological study designs (adapted from Hennekens & Buring 1987).

From theory to practice in environmental epidemiology: developing, conducting and disseminating health research. C.L. Soskolne, J.E. Andruchow, F. Racioppi http://www.euro.who.int/____data/assets/pdf_file/0006/91095/E91890.pdf

Refer https://www.ijpc-se.org/, Professor C Soskolne, University of Alberta, Collegium Ramazzini

Way forward

- Medical protocol
- Bleed air contamination mitigation NOW
- Education/training
- REPORT it campaign
- Disease recognition
- Stop -Regulation failure to protect/maintain safety

We need your help

Ways forward -Solutions - Training



Cir 344-AN/202

Guidelines on Education, Training and Reporting Practices related to Fume Events

- Education
- Training
- Reporting
 - Cabin crew
 - Pilots
 - Maintenance
 - Management

Filtration & sensors



- CS 1309C -Warning information must be provided to alert the crew to unsafe system operating conditions and to enable them to take corrective action. X
- NEW
 - PURE Air Bleed air filtration & sensors- Ready for flight trials – Pall Aerospace



Solutions – Bleed free





Liebherr Aerospace
Electrical ECS

https://www.youtube.com/watch?v=swB1cp5jRbw



 Future generation engines: Air taken from bypass air? Rolls Royce ultra fans?

https://www.rolls-royce.com/products-and-services/civil-aerospace/future-products.aspx#/



THANK YOU to all here

FURTHER INFORMATION AVAILABLE:

CAQ PAGE: susanmichaelis.com MSc: point 4 www.gcaqe.org

susan@susanmichaelis.com GCAQE University of Stirling Michaelis Aviation Consulting MSc award (Cranfield 2017) Course Directors best MSc student award

