The History of Aircraft Contaminated Air & the Way Forward

Reykjavik Flight Safety Symposium

13 April 2018

Global Cabin Air Quality Executive

Captain Tristan Loraine BCAi - ATPL

Dr. Susan Michaelis - ATPL, PhD, MS

UNIVERSITY of STIRLING

Who am I?

Health and Flight Safety Implications from Exposure to Contaminated Air in Aircraft

PhD
S. Michaelis
2010

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

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Capt. Tristan Loraine BCAi

B757/767 Capt (ret)
Spokesperson GCAQE
Subject matter expert

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Presentation outline

- History
- Hazards
- Flight safety
- Airworthiness
- Health
- Science
- Solutions

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1921 – 1st Pressurised Aircraft Engineering Division USD-9A

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1938 - 1st Pressurised Airliner

Boeing Model 307 Stratoliner

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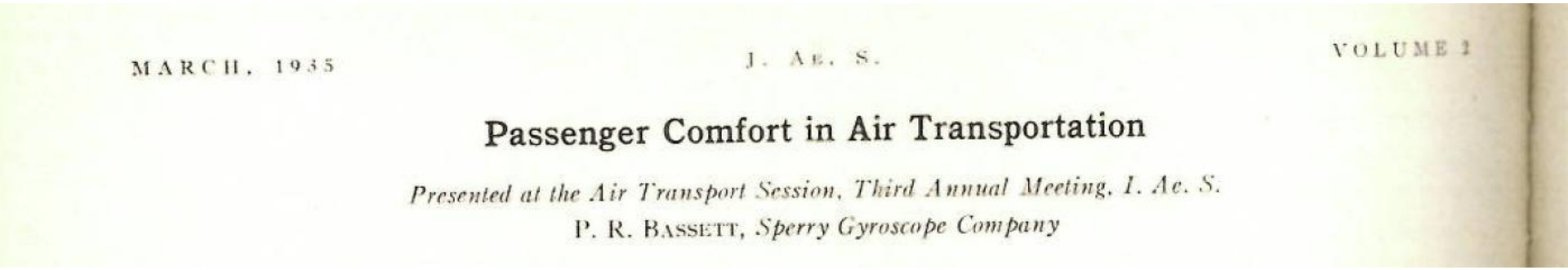
1935 – P.R.Bassett



MARCH, 1935 J. AE. S. VOLUME 2

Passenger Comfort in Air Transportation

Presented at the Air Transport Session, Third Annual Meeting, I. Ae. 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."

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Cabin Blower - AiResearch - Garrett

Lockheed L-647/749 Constellation

First Flew: 1943

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1947 - Boeing 377 Stratocruiser

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

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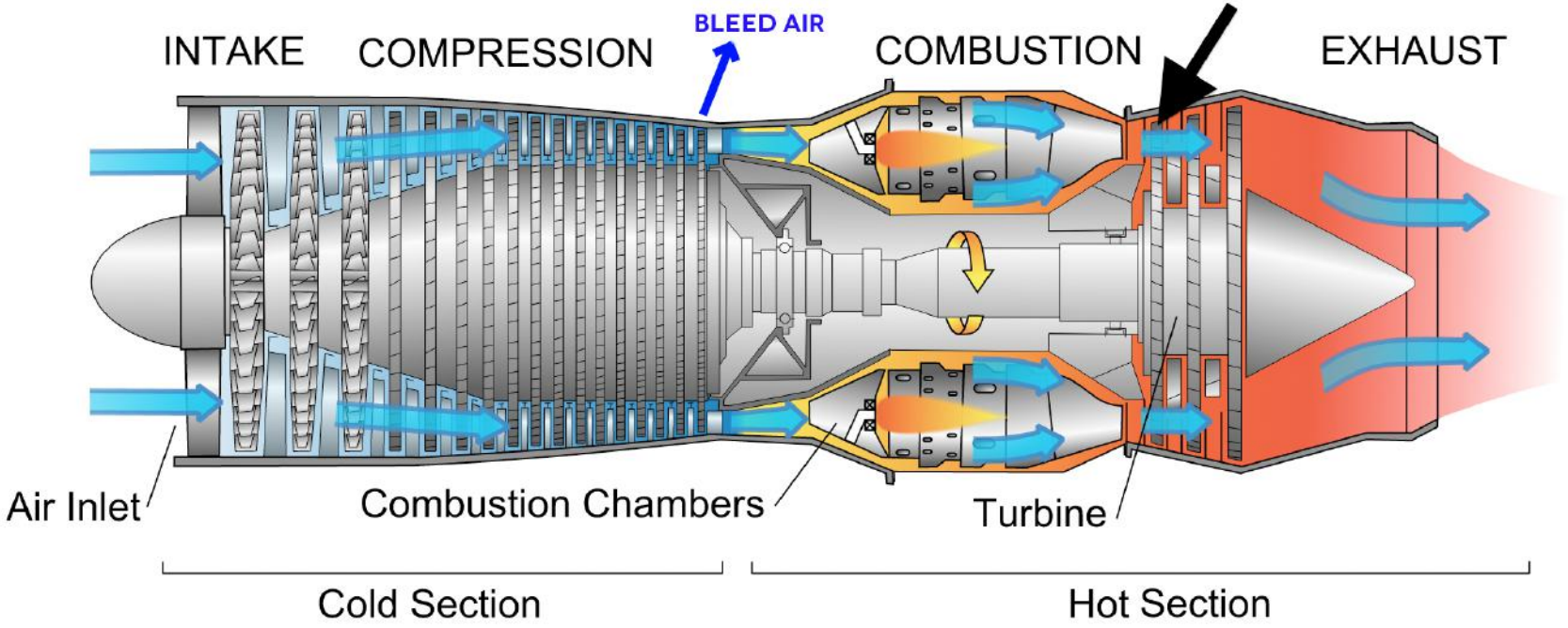
Jet engine and ‘Bleed Air’



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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

18 December 1953

Boeing Document D-14766-2
B-52 Decontamination Program

- Testing of a filter system
- The possible toxic effect of the contamination is still unknown.
- Smoke or haze is reported in only a few flights.
- Obvious increases in the contamination level were noted during changes in engine power conditions.

BOEING AIRPLANE COMPANY
SEATTLE 14, WASHINGTON

DOCUMENT NO. D-14766-2 DATE December 18, 1953
MODEL B-52 CONTRACT NO.
TITLE DECONTAMINATION PROGRAM

ISSUE NO. TO DATE
SHORT TITLE
(For Classified Data)

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PREPARED BY G. A. Gutkowski, R. N. Page, M. D. Peterson
SUPERVISED BY 12/15/53
APPROVED BY 12/17/53
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BAC 324 B - R6 BAC DOCUMENT TITLE PAGE

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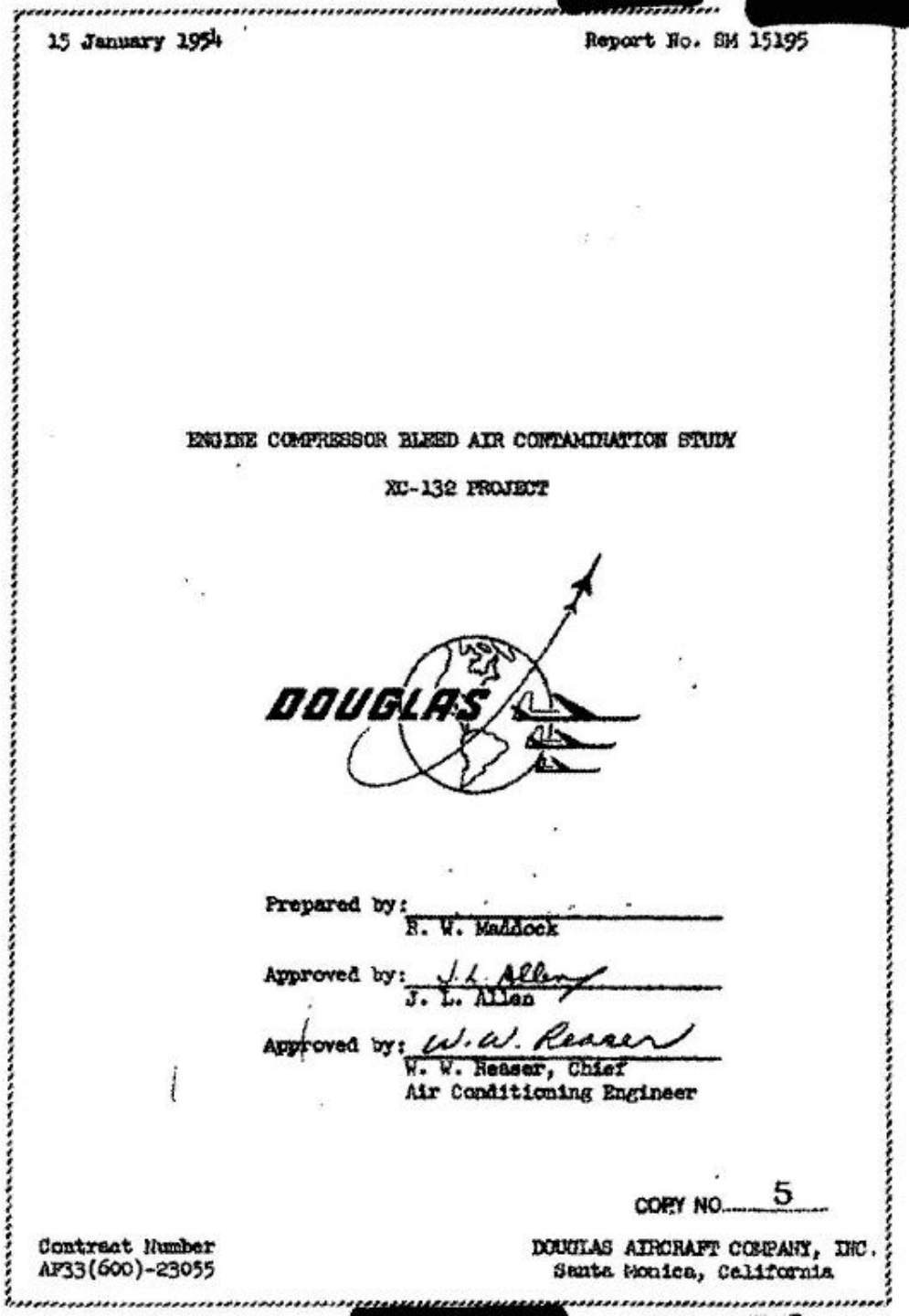
15 January 1954

Engine Compressor Bleed Air Contamination Study - XC-132 Project - R.W. - Douglas

- J-57 & T-57 engine contamination problems.
- Apparently the occurrence is completely erratic, with no predictable pattern since contamination has occurred at all modes of airplane operation, such as take-off, high altitude cruise, descent and taxi. So far there is no known condition or sequence of conditions, which will reliably reproduce the trouble.



15 January 1954 Report No. SM 15195

ENGINE COMPRESSOR BLEED AIR CONTAMINATION STUDY

XC-132 PROJECT

DOUGLAS

Prepared by: R. W. Maddock

Approved by: J. L. Allen
J. L. Allen

Approved by: W. W. Reaser
W. W. Reaser, Chief
Air Conditioning Engineer

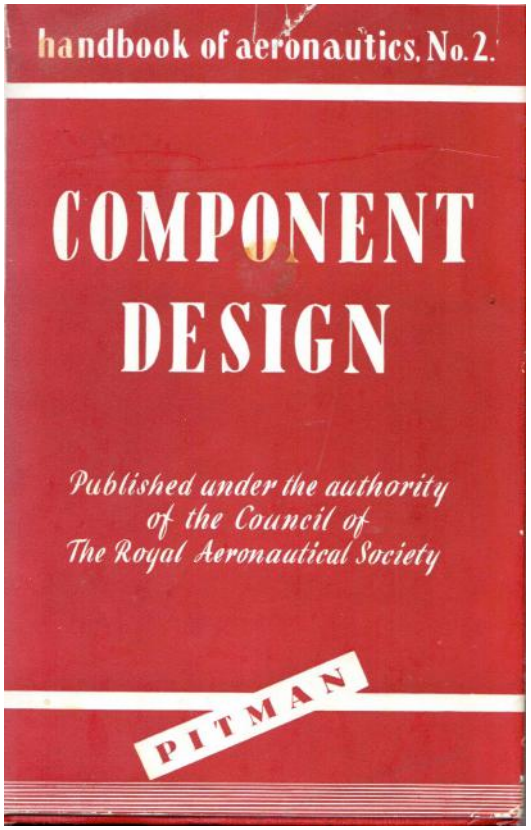
COPY NO. 5

Contract Number
AF33(600)-23055

DOUGLAS AIRCRAFT COMPANY, INC.
Santa Monica, California

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’

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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."

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1954 – Dash 80 (Boeing 707)

Turbo compressors

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October 1955

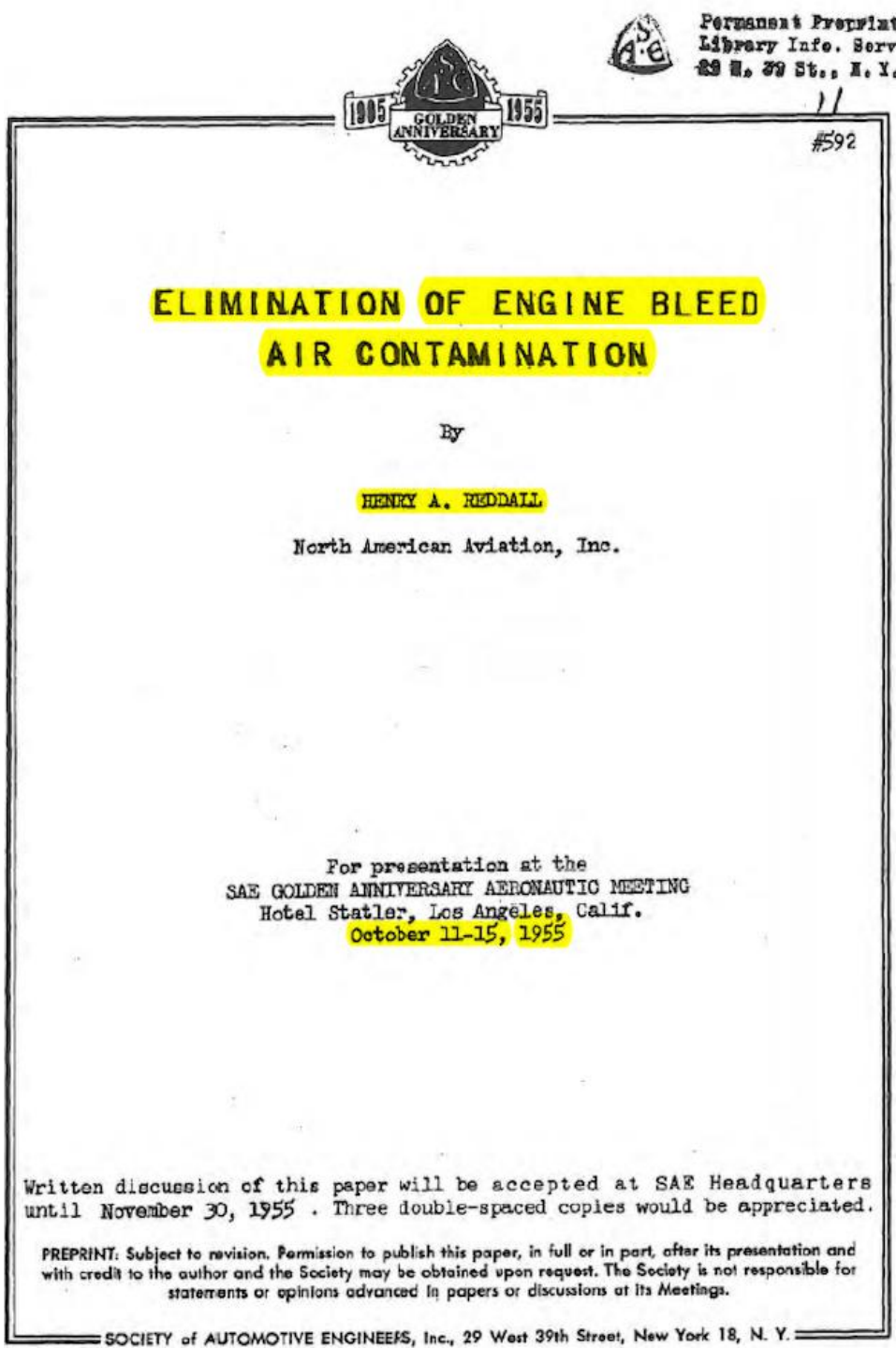
North American Aviation

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.



1905 GOLDEN ANNIVERSARY 1955

#592

ELIMINATION OF ENGINE BLEED AIR CONTAMINATION

By

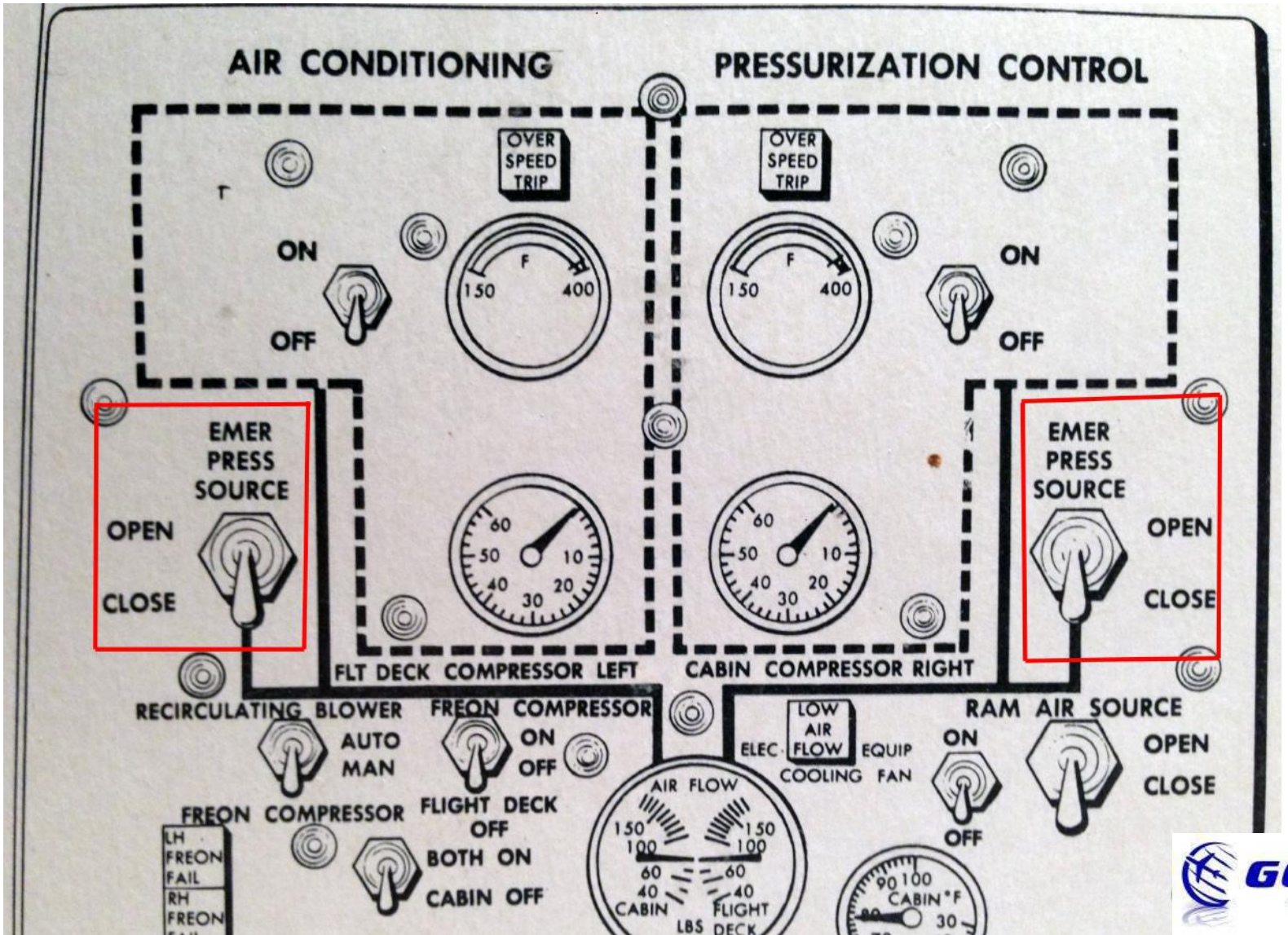
HENRY A. REDDALL

North American Aviation, Inc.

For presentation at the
SAE GOLDEN ANNIVERSARY AERONAUTIC MEETING
Hotel Statler, Los Angeles, Calif.
October 11-15, 1955

Written discussion of this paper will be accepted at SAE Headquarters until November 30, 1955 . Three double-spaced copies would be appreciated.

1959 - CV 880 – Cabin Compressors



27 May 1955 – Caravelle 1st Flight

1st airliner to use Bleed air for pressurisation

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1963 - Boeing 727

Bleed Air

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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 premise

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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."

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Oils and fluids are hazardous

- Material safety data sheet: Boeing, ExxonMobil…
- Oil can label
- EU regulations: EU Classification reg. 1272/2008
- Chemical databases
- 1954 patent
- Published literature: Michaelis et al (2017)….
- Industry reports: FAA (2009), Rolls Royce (2003)

…

Heated complex mixture - Cannot define toxicity
(howard 2018)

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Substances – Oils & Hydraulic fluids

- Synthetic ester base stock ~95%
- 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)

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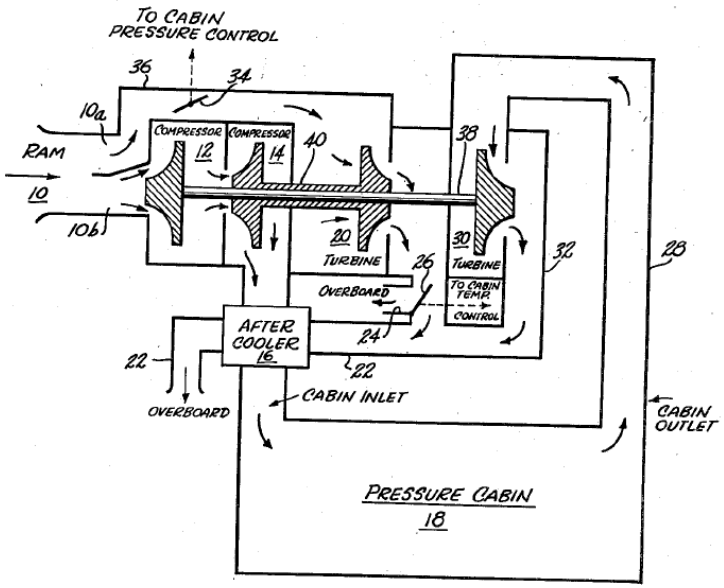
Ram Air Cabin Pressurizing System- Patent 1954

Oct. 23, 1956 B. I. SEEGER 2,767,561

RAM AIR CABIN PRESSURIZING SYSTEMS

Filed May 20, 1954



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

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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

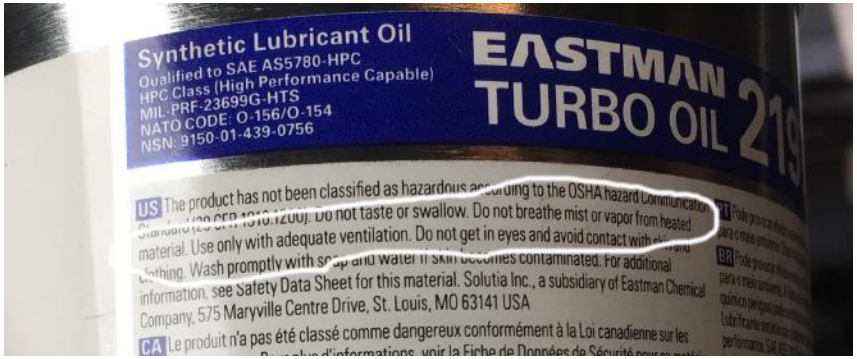
✈ **May cause harm to the unborn/Impair fertility**

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

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Conflicting views

- Boeing & FAA

✈ 1954: Unknown mixture /Hazardous/toxic

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

✈ 2013: "Decomposition reactions of engine oils & hydraulic fluids are largely unknown."

  – Levels are too low to be harmful

BUT

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

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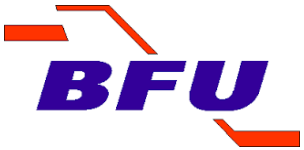
International actions

AIRBUS

LIEBHERR
Aerospace

cen

CENELEC



Honey

Rijksoverheid

Flight Safety

- Under reporting is occurring (FAA, EASA, Michaelis etc…)
- Flight safety issue widely recognized
  - ICAO (2015) – CIR 344-AN/202
    - Fumes- negative impact on safety issue
    - Slow degradation of performance/not recognized
  - IFALPA/ECA (2013/2017)
  - ADs- CAA, FAA, CASA…
  - FAA - SAFO (2018) - enhance flight crew procedures that mitigate the risk to passengers and crew in the event of odors, smoke and/or fumes.
  - SAE (2005)
  - Others: Michaelis (2010), Harisson (2009); FAA (2009)

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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

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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

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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

Key recommendations -

- 2001:  Suspicion of unhealthful cabin air – Pilots to use of oxygen masks selected to 100% oxygen
- 2007/2009:  Detection system for smoke/ oil mist
- 2014:  EASA demonstrate certification & compliance (airframe/engine/APU) that CAQ does not lead to permanent health effects

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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

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BA 286 – October 2016

Air Traffic Control

Emergency Landing- Vancouver

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ICAO Annex 13 and EU Reg 996/2010

- Serious incident: Annex 1 ✔
  - Events requiring emergency use of oxygen by pilots
  - Pilot incapacitation
- 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)**

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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

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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

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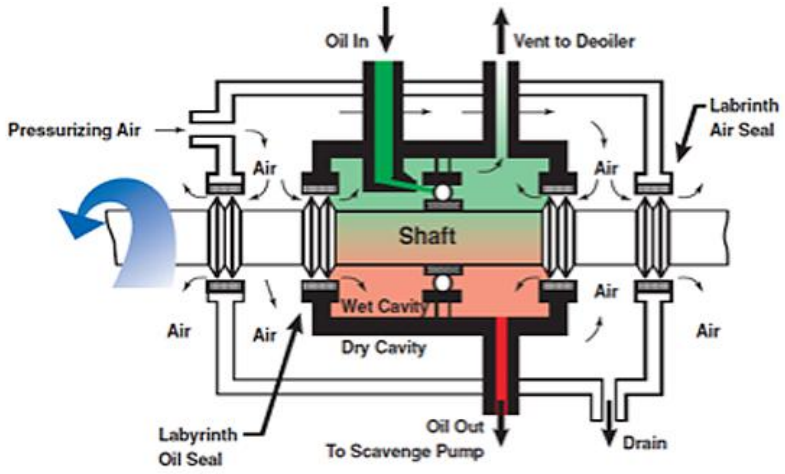
Oil seals

Oil bearing compartment



Oil seals

- Labyrinth: Clearance (200-400nm)
- Mechanical/face seals: lubricated face (250-1000nm)

✈ rely on pressurised air

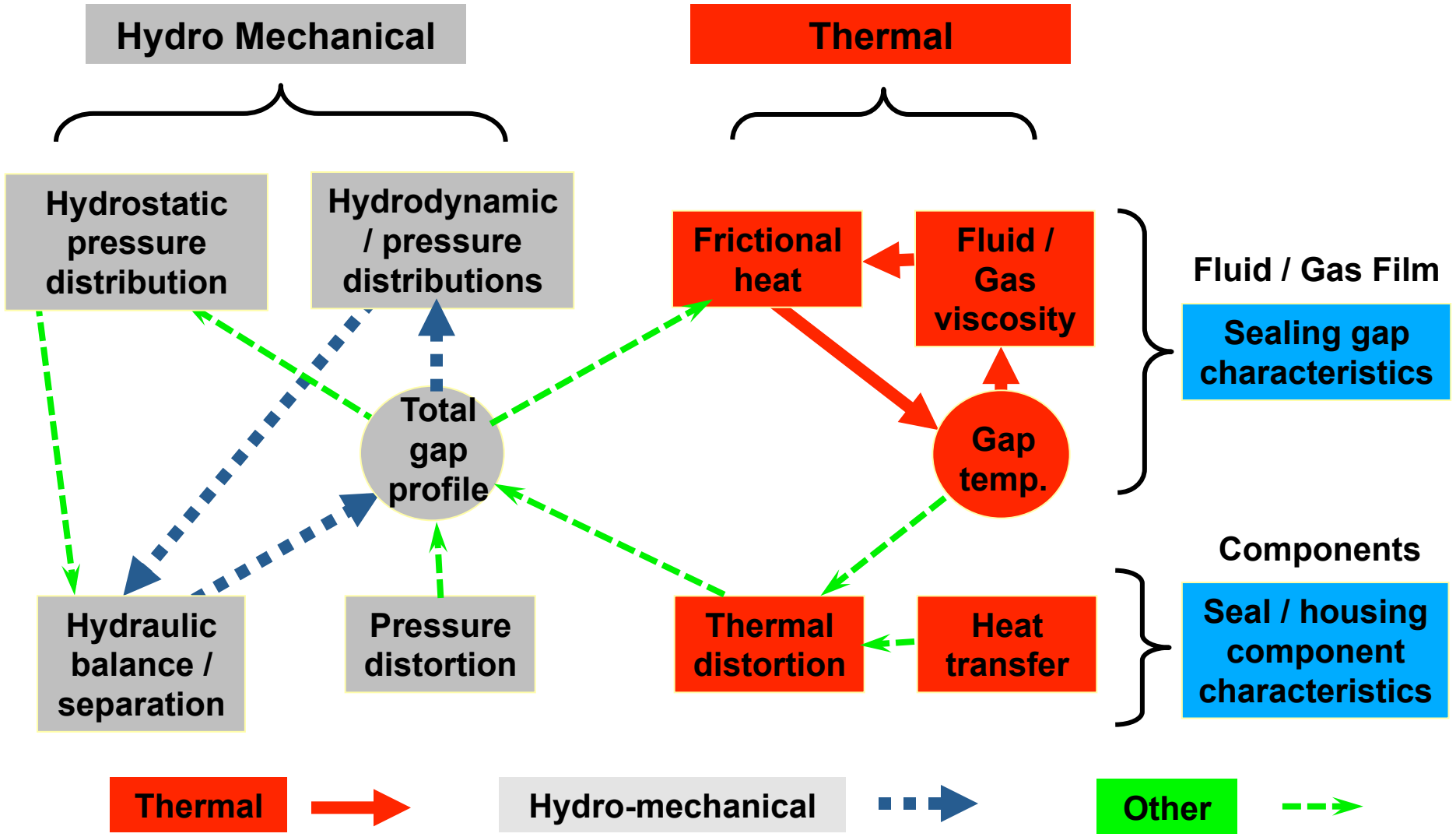
✈ Responsive to thermal/ mechanical changes in structures & pressure changes

✈ **All dynamic seals designed to leak - in normal operation**

✈ **Path to enter cabin air supply ✔**

Factors affecting seal leak rates

- **Seal leakage concepts**



Common assumptions – Oil leakage

1. Higher pressure in gas path than inside bearing chamber – Keeps oil in bearing chamber
2. Seals only leak when failure occurs
3. Reverse pressures to be avoided –prevents leakage

X

INCORRECT

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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

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

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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…**

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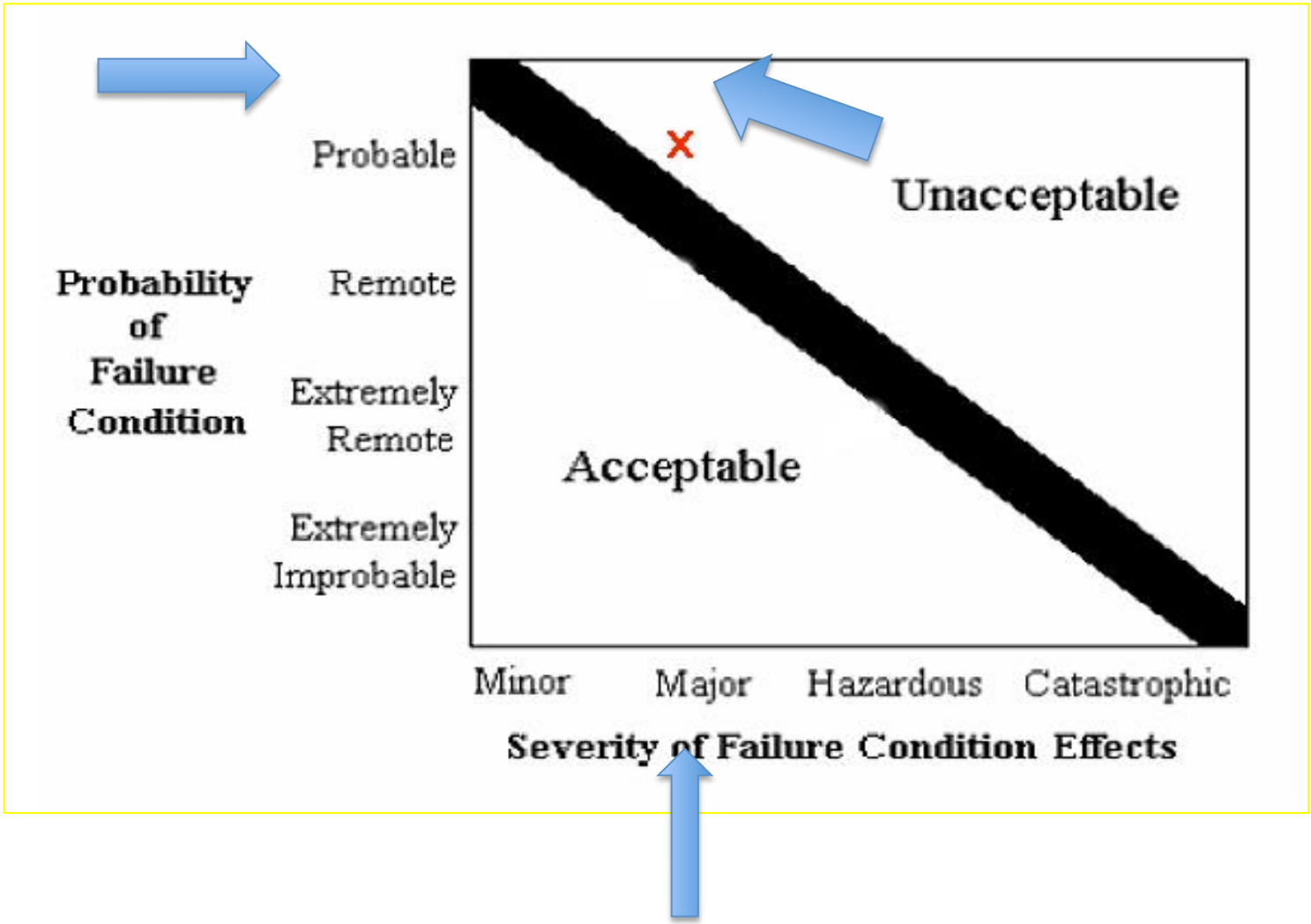
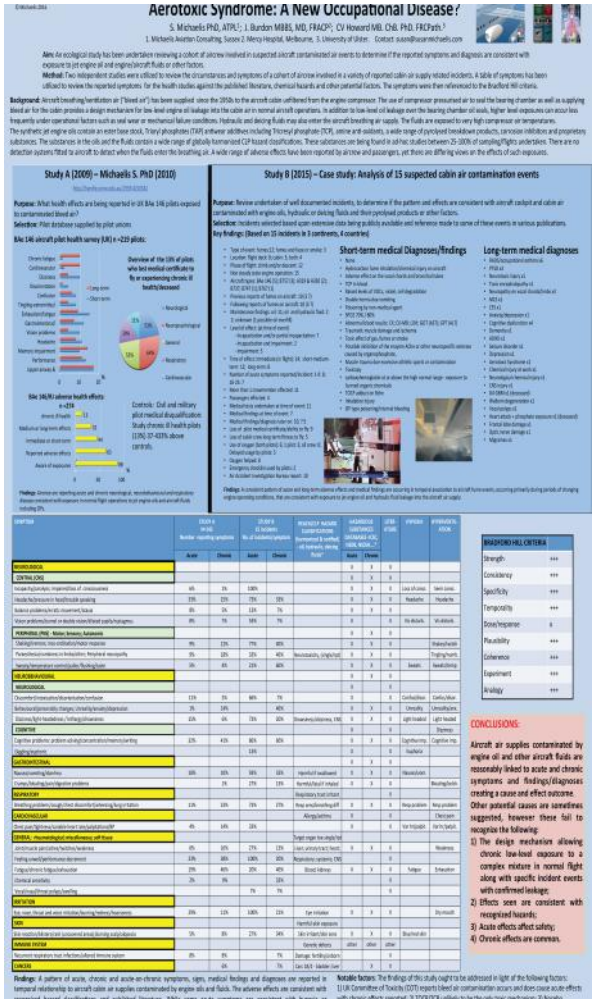
Conclusions



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?



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

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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 cholinesterase 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)

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Solutions

- Bleed air filtration – DHL and the new *Pure*Cabin system by Pall Aerospace being introduced by Easyjet and Spirit.
- Bleed air sensors & flight deck warning
- Bleed free designs
- Advanced seal/engine designs
- Less toxic oils
- Better maintenance practices
- Improved reporting & analysis of data
- Greater understanding of physiological effects to chronic low-level exposures
- Improved checklists/O^2 use if air suspected to be contaminated
- Review of compliance
- Effective medical protocol/disease recognition
- Training & education – ICAO Guidance > GCARS

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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**

Solutions - Filtration

- Current
  - HEPA – Standard fit (dust/microbial) - RECIRC
  - Carbon / HEPA – Optional for some major airlines (VOCs/ airport pollution…) – RECIRC
  - B757 cockpit filter – Bleed air – approved by EASA (2010)
- NEW
  - PURE Air – Bleed air filtration & sensors- Ready for flight trials

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Solutions - Sensors

- CS/FAR 25.1309C

✈ Warning information must be provided to alert the crew to unsafe system operating conditions and to enable them to take corrective action.

✈ CAQS- PALL Aerospace- CAQ sensor

✈ pattern recognition algorithms – eg: jet s, deicing fluids…. Flight

✈ Measure background air quality & fume events

✈ Part of PALL PURE Air

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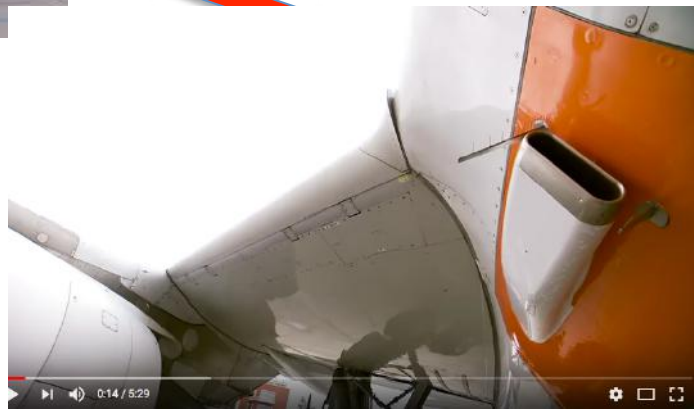
Solutions – Bleed free

- B787

- 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#/

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THANK YOU to all here

FURTHER INFORMATION AVAILABLE:

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